EXPERIMENTAL ASSESSMENT OF CERAMIC WASTE AS PARTIAL REPLACEMENT OF FILLER MATERIAL FOR BC–II MIX

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Abstract : The study is carried out to evaluate the suitability of ceramic waste as replacement of stone dust in Bituminous Concrete. Bituminous concrete mixes with and without ceramic dust were prepared in different proportions (2.5% to 12.5% at interval of 2.5%) as filler using bitumen grade VG–30 as binder. The amount of optimum binder content was determined by Marshall Stability test for samples. The mechanical performance of samples was determined for Marshall Stability, deformation behavior or flow, as well as for density and void characteristics based on MORTH specifications. Results showed that the stability values and other parameters of Marshall Test containing ceramic wastes are improved in comparison to conventional samples. Mixture which contains ceramic waste was lighter than the conventional mix and addition of ceramic dust shows increase in air voids content and decrease in voids filled with bitumen. In addition, water sensitivity test and repeated load test were carried out for conventional and optimized ceramic BC mixes. Results showed tensile strength ratio and fatigue resistance are improved in comparison to conventional mixes. No anti-stripping agents are required for both BC mixes. From the study, the benefit of using ceramic waste in bituminous concrete mixes as filler material (7.5%) is therefore recommended. The replacement of dust in bituminous concrete by ceramic wastes will have major environmental benefits and also reduces the cost of construction.

***IndexTerms* - Bituminous concrete, ceramic tile waste, Marshall Properties, Water sensitivity, Fatigue, cost analysis.**

I. INTRODUCTION

In India, different types of waste materials are produced as byproducts in an enormous amount from agriculture and industries. These waste materials are disposed off near the plants or as landfills. Waste materials may be hazardous if not deposited properly. This dumped waste may pollute environment and underground due to leaching effect and cause health issues. In recent times, the increased construction activity is resulting in scarcity of conventional construction materials and led to increase in construction cost. Non-hazardous industrial wastes are identified for construction to reduce waste disposal problem and construction cost. In this sense, there is a need for research work to find out more alternative materials. Various industrial wastes such as GGBS, Fly ash, silica flume, marble dust, granite dust and steel slag are used in road construction. Ceramic industry also produces more waste and researches are being carried out to utilize the waste ceramic in road construction (Vishwajit Jaiswal et. al[17]).

In India, ceramic production is about 100 million ton per year. In this production 15 to 30% of material is generated as waste. At present ceramic waste is not being reused and recycled. Ceramic waste is mainly produced from two sources. First one is ceramic industries and other one is significant fraction of construction and demolition activity (Jinal V. Patel et. al[10]). Disposal of ceramic waste produce is a huge problem due to limited availability of land to dispose of safely and cause environment pollution. Use of ceramic waste in construction industry reduces the disposal problem and provides economic feasibility to construction industry. Ceramic waste can be recycled due to its following advantage

- Available at low cost
- Durable, hard and wear resistant
- Reduce environment problem related to waste disposal and environment pollution

In the present investigation, the study is carried out on bituminous concrete layer using ceramic tile waste as replacement of stone dust to utilize and recycle ceramic waste materials in pavement construction. This helps to protect the natural resources, reduce environmental pollution of solid waste, disposal problems and potential saving in cost.

II. MATERIALS AND EXPERIMENTS

2.1 Materials

Aggregates: The performance of bituminous mixes is mainly depending upon the physical properties of aggregates and proper blend of aggregates to be used in the mix. The aggregates used for the study were of good quality, durable and crushed. The aggregates to be used in bituminous concrete mix were subjected to various tests as specified by MORTH 5th Revision Table 500-16. The results are presented in the Table 1.

Table 1. Properties of Aggregate

Property	Test	Results
Cleanliness (Dust)	Grain size analysis	3.8%
Particle shape	Combined Flakiness and Elongation Index	18.62%
Strength	Los Angeles Abrasion value	20.38%
	Aggregate Impact Value	11.9%
Water Absorption	Water Absorption	0.5%
Specific Gravity	20mm down 12mm down 6mm down Stone Dust	2.62 2.65 2.69 2.73
Stripping	Coating and Stripping of Bitumen Aggregate mix	100%

Binder: Bitumen Grade VG-30 is commonly used binder in our country in the construction of wearing and binder courses. The Bitumen Grade VG 30 used for the study was tested in the laboratory to determine the physical characteristics. The basic tests were conducted on binder VG-30 as per IS 73:2013 – Paving Bitumen Specification. The test results are tabulated in the Table 2.

Table 2. Basic Tests on Bitumen (VG-30)

Characteristics	Results	Specifications as per IS 73:2013
Penetration @25^{0}c, 0.1mm, Min	66	45
Flash Point, ^{0}c Min	265	220
Softening Point, ^{0}c Min	52.6	47
Specific Gravity	1.02	0.97 – 1.02

Ceramic waste: The Ceramic waste of size 2.36mm passing and retained on 0.075mm is used for the study which was same as that of stone dust. The specific gravity and Grain size analysis study was carried out. The specific gravity was found to be 2.42 for the ceramic waste used in the study. The chemical composition of ceramic waste is tabulated in the Table 3 and gradation is shown in Fig. 1.

