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Research Paper

"A Laboratory Investigation to Study Characteristics of Bituminous Mix Using Marginal Aggregate and Waste Plastic"

Bitumen and Aggregate Tests for Road

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Abstract—*In India, infrastructure development is increasing day to day which requires more quantity of good quality aggregate. Due to the high demand of regular quality aggregate scarcity of it may occur in future, hence Marginal aggregate would have to be used in place of regular quality aggregate. Marginal Aggregates are the ones which do not satisfy physical properties test result such as crushing, impact, abrasion, shape index, specific gravity as per the specifications of MORTH. Regular quality aggregate has high crushing strength compared to Marginal aggregate which effects on the stability of bituminous mix. During this study, an experimental investigation has been carried out find out maximum percentage of regular quality aggregates which can be replaced by Marginal aggregates. In laboratory investigation regular qualityaggregates replaced with Marginal aggregates at 10% interval (0%,10%,20%,30%,40%,50%,60%,70%,80%,90%,100%) at OBC 5.2%.from the experimental results its carried out that maximum percentage of regular quality aggregate that can be replaced by Marginal aggregate is 40% after that physical properties of Marshall mix is not satisfied as per MORTH. so it is required to regain that stability lost by the use of Marginal aggregate. From the past research, it shows that use of waste plastic (PET/7.5% weight of binder) of size 1.18 mm-600µ with bituminous mix provides high stability compared to conventional bituminous mix. hence laboratory experiments carried out of bituminous mix with 7.5% PET weight of binder and regular quality aggregates replaced by Marginal aggregates(50%-100%) at 10% intervals. experimental results shows that using of PET in bituminous mix regain the stability lost by use of Marginal aggregates up to 90% replacement of regular quality aggregates with Marginal aggregates. Hence it is feasible to use up to 40% replacement of regular quality aggregates without use of PET and after that it is feasible to use up to 90% replacement of regular quality aggregates with use of PET (7.5% by weight of binder) at OBC 5.2%.*

Keywords*-Marginal aggregates; PET; Marshall mix Properties; Indirect tension test;*

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I. INTRODUCTION

Bituminous mix is that pourable mix of bitumen, and aggregates that hardens into super-strong highway pavements. Aggregates are the important constituents in the bituminous mix that help in provide high stability and durability to pavements. River sand used as fine aggregate in concrete is derived from river banks. Igneous rock from mountains has been the most popular choice for the aggregate component of concrete in the past, but overuse of the material has led to environmental concerns, the depleting of mountains and an increase in the price of the material. The developing country like India facing shortage of good quality good quality aggregates and particularly in India, mountains are being used up and causing serious threat to environment as well as the society. The rapid extraction of aggregates from the mountains causes problems like deepening of the mountains, loss of vegetation on the mountains, disturbance to the agriculture life due to excavation of rocks
.

In India, infrastructure development is increasing day to day. Road pavement construction is major part of development of country. Road pavement is made from bituminous mix with components of aggregates and bitumen. As the infrastructure development is increasing day to day it requires more quantity of aggregates.

Good quality aggregates are required to provide high stability and durability to pavement. But as the aggregates used in bituminous mix excavated from mountains and mountains are the non renewable it may create scarcity of good quality aggregates further. To decrease use of good quality aggregates it may require using marginal aggregates as well.

Hence, Marginal aggregate would have to be used in place of regular quality aggregate. Marginal Aggregates are the ones which do not satisfy physical properties test result such as crushing, impact, abrasion, shape index, specific gravity as per the specifications of MORTH. Regular quality aggregate has high crushing strength compared to Marginal aggregate which effects on the stability of bituminous mix.

From the past researches it shows that use of PET as additive in bituminous mix increases stability of mix. Hence PET can be use with Marginal aggregates to regain the loss of stability.

Studies have revealed that waste plastics have great potential for use in bituminous construction as its addition in small doses, about 5-10%, by weight of bitumen helps in substantially improving the Marshall stability, strength, fatigue life and other desirable properties of bituminous mix, leading to improved longevity and pavement performance. The use of waste plastic thus contributes to construction of green roads. (IRC: SP: 98-2013).

Reuse of waste materials in asphalt industry has emerged as a propitious way to enhance sustainability from perspectives of environment and economy. Considering the fact that plastic wastes, being non-biodegradable, persist in the environment over long time periods, their use in highway construction will help to reduce the negative impact caused due to indiscriminate dumping

Polyethylene terephthalate (PET), a semi-crystalline thermoplastic polymer, is extensively used to produce packaging contenders for soft-drinks, food items and other consumer products. PET bottles have taken over glass bottles as preferred storage option due to ease in handling, lightweight and chemical resistance. Global consumption of PET bottles is nearly 20 million tons which is increasing by 15% every year (Yao et al., 2016); however, the recycling rate of PET bottles is just 29.3%, which is very low (Miller, 2012; Mariaenrica, 2010).

Marginal Aggregate

In constructions of highway pavements to provide strength good quality aggregates are required .as the growth of infrastructure development increasing it requires more quantity of good quality aggregates hence scarcity of good quality aggregates may occur in future and rate of good quality aggregate also increasing due to high demand of good quality aggregates. Hence it requires finding substitute of good quality aggregates. Marginal aggregates can be used in place of good quality aggregates within limits. Marginal aggregates are which does not satisfy physical properties of aggregates as per MORTH. Marginal aggregate may affect the strength of mix and some additive like PET requires regaining that loss by Marginal aggregates.

Abbreviations and Acronyms

VG	Viscosity grade
OBC	Optimum binder content
SGMA	Specific gravity of mix aggregate
CDM	Compacted Density of Mix
CDMA	Compacted Density of Mixed Aggregate
SGM	Specific Gravity of Mix
VIM	Voids in Mix
VMA	Voids in Mixed Aggregate
VFB	Voids Filled by Bitumen
BC	Bituminous Concrete
PET	Polyethylene Terephthalate
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
TSR	Tensile Strength Ratio

Methodology

- ***Identification of Problem :***

In India, infrastructure development is increasing day to day which requires more quantity of good quality aggregate. Due to the high demand of regular quality aggregate scarcity of it may occur in future, hence Marginal aggregate would have to be used in place of regular quality.

- ***Defining scope:***

This study is about the laboratory performance of hot mix and needs to be conducted to explore the use waste plastic and Marginal aggregate in pavement construction using VG 30 and detailed laboratory investigations will be carried out to find out whether it is viable to use in terms of suitability, economically and environmentally.
This study is base on the use of waste plastic and Marginal aggregate using VG 30 in flexible pavement. The present study will focus basically on following points:
Study the effect on Marshall Stability of bituminous mix with and without addition of waste plastic and low quality aggregate.

- ***Objectives:***

To study the comparison of physical properties of regular aggregate and Marginal aggregates.
To study the effect of Marginal aggregate on characteristics of bituminous mix.
To evaluate the combined effect of waste plastic and Marginal aggregates on characteristics of bituminous mix.
To determine the optimum content of Marginal aggregate and waste plastic for satisfying the properties of bituminous mix.

- ***Selection of Marginal aggregates and plastic waste to be added to aggregate:***

An aggregate which does not satisfy the specified limits as per MORTH are considered as Marginal aggregates. Different samples of aggregates are selected which were obtained from the nearer quarry in halol.
The sheer amount of disposable bottles produced nowadays makes it imperative to identify alternative procedures for recycling them since they are non-biodregrable. This project describes an innovative use of consumed plastic bottle waste.

- ***Addition of Marginal aggregates and plastic waste in different proportions and different size:***

According to standard Marshal design method designated as ASTM D 1559-89, 15 numbers of samples each of 1200 gm in weight were prepared using five different bitumen contents (from 4 - 6% with 0.5 % incremental). Also number of samples are prepared for different proportion of Marginal aggregates (from 0-100% with 10% incremental) and for waste PET (7.5%) of size 1.18 mm-600µ.

- ***Comparison of Marshall Test results of mix with Marginal aggregates and PET with conventional mix:***

Firstly the conventional mix are prepared and then compared with mix of Marginal aggregates and PET.

Table-1 Physical properties of aggregate

Test	Results		Specifications	Method
	SAMPLE 1	SAMPLE 2		
Aggregate Impact Value, %	31.26	11.08	Maximum 30%	(IS(2386 PART I), 1963)
Water Absorption, %	2.2%	0.7%	Maximum 2%	(IS(2386 PART-III), 1963)
Specific Gravity	2.59	2.83	2.6 – 2.9	(IS(2386 PART-III), 1963)
Abrasion Value%	28	14.28	Maximum 30%	(IS(2386 PARTI-V), 1963)
Crushing Value %	32.4	12.53	Maximum 30%	(IS(2386 PART-IV), 1963)
Combined index (Elongation Index + Flakiness Index)	21.43+17.78 =39.21%	10.08+17.78 =27.84%	Maximum 30%	(IS-2386 (PART I), 1963)

Table-2: Physical properties of bitumen

Property	Test Results	Specified Limits as per IS 73:2006
Penetration at 25ºC/100 gm. /5 sec, mm	63.33	50-70
Ductility, cm	>100	40 cm minimum
Softening Point	55 ^{0} C	Minimum 47 ^{0} C
Specific Gravity	0.971	0.97 to 1.02
Absolute Viscosity (poise)	2768.80	2400-3600

Kinematic Viscosity (cSt)	592.41	Minimum 350
Solubility Test	99.99%	Minimum 99%

Table-3 Theoretical mix proportion of aggregates for bituminous concrete

IS Sieve Size (mm)	Individual gradation of aggregate % Passing by weight				Blending proportions				Actual combine grading	Mid valve of specification	Ideal require combine grading as per MORTH
	Coarse Aggregate (CA)	Grit (G)	Stone dust (SD)	Lime (L)	CA (37%)	G (22%)	SD (38%)	L (3%)			
26.5	100	100	100	100	37	22	38	3	100	100	100
19.0	89.14	100	100	100	32.98	22	38	3	94.25	95	90-100
13.2	38.76	100	100	100	14.34	22	38	3	73.83	69	59-79
9.5	7.56	86.07	100	100	2.80	18.94	38	3	61.5	62	52-72
4.75	00	2.43	100	100	00	0.53	38	3	41.17	45	35-55
2.36	00	0.17	96.2	100	00	0.04	36.56	3	39.33	36	28-44
1.18	00	0.07	68.7	100	00	0.02	26.11	3	30.17	27	20-34
0.6	00	0.07	47.3	100	00	0.02	17.97	3	23.5	21	15-27
0.3	00	0.07	30	100	00	0.02	11.40	3	16.17	15	10-20
0.15	00	0.07	18.3	96.2	00	0.02	6.95	2.89	10.92	9	5-13
0.075	00	0.07	12	54.8	00	0.02	4.56	1.64	7.42	5	2-82232… 2-4

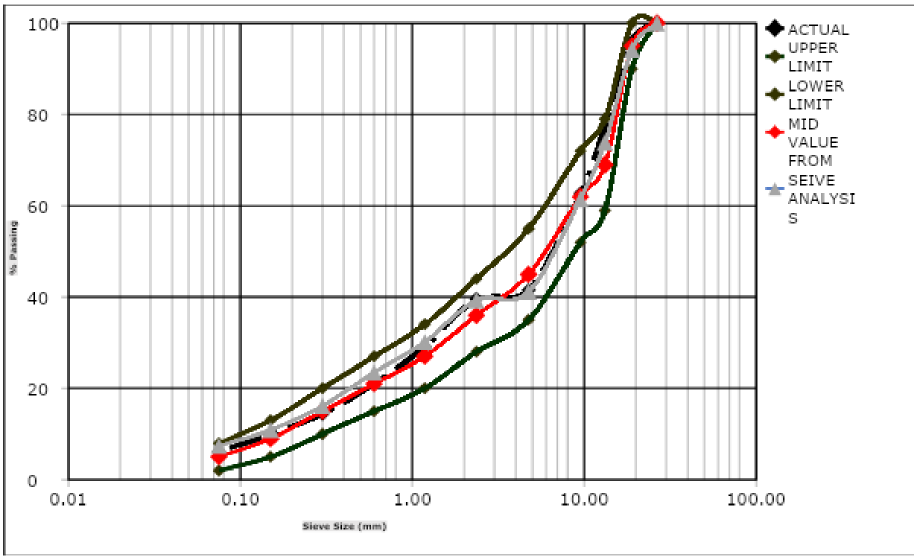


Figure-1 Bituminous concrete gradation

The blended aggregates are further checked by gradation to meet the requirements of combined grading of materials of 1200 gm. weight as shown Figure 3.1. The weight of each aggregates in mix are as below:

- **Course aggregate** = 37% = 444 gm.
- **Grit** = 22% = 264 gm.
- **Stone Dust** = 38% = 456 gm.
- **Lime** = 3% = 36 gm.

After mixing the aggregate by this proportion, further the sieve analysis is done and gradation curve was plotted as shown in Figure 3.3. This evidently shows blended aggregate proportion comes near the mid value of the specification but it fluctuates near the upper limit of the specification representing that the fines ingredient is more in the selected proportion as per MORTH, 2013.

Table-4 Theoretical mix proportion of aggregates for bituminous concrete

IS Sieve Size (mm)	Individual gradation of aggregate % Passing by weight				Blending proportions				Actual combine grading	Mid valve of specification	Ideal require combine grading as per MORTH
	Coarse Aggregate (CA)	Grit (G)	Stone dust (SD)	Lime (L)	CA 35%	G (25%)	SD (37%)	L 3%			
26.5	100	100	100	100	35	25	37	3	100	100	100
19	78.08	100	100	100	27.328	25	38	3	93.328	95	90-100
13.2	14.9	98.3	100	100	5.215	24.575	38	3	70.79	69	59-79
9.5	5.62	72.14	100	100	1.967	18.035	38	3	61.002	62	52-72
4.75	0.1	1.23	100	100	0.035	0.3075	38	3	41.3425	45	35-55
2.36	0	0.07	96.2	100	0	0.0175	35.594	3	38.6115	36	28-44
1.18	0	0.05	68.7	100	0	0.0125	25.419	3	28.4315	27	20-34
0.6	0	0.05	47.3	100	0	0.0125	17.501	3	20.5135	21	15-27
0.3	0	0.05	30	100	0	0.0125	11.1	3	14.1125	15	10-20
0.15	0	0.05	18.3	96.2	0	0.0125	6.771	2.89	9.6735	9	5-13
0.075	0	0.05	12	54.8	0	0.0125	4.44	1.64	6.0925	5	2-8

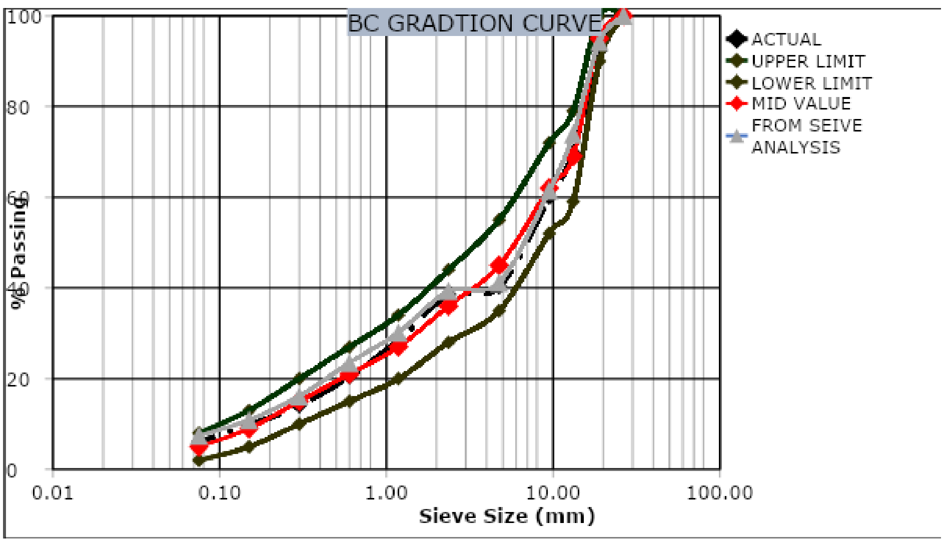


Figure-2 Blending of Marginal aggregates

The blended aggregates are further checked by gradation to meet the requirements of combined grading of materials of 1200 gm. weight as shown Figure 3.4. The weight of each aggregates in mix are as below:

- **Course aggregate** = 35% = 420 gm.
- **Grit** = 25% = 300 gm.
- **Stone Dust** = 37% = 444 gm.
- **Lime** = 3% = 36 gm.