Table 3. Composition of Ceramic waste

Materials	Ceramic powder %
SiO_2	63.29
Al_2O_3	18.29
Fe_2O_3	4.32
CaO	4.46
K_2O	2.18
Na_2O	0.75
MgO	0.72
P_2O_5	0.16
Loss of Ignition	1.61

Source: Geo-Test House, Baroda, Gujarat

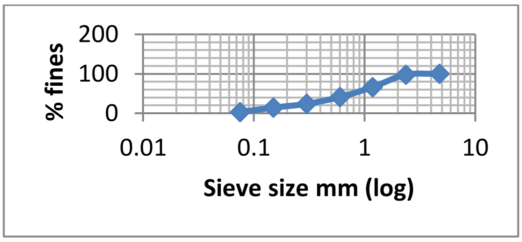

Fig. 1. Gradation graph of Ceramic waste

Aggregate gradation: After the basic tests of aggregates, the obtained test results were analyzed with the requirement of Bituminous Concrete. The aggregates fulfilling the requirements of physical properties of aggregates for Bituminous Concrete were further used for the proper blend to give good mix consisting different sizes of aggregates. The aggregate sizes 20mm down, 12mm down, 6mm down and stone dust were used to obtain proper blend. 4000g of aggregates were taken for sieve analysis. The Aggregate gradation was carried out using Trial and Error method to obtain individual percentages of different aggregate sizes to be used in the BC mix confining to the lower and upper limits specified as per MORTH Table 500-17: Composition of Bituminous Concrete Pavement Layers. The obtained gradation for BC mix is shown in Table 4 and Table 3.6 respectively. The gradation chart is shown in Fig. 2.

Table 4. Gradation Table of Aggregates

IS Sieve size mm	Desire Gradation As per MORTH -5		Obtained Gradation
	Lower limit	Upper limit	
19	100	100	100
13.2	90	100	91.615
9.5	70	88	81.768
4.75	53	71	60.456
2.36	42	58	44.1
1.18	34	48	34.92
0.6	26	38	27.81
0.3	18	28	19.26
0.15	12	20	12.6
0.075	4	10	5.22

Materials	20mm	12mm	6mm	dust	Total
Proportion %	10	24	21	45	100

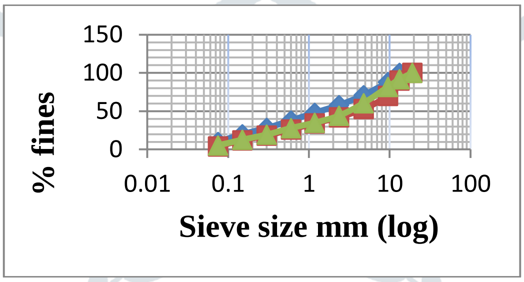

Fig. 2. Gradation Chart of Aggregates

2.2 Mix design and sample preparation

Approximately 1200g of aggregates of different size were mixed in different proportions. Specimens were prepared at varying bitumen contents. Bitumen content varied as 5%, 5.25%, 5.5%, 5.75%, 6%, and 6.25% at interval of 0.25%. Stone dust is replaced by ceramic waste in the proportion 2.5% to 12.5% at interval of 12.5%. The mixed aggregates were heated to a temperature of 150^0c – 170^0c. The bitumen grade VG 30 was heated to a temperature of 150^0c – 165^0c. The aggregates and bitumen were mixed thoroughly in the mixer at a temperature of 150^0c – 165^0c. The mixture was then transferred to the preheated mould of diameter 101.6mm and compacted with the help of rammer weighing 4.5kg with the fall of 457mm. The specimen was compacted with 75 blows on each side. After compaction the specimen was placed to cool down at room temperature for a period of 24 hours. After 24 hours, the specimen was extracted. Dimensions and weight of the specimen in air and water were noted. The specimen was then kept in thermostatically controlled water bath maintained at a temperature of 60^0c for 30 to 40 minutes. The specimen was then removed from the water bath and placed in Marshall Test setup which is loaded at a rate of 0.58mm/min. Once the specimen was placed in test setup, load was applied. Maximum load carried by the specimen and corresponding flow value were noted.