After mixing the aggregate by this proportion, further the sieve analysis is done and gradation curve was plotted as shown in Fig.2. This evidently shows blended aggregate proportion comes near the mid value of the specification but it fluctuates near the upper limit of the specification representing that the fines ingredient is more in the selected proportion as per MORTH, 2013.

- *Marshall Stability test*

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

This test has been carried out to determine the Optimum Binder Content (OBC) for BC mixes. The properties evaluated by the test are stability, flow value, compacted density, air voids, voids filled with bitumen and voids in mineral aggregate.

The Marshall Stability of mix is defined as a maximum load carried by a compacted specimen at a standard test temperature of 60 °C. This temperature represents the weakest condition for a bitumen pavement in use. The flow value is the deformation that Marshall Test specimen undergoes under loading, up to the maximum load, in 0.25 mm units.

In this method, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measured when the same is loaded at the periphery. This test procedure is used for designing and evaluating bituminous paving mixes. There are two major features of the marshal method of designing mixes, namely:

a. Stability test
b. Density-void analysis.

Apparatus: (ASTM D6926-04, 2004)

1. Mould assembly for BC-cylindrical moulds of 10 cm diameter and 7.5 cm height and consisting of a base plate and collar extension.
2. Sample Extractor: for extruding the compacted specimen from the mould.
3. Compaction pedestal and hammer.
4. Breaking head, loading machine, flow meter, water bath, thermometers.

Figure 3 Marshall Apparatus

- ***Preparation of test specimen for bituminous concrete (ASTM D6926-04, 2004)***

1. Total of 1200gm of aggregates and filler are mixed and heated to a temperature of 160-170°C.
2. Bitumen is heated to a temperature of 121^0 C to 135 °C with the trial percentage of bitumen (say 4% by weight of the mineral aggregates). Then the heated aggregates and bitumen are thoroughly mixed at a temperature of 150 - 160°C.
3. The mix is placed in a preheated mould and compacted by a hammer weighing 4.5 kg and a free fall of 45.7 cm giving 75 blows on either side at a temperature of 130 to 145°C to prepare the laboratory specimens of compacted thickness 63.5±3 mm.
4. In present study three samples were prepared for each percentage of bitumen ranging from 4.00% to 6.00% with interval of 0.5% to obtain better result.

- ***Stability and flow value determination (ASTM D6927-06, 2006)***

1. The specimen diameter and height are measured.
2. The specimen wt. in air and in water is found.
3. The specimen to be tested is kept immersed in water in a thermostatically controlled batch maintained at 60 °C + 1 °C for 30 to 35 minutes.
4. The load is applied at the constant deformation rate of 50.8 mm per minute and load and deformation readings are closely observed. The maximum load reading and the corresponding deformation of the specimen at failure load are noted.
5. The maximum load value expressed in kg is recorded as the "Marshall Stability" value of the specimen. The vertical deformation of the test specimen corresponding to the maximum load, expressed in mm is recorded as the "Flow value". The specimen is removed from the test head and the test is repeated on other specimen.

- Voids analysis

Further the voids analysis has been done using following relationship.

- **Specific Gravity of Mixed Aggregate(SGMA)**

Since the aggregate mixture consists of different fractions of coarse aggregate, fine aggregate, and mineral filler with
different specific gravities, the bulk specific gravity of the total aggregate in the paving mixture is given as

SGMA=100P1G1+P2G2+P3G3+P4G4

Where,
P_1, P_2, P_3, P_4 = individual percent by weight of aggregate
G_1, G_2, G_3, G_4 = individual bulk specific gravities of aggregate

- **Specific gravity of mix (SGM) is found using the relation:**

SGM=100+B100SGMA+BGb

- **Compacted density of mix(CDM):**

CDM=Weight in air/Weight in air-Weight in water

- **Compacted density of mix aggregate (CDMA) is given by the relation:**

CDMA=CDM1+B100

- **Voids in mixed aggregates (VMA) is given by the relation:**

VMA=SGMA-CDMASGMA×100

- **Voids in mix (VIM) is given by the relation:**

VIM=(SGM-CDMSGM)×100

- **Voids filled by bitumen (VFB) is given by the relation:**

VFB=VMA-VIMVMA×100

Control mix

Initially a bituminous concrete mix (control mix) grade-1 without Marginal aggregates and PET is prepared to determine the
optimum binder content, which is consider as standard bitumen content for comparison.
The Marshall test on moulds prepared using blended aggregates using different percentages of VG30 bitumen is done and the average results of each proportion of bitumen are shown in Table 7 and further the relation between
percentage bitumen and various properties of mix design are plotted as shown in Figure 4.

Table 5 Criteria for Marshall Method of mix design for bituminous concrete

Properties	Requirement
Numbers of blows	75 blows on each face of specimen
Marshall Stability, KN	Min, 9
Marshall Flow, mm	2-4
Marshall Quotient, KN/mm	2-5
Air voids, %	3-5
Voids in mineral aggregates, %	Min.12
Voids filled with bitumen, %	65-75
Tensile strength ratio (%)	80

Source: (MORTH section 500 clause 505, Table 500-11, 2013)

Table 6 Minimum percentage voids in mineral aggregate (VMA)

Nominal maximum particle size (mm)	Minimum VMA percent related to design percentage air voids, (%)		
	3.0	4.0	5.0
26.5	11	12	13

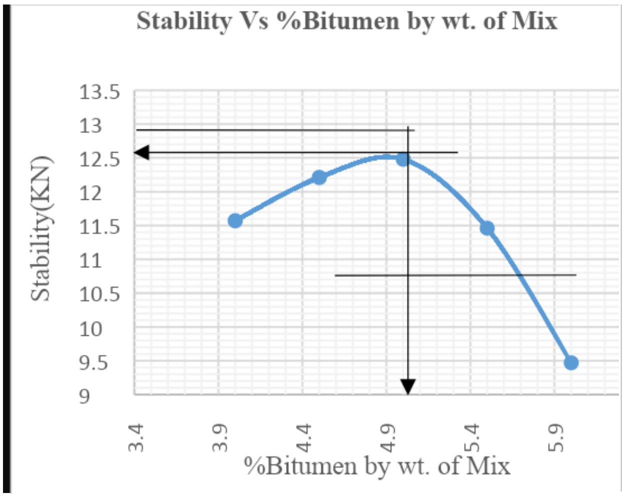
Source: (MORTH section 500 clause 505, Table 500-12, 2013)

Results and Calculations

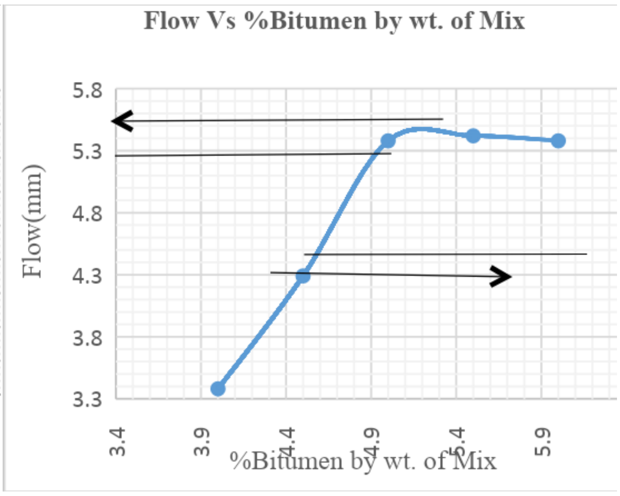
Following analysis was performed and the calculations are carried on the basis of the results obtained from the experiments.

Table 7 Result of Marshall test on bituminous concrete using VG 30 bitumen

%Bit. By Wt.	Stability (KN)	Flow (mm)	CDM (gm./cc)	VMA (%)	VFB (%)	VIM (%)	Parameters	Binder content 5.2%
4	11.57	3.38	2.49	14.64	67.35	4.78	**Stability (KN)**	12.25
4.5	12.21	4.29	2.5	14.71	75.36	3.62	**Flow(mm)**	5.4
5	12.48	5.38	2.51	14.78	83.29	2.47	**VIM %**	2.25
5.5	11.64	5.42	2.5	15.52	86.48	2.1	**VFB %**	85
6	9.47	5.38	2.5	15.92	91.55	1.34	**VMA%**	15



(a)



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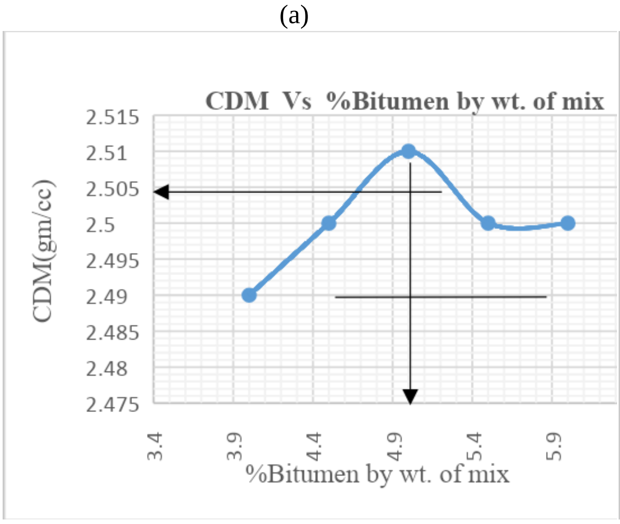

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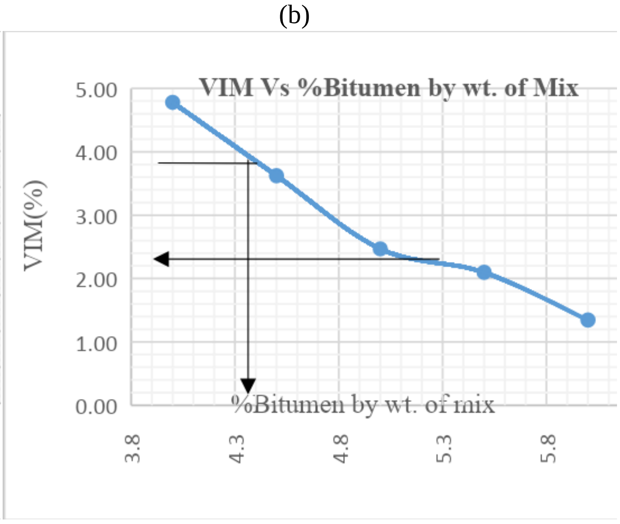

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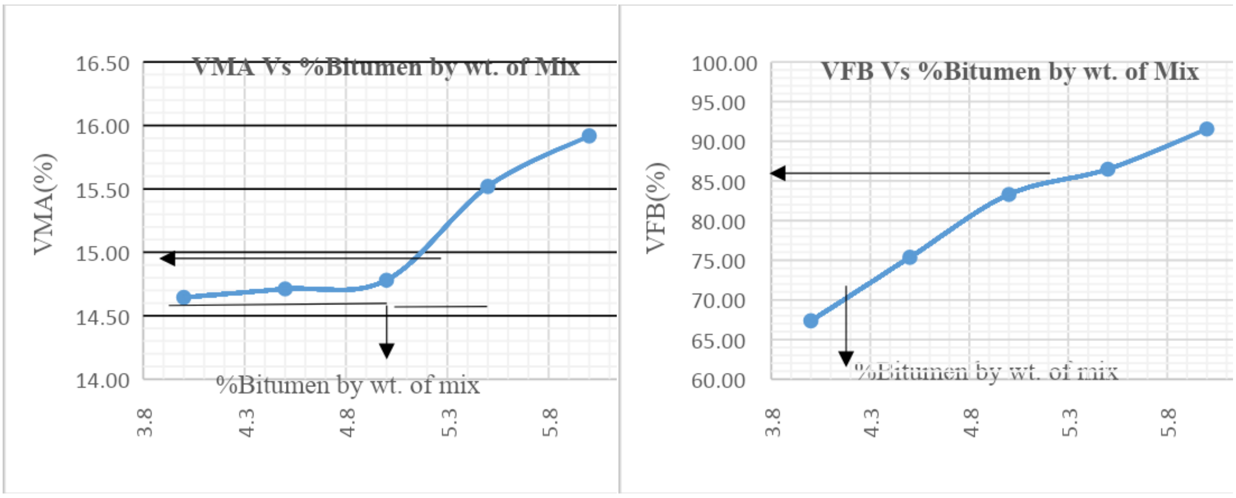

(e) (f)

Figure 4 Marshall Curves for bituminous concrete using VG 30 Bitumen

For the determination of the optimum binder content (OBC) in mix, apart from stability (corrected stability) and flow, the following volumetric properties were evaluated: compacted density, the percentage of air voids(VIM), the percentage of voids in the mineral aggregate (VMA) and the percentage of voids filled with bitumen (VFA).

The above parameters at optimum binder content completely characterize the BC mix. Stability ensures sufficient strength, while flow ensures acceptable deformation over a period of service life.

If BC is designed with a lower void content than the one specified, it will certainly deform prematurely, presenting rutting and shoving. VMA and VFA are additional parameters for ensuring good performance. VMA ensures that the space among aggregates is adequate to accommodate the mass of bitumen, whereas VFA ensures that an adequate number of voids are filled with bitumen. The latter is of great importance because it determines the minimum bitumen quantity required for good mix cohesion and the maximum bitumen content to avoid premature deformation or bleeding. How to calculate the above parameters is explained in above Figure 4.(a to f).

Once the above properties are calculated, six diagrams are plotted. They all have the horizontal axis representing the binder content and the vertical axis representing the above properties.

Figure 4 a shows the stability curve always present an ascending trend and sometimes a maximum value. Correspondingly, the deformation increases as the binder content increases as shown in (Figure 4b), Figure 4c the density curve may present a maximum value as the binder content increases. Air voids continuously decrease as the binder content increases (Figure 4d). Whereas the VMA initially decreases up to a minimum value and then increases (Figure 4e). Finally, the VFA continuously increases as the binder content increases (Figure 4f).The mixture that meets all the requirements of Table 7 at the same time is selected as the Target mixture. The optimum binder content is designated as the average binder content value corresponding to the above properties with acceptable variation of binder content for good performance.

OBC VALUE%=4.9+5.0+4.83=4.9%

The tests are performed for different binder content from that it is found that the OBC is 4.9%. But the value achived is less than the minimum criteria given by the MORTH, therefore an optimum binder content of 5.2% is adopted for performing Marshall Stability tests.

Bituminous mix properties replacing normal aggregates with marginal aggregates

Fundamentally, mix design is meant to determine the volume of bitumen binder and aggregates necessary to produce a mixture with the desired properties. Since weight measurements are typically much easier, weights are taken and then converted to volume by using specific gravities. The following is a discussion of the important volumetric properties of bituminous mixtures.

For the present study **0-100% (at 10% interval)** were adopted as the Marginal aggregates replacing normal aggregates. For preparation of the specimens for **BC Grade I** the results are tabulated below:

Table 8Summary of test results for VG 30 + MARGINAL AGGREGATES for BC Mix Design Grading I

% Normal aggregates replaced by Marginal aggregates	Stability(KN)	CDM (gm./cc)	VIM(%)	VMA(%)	VFB(%)	FLOW(mm)
10	11.47	2.33	4.06	15.91	74.53	2.9
20	10.23	2.32	4.2	16.06	73.87	2.93
30	9.53	2.32	4.34	16.15	73.17	2.98
40	9.35	2.31	4.61	16.39	71.86	2.96
50	8.28	2.31	4.68	16.45	71.56	3.02
60	7.37	2.3	5.16	16.33	69.441	3.07
70	7.02	2.3	4.54	16.87	72.185	3.12
80	6.66	2.29	5.37	17.05	68.601	3.13
90	6.37	2.29	5.57	17.23	67.795	3.21
100	6.1	2.28	5.57	17.23	67.98	3.23