Fig. 5. Marshall test specimens

Fig. 6. Marshall test setup

III. EXPERIMENTAL INVESTIGATIONS

3.1 Marshall Stability Test

The Marshall Test was carried out on the conventional BC mix to determine the Optimum Binder Content and other Marshall parameters. The binder content in the preparation of specimens varied as 5%, 5.25%, 5.5%, 5.75%, 6% and 6.25% for the obtained blend of aggregates for BC mix. The optimum proportion of ceramic waste to be added to the BC mix was determined with the help of Marshall Properties. The proportion of ceramic waste is varied as 2.5%, 5%, 7.5%, 10% and 12.5% to determine the optimum filler replacement. The binder content varied in the same range as used in conventional mix. Obtained test results for conventional and different proportions of ceramic waste BC mixes are tabulated in Table 5. From the test results, it was observed that stone dust could be replaced upto 7.5% by ceramic waste in BC mix. The optimum filler replacement for BC mix from the study was found to be 7.5%. Marshall Properties at 7.5% ceramic waste were satisfactorily good and provided more stability compared to other mixes. The optimum replacement of 7.5% ceramic waste was used for further studies.

Table 5. Marshall parameters obtained for BC mixes

Ceramic waste %	Bitumen content %	Bulk density g/cc	Air voids %	Voids in mineral aggregates VMA %	Voids filled with bitumen VFB %	Stability kN	Flow mm
Conventional	5	2.32	7.06	19.11	61.69	13.28	2.38
	5.25	2.33	6.44	18.51	65.02	13.44	2.79
	5.5	2.35	5.18	18.42	67.94	16.56	2.94
	5.75	2.36	4.46	17.77	74.90	17.93	3.52
	6	2.36	4.29	18.16	76.36	16.54	3.72
	6.25	2.35	4.14	18.56	77.69	14.90	4.45
2.5%	5	2.33	6.39	17.84	64.15	13.28	2.42
	5.25	2.34	5.96	17.99	66.86	14.38	2.79
	5.5	2.35	5.20	17.86	70.88	15.94	2.86
	5.75	2.36	4.52	17.80	74.61	18.19	3.36
	6	2.35	4.43	18.26	75.73	16.80	3.69
	6.25	2.35	4.29	18.67	77.02	15.94	3.94
5%	5	2.32	6.92	18.28	62.15	12.27	2.21
	5.25	2.32	6.45	18.40	64.94	13.85	2.81
	5.5	2.33	5.77	18.34	68.53	15.52	2.92
	5.75	2.35	4.63	17.88	74.12	20.04	3.24
	6	2.35	4.49	18.29	75.47	17.91	3.43
	6.25	2.34	4.62	18.93	75.61	15.02	3.81
7.5%	5	2.31	7.20	18.52	61.09	15.44	2.43
	5.25	2.32	6.33	18.21	65.38	17.70	2.67
	5.5	2.33	5.87	18.41	68.10	19.23	2.93
	5.75	2.34	4.83	18.04	73.22	21.23	3.14
	6	2.34	4.57	18.35	75.07	17.16	3.43
	6.25	2.33	4.31	18.65	76.87	16.71	3.81
10%	5	2.30	7.23	18.53	60.97	11.13	2.42
	5.25	2.32	6.43	18.35	64.96	11.76	2.67
	5.5	2.32	5.82	18.35	68.27	13.07	2.69
	5.75	2.32	5.47	18.58	70.54	15.14	3.37
	6	2.33	4.78	18.51	74.16	14.66	3.17
	6.25	2.33	4.73	18.99	75.11	14.27	3.84
12.5%	5	2.30	7.18	18.47	61.12	11.15	2.32
	5.25	2.30	7.06	18.89	62.62	12.42	2.52
	5.5	2.31	6.18	18.64	66.87	13.27	2.69
	5.75	2.31	5.95	18.97	68.65	13.75	3.13
	6	2.32	5.36	18.99	71.75	14.66	3.48
	6.25	2.32	5.03	19.23	73.84	13.84	3.95

IV. WATER SENSITIVITY TEST

The performance of bituminous mixes depends on durability of materials used in the construction. The proper adhesion between bitumen binder and aggregates is quite complex for long period. Presence of moisture between the aggregates and bitumen binder results in stripping of bitumen. The following tests are carried out to determine the moisture susceptibility of bituminous paving mixes.

a. Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR)

b. Retained Marshall Stability

From the trial specimens, it was decided that 29 number of blows required to obtain the voids percent of 7±0.5% in the compacted specimen. Based on the tensile strength of controlled and conditioned state specimens, tensile strength ratio for both conventional BC mix and optimized ceramic added BC mix is calculated. Obtained ITS and TSR results for conventional BC mix and optimized ceramic added BC mix are tabulated in Table 6.

Table 6. ITS and TSR values of BC mix

State	ITS, kpa	TSR, %
Conventional mix		
Controlled	469.96	81.17%
Conditioned	381.47	
Optimized ceramic mix		
Controlled	530.33	84.75%
Conditioned	449.45	

The procedure for preparation of specimens to conduct retained Marshall Stability test is same as that of Marshall Test. Two sets of specimens were prepared. One set of two specimens for controlled state and another set of specimens for conditioned state. The controlled state specimens were tested as per normal Marshall testing procedure. Conditioned set specimens were kept in the water math maintained at a temperature of 60^0c for 24 hours. After 24 hours