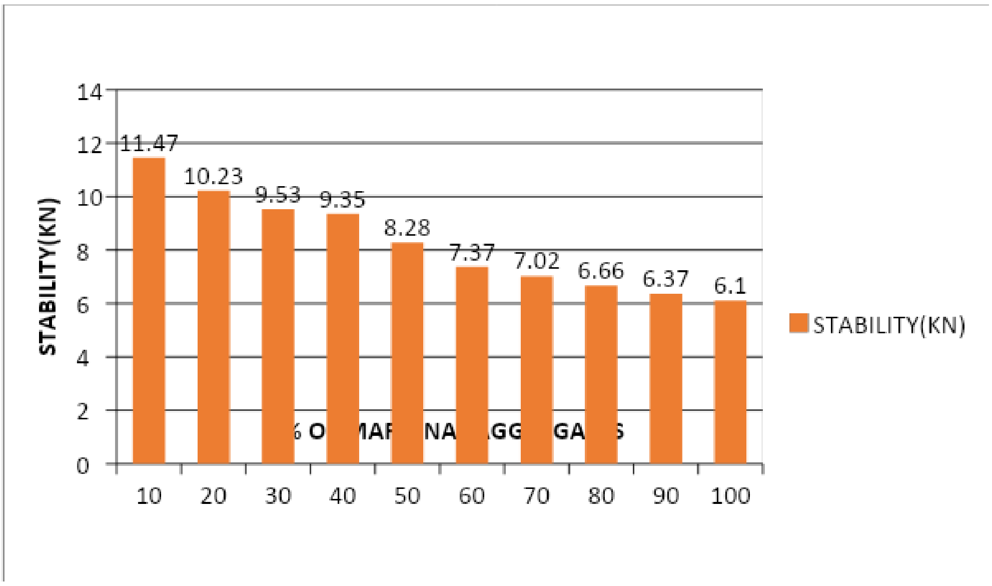

Figure 5 Variation of Stability with different % marginal aggregate dosage

From Table 5 and Table 6, it is evident that the presence of Marginal aggregates in the HMA mixtures effectively reduces the stability values. This result indicates that the mixture using Marginal aggregates would result in decreases stability of BC mix. Variation of Marshall Stability with different Marginal contents are given in Figure 6

Figure 5 indicates that the stability of mixture decreases as the increase proportion of Marginal aggregates in mixture. figure shows that stability specification as per MORTH satisfy up to 40% after that stability does not satisfy specification of MORTH, hence permissible limit of Marginal aggregates is 50% without any additive.

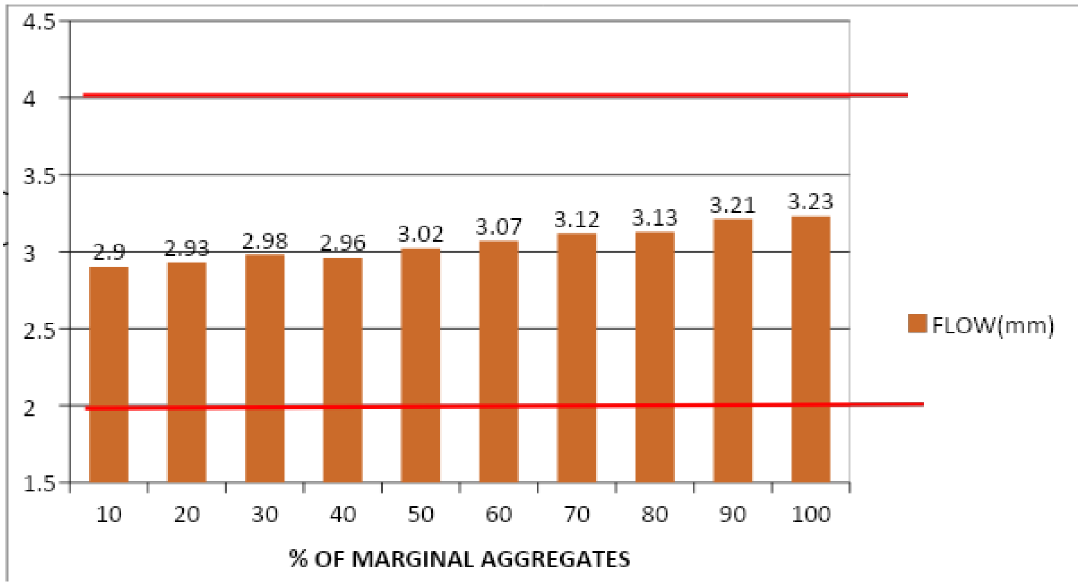

Figure 6 Variation of FLOW with different % marginal aggregate dosage

Flow value of HMA mixture increases after adding MARGINAL aggregates as shown in Figure 6. Owing to the flexibility of Marginal aggregates in the mixture, the mixes become more flexible and the resistance to deformation decreases resulting in a low flow value. However, flow values are lies within the required specification range of 2 to 4 mm (MORTH section 500 clause 505, Table 500-11, 2013) from the Figure 6 it is clearly visible that initially low percentage of dosage gives the lower value of flow and varies linearly with different mix temperature.

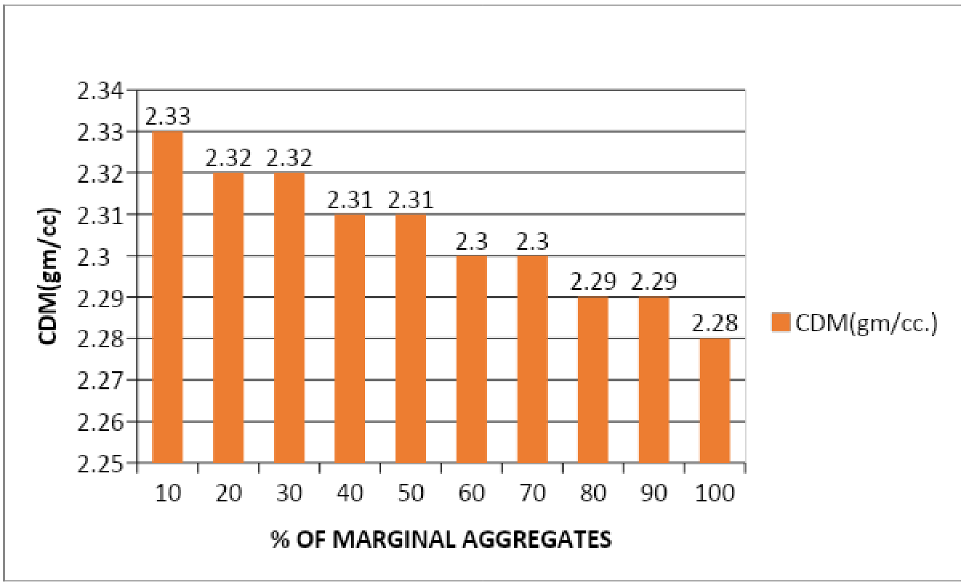

Figure 7 CDM with different % marginal aggregate dosage

The density of Marginal aggregate added bitumen is much lower than that of aggregates. Owing to the uneven shape of Marginal aggregates offered by these Marginal aggregates results in fewer voids and reduce density of mix as the increases of proportion of Marginal aggregates as shown in figure 7.

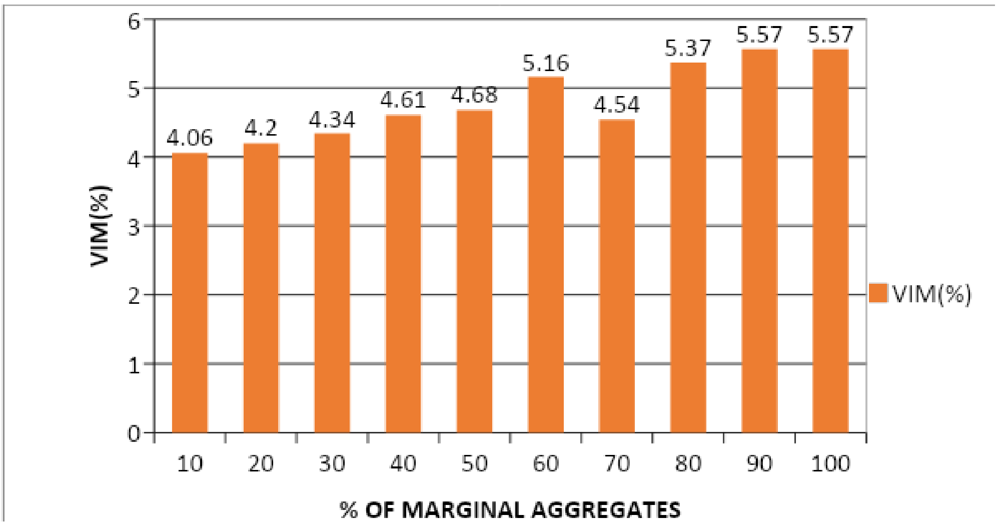

Figure 8 VIM with different % marginal aggregate dosage

Excessive air voids in the mixture would result in cracking due to insufficient bitumen binders to coat on the aggregates, while too low air voids may induce more plastic flow (rutting) and bitumen bleeding. Here the test results (Figure 8) show that air void increases as proportion of Marginal aggregate increases in bituminous mixtures. But up to proportion of 40% it gives within the required criteria given by the MORTH Table 500-11.more than 40% proportion it does not satisfy required criteria given by MORTH. This results obtained are with in specification range of 3% to 5% (MORTH) which support the use of these aggregates up to 50% proportion.

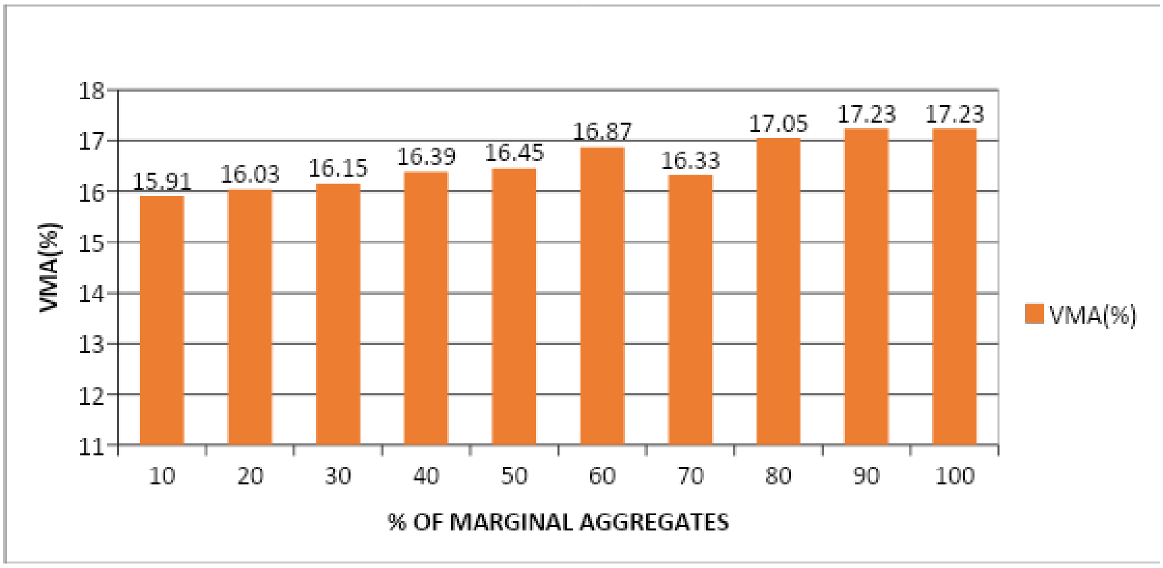

Figure 9 VMA with different % marginal aggregate dosage

VMA includes the air voids and the volume of bitumen not absorbed into the aggregate. When VMA is too low, there is not enough room in the mixture to add sufficient bitumen binder to coat adequately over the individual aggregate particles. Excessive VMA will cause significant low mixture stability. From Figure 9 it can be stated that bituminous mixes using Marginal aggregates increases VMA as increase in proportion of Marginal aggregates, However VMA derived from all the proportion within the criteria given by MORTH table 500-11.

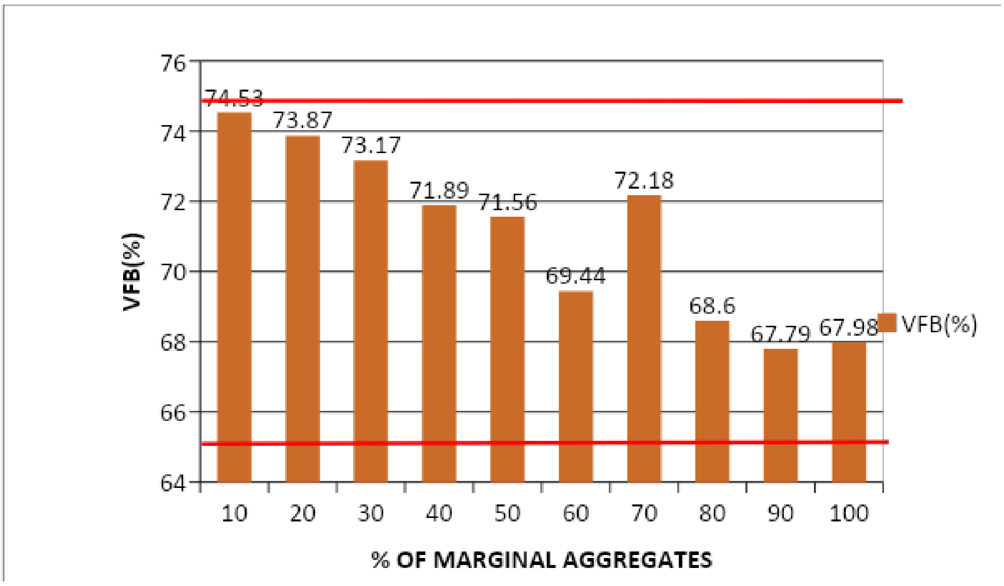

Figure 10 VFB with different % marginal aggregates dosage

VFB of mixtures does not follow the same trend of increase or decrease after addition of Marginal aggregates into the mixture, as portrayed in Figure. all the proportion of the Marginal aggregates complies with the criteria stated by MORTH. From graph VFB decreases up to 60% then increases at 70%.there after again decreases' up to 90% and increases at 100%

- From figure 4 to 10 and Table 9 it shows that Marginal aggregate can be used but within permissible limit. All the mix criteria as per the IS code are satisfy up to 40% replacement of Normal aggregates with Marginal aggregates.

Bituminous mix properties replacing normal aggregates with marginal aggregates adding pet

- From the past researches it shows that use of PET increases stability which may help to use higher proportion of Marginal aggregates.
- Optimum dose and size of PET taken from the past researches.

Results of Marshall mix after addition of PET (7.5%/) size(1.18 mm-600µ) given below.

Table 9 Summary of test results for VG 30 + MARGINAL AGGREGATES + PET for BC Mix Design Grading I

MARGINAL AGGREGTE %	Stability(KN)	CDM (gm./cc)	VIM(%)	VMA(%)	VFB(%)	FLOW(mm)
50	10.19	2.3	4.98	17.2	69.52	3.14
60	10.08	2.305	4.96	16.69	70.316	3.32
70	10.015	2.315	4.54	16.33	72.185	3.41
80	9.735	2.32	4.34	16.15	73.183	3.59
90	9.34	2.325	3.76	15.61	74.185	3.82
100	8.78	2.335	3.42	14.89	78.98	4.2

From the table it shows that all the proportion of Marginal aggregates except 100% satisfy the criteria given by MORTH when PET adding to mixture.

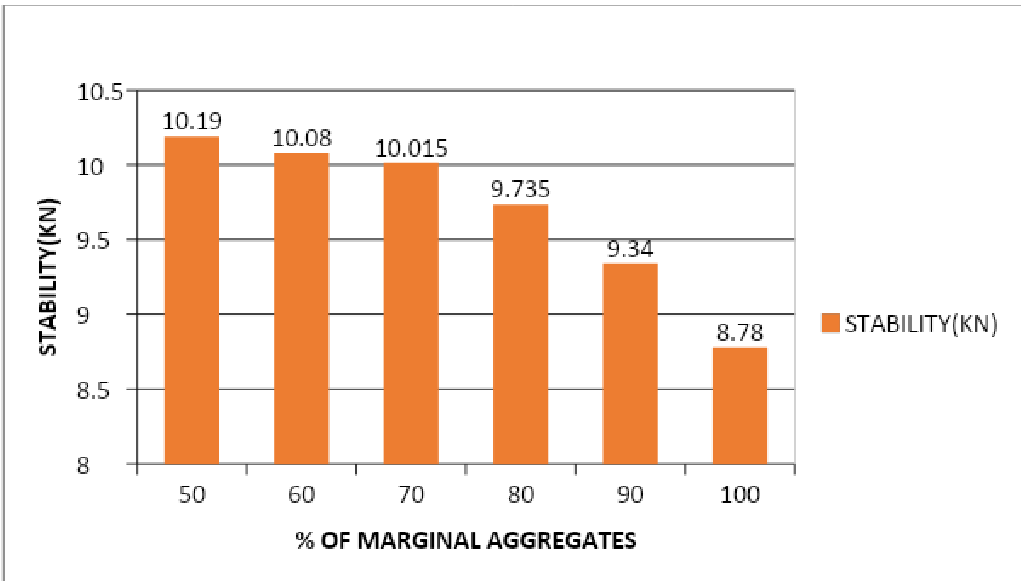

Figure 11 STABILITY with different % marginal aggregates +7.5% PET dosage

Figure 11 indicates the stability of mixture at various proportion of aggregates with PET. it shows that all the proportions satisfy criteria given by the MORTH except 100% proportion of Marginal aggregates

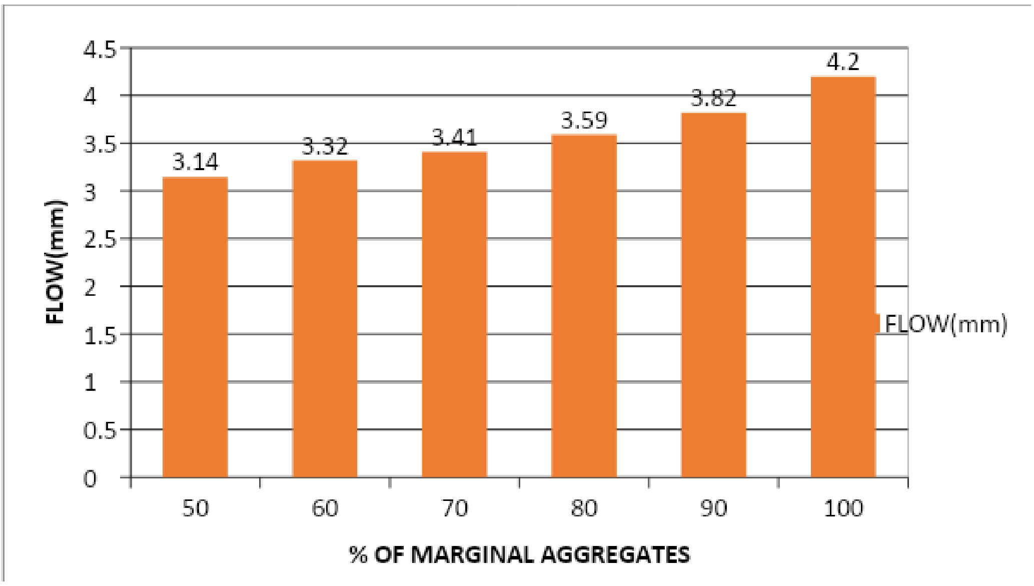

Figure 12 FLOW with different % marginal aggregates + 7.5% PET

Figure 12 indicates the FLOW of mixture at various proportions of aggregates with PET. it shows that all the proportions except 100% with PET additive satisfy criteria given by the MORTH.

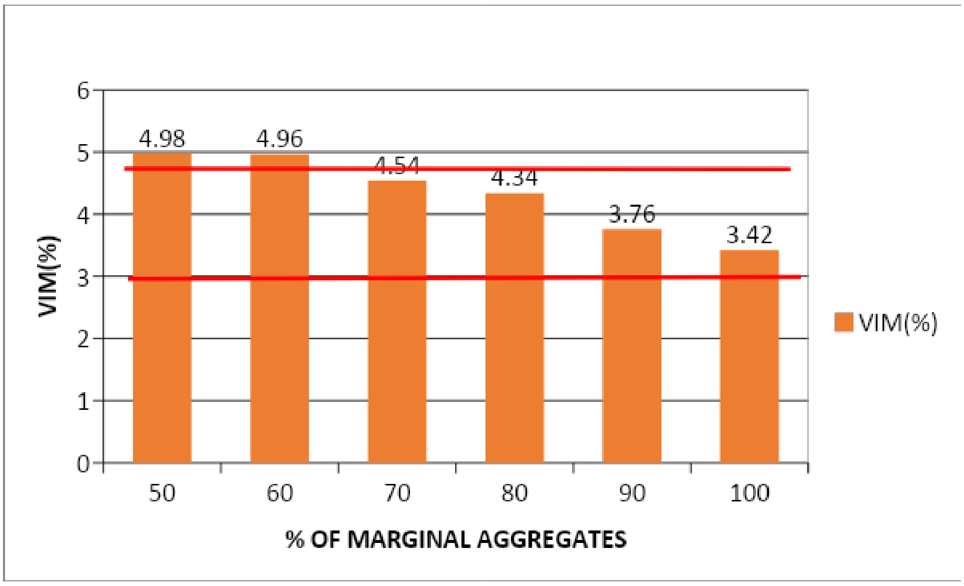

Figure 13 VIM with different % marginal aggregates + 7.5% PET dosage

Figure 13 indicates the VIM of mixture at various proportions of aggregates with PET. it shows that all the proportions with PET additive satisfy criteria given by the MORTH.

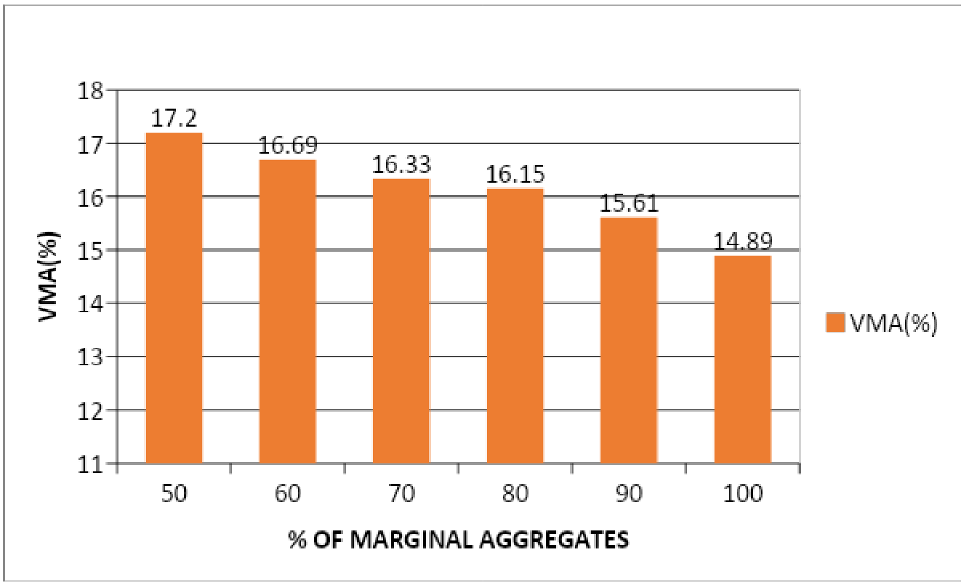

Figure 14 VMA with different % marginal aggregates + 7.5% PET dosage

Figure 14 indicates the VMA of mixture at various proportions of aggregates with PET. it shows that all the proportions with PET additive satisfy criteria given by the MORTH.

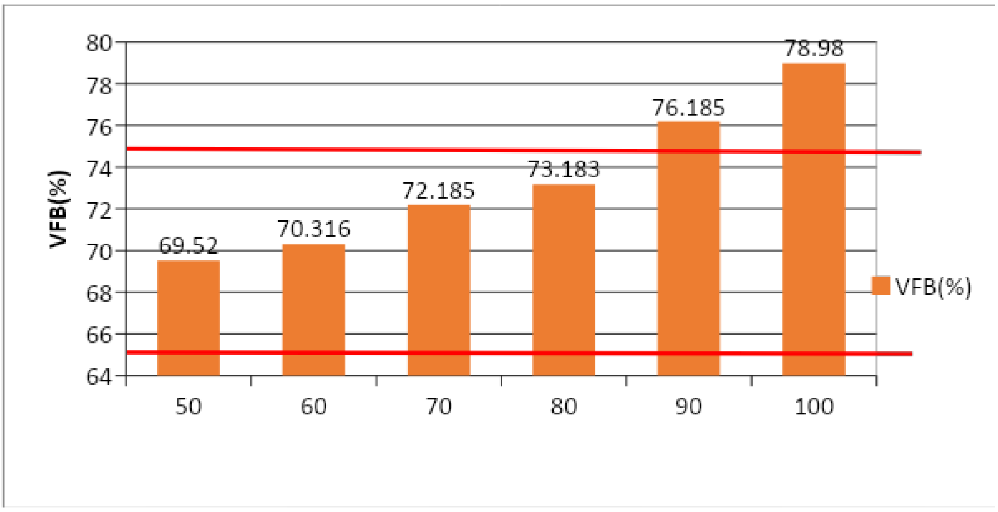

Figure 15 VFB with different % marginal aggregates + 7.5% PET dosage

Figure 15 indicates the VFB of mixture at various proportions of aggregates with PET. it shows that all the proportions except 100% with PET additive satisfy criteria given by the MORTH.

- From the figure 11-15 it derived that Marginal aggregates can be use up to 90% with PET (7.5%).

Performance test for bituminous concrete

Standard test method for indirect tensile strength (ITS) of asphalt mixtures (ASTM D6931-17)

Significance and use:

The values of ITS strength may be used to evaluate the relative quality of asphalt mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both moisture-conditioned and unconditioned specimens.

"Resistance of compacted asphalt mixture samples to moisture induced damage"

- To predict the long term stripping susceptibility of asphalt mixtures.
- Moisture sensitivity testing was conducted using the AASHTO T-283 (TSR) method.

- **Test Procedure:**
- The TSR test consists of conditioning and testing stages. In the conditioning stage, half of all specimens are conditioned using a freeze/thaw cycling procedure while the other half is allowed to remain unconditioned. The sets are broken down such that each set's average air contents are approximately equal.
- The conditioned set is saturated with water between 70 and 80%,frozen for 16 hours at -18^{0}C, and thawed for 24 hours at 60^{0}C. Further, the conditioned and unconditioned specimens are brought to 25^{o}C prior to measuring the indirect tensile strength of all asphalt concrete specimens.
- Consequently, the quotient of the average indirect tensile strengths of the conditioned to unconditioned specimens is calculated to determine the tensile strength ratio,

TSR= Tensile strengths of the conditioned sample Tensile strength of the unconditioned sample×100

In general, researchers arrived at a conclusion that TSR results greater than 80% are acceptable. Finally, a rating 0 (least stripped) to 5 (significantly stripped) is given for visual stripping of the fine and coarse aggregate particles.

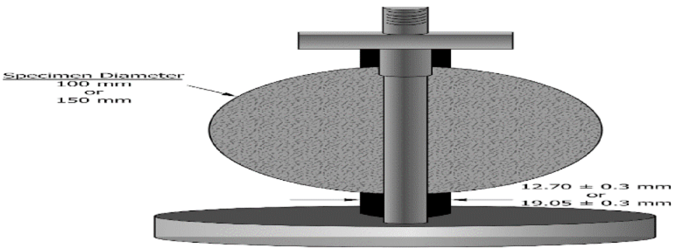

Figure 16 : Diagram of an IDT Strength-Loading Fixture

Table 9 Tensile Strength Ratio Test Results for Conventional Bituminous Concrete Grade I:

TYPES OF MIX	MIX TEMPERTURE^{0} C	TSR%
HMA	**170**	**80.47**

- **Calculation of tensile strength ratio:**

Table 10 Tensile strength ratio at different % of Marginal aggregates without PET

% of inferior aggregate	Condition	P (KN)	D (mm)	T (mm)	S1 (unit: Pascal) 2000P/πDT	Condition	P (KN)	D (mm)	T (mm)	S2 (unit: Pascal) 2000P/πDT	Tensile strength Ratio $\frac{S1}{S2}*100(\%)$
0	Soaked	4.29	100	63	0.43373	Unsoaked	5.2	100	63	0.52573	87.33061394
10		4.25	100	63	0.42968		5.15	100	64	0.51254	88.69091809
20		4.28	100	64	0.42596		4.98	100	63	0.50349	84.56057007
30		4.05	100	63	0.40946		4.99	100	63	0.5045	85.53549757
40		4.01	100	64	0.39908		4.52	100	63	0.45698	87.3306194

Table 11 Tensile strength ratio at different % of Marginal aggregates with PET

% of inferior aggregate	Condition	P (KN)	D (mm)	T (mm)	S1 (unit: Pascal) 2000P/πDT	Condition	P (KN)	D (mm)	T (mm)	S2 (unit: Pascal) 2000P/πDT	Tensile strength Ratio $\frac{S1}{S2}*100(\%)$
50	Soaked	3.92	100	63	0.39632	Unsoaked	4.49	100	64	0.44686	88.69091809
60		3.56	100	63	0.35992		4.21	100	63	0.42564	84.56057007
70		3.58	100	64	0.35629		4.12	100	63	0.41654	85.53549757
80		3.69	100	63	0.37307		4.19	100	64	0.417	89.4647119
90		3.54	100	63	0.3579		4.23	100	63	0.42766	83.68794326

Cost analysis

- As the main objective of the study to find out the use of marginal aggregates in place of normal aggregates as per design criteria. Further the attempt has been made to find out saving in the cost due to use of marginal aggregates. In the following table analysis has been showed.

- Quantity estimation of bituminous concrete for 1 MT

Parameter	**Calculation**
Optimum binder content	5.20%
Total Aggregate Weight per M.T of mix	(100-5.2)*1000/100 = 948 kg

Table 12 Difference of Cost of Marginal aggregate & regular aggregates in BC per m^3

% of Marginal aggregate	Total Cost of Marginal aggregate per m3(RS.)	% of Normal regular aggregate	Total Cost of Normal aggregate per m3(RS.)	Total Cost of aggregates per m^3(Marginal mix)(RS.)	Total Cost of aggregates per m^3(conventional mix)(RS.)	Savings in cost (RS / m^3)
10	618.2	90	744.69	732.041	744.69	12.649
20	618.2	80	744.69	719.392	744.69	25.298
30	618.2	70	744.69	706.743	744.69	37.947
40	618.2	60	744.69	694.094	744.69	50.596
50	618.2	50	744.69	681.445	744.69	63.245
60	618.2	40	744.69	668.796	744.69	75.894
70	618.2	30	744.69	656.147	744.69	88.543
80	618.2	20	744.69	643.498	744.69	101.192
90	618.2	10	744.69	630.849	744.69	113.841

Cost estimation for 1km per lane road.

Total quantity of road = (3.5*1000*0.05) = **175 m^3**
Weight of bituminous mix with normal aggregate in Kg = 175*2303 = 403025 Kg
Weight of normal aggregates in Kg = 382068.9 Kg
Volume of normal aggregates in m^3 =382068.9/2.761*1000 =138.38 m^3
Weight of bituminous mix with marginal aggregate in Kg = 175*1998 = 349650 Kg
Weight of marginal aggregates in Kg = 331021.1 Kg
Volume of marginal aggregates in m^3 =331021.1/2.51*1000 = 131.88 m^3
Cost of normal aggregate per km per lane road = 123544.071

Table 13 Difference of Cost of Marginal aggregate & regular aggregates in BC Per Km Per Lane

% of Marginal aggregate		% of normal aggregate	Total quantity of normal aggregate per lane per km(m3)	Total quantity of marginal aggregate per lane per km(m3)	cost of normal aggregates per m3(RS.)	cost of marginal aggregates per m3(RS.)	Total cost of road per lane per Km(Rs.)	Savings in cost(Rs.)
40		60	138.38	131.88	744.69	618.2	94441.40772	8608.794
90		10	138.38	131.88	744.69	618.2	83680.41462	19369.79
0		100	138.38	131.88	744.69	618.2	103050.2022	NA

CONCLUSION

Based on the results obtained and from its analysis, the main conclusions that can be drawn from the present study are as following:

- Significant difference is obtained in the physical properties of BC mix such as stability, VMA, VIM, FLOW and VFB when it is prepared using regular aggregates and when it is prepared with Marginal aggregates and PET.
- Experimental study revealed that the Marshall Stability decreases with increase in % of Marginal aggregates.
- A notable increase in VIM is observed with increase in % of Marginal aggregates. Criteria given by MORTH is satisfied up to 40% of Marginal aggregates and above 40%, PET is added to the mix which decreases the VIM and allows using Marginal aggregates up to 90%.
- FLOW increases with the increase in % of Marginal aggregates but it is obtained within the limits for all the proportions.

- VMA increases with the increase in % of Marginal aggregates but it is also obtained within the limits for all the proportions.
- VFB decreases with the increase in % of Marginal aggregates but it is obtained within the limits for all the proportions.
- The permissible stability of BC is satisfied only up to 40% replacement by marginal aggregates.
- To increase the stability further using above marginal aggregates, other material PET is added.
- Results reveals that using 7.5% PET (300-600µ) by weight of the binder in the BC mix, marginal aggregates can be replaced up to 90% with satisfactory results of all design parameters.
- Further cost analysis results shows that there is a huge amount of saving in cost using marginal aggregates.
- So present study reveals that if normal aggregate is replaced by marginal aggregate, the scarcity of normal aggregate can be overcome, further as waste plastic(PET) is also used in the mix, some environmental hazardous problems (disposing of plastic) can also be solved out.

FUTURE SCOPE

- In addition to laboratory investigation more significant investigation such as performance analysis is also required to recognize the mix behavior under actual traffic loading condition.

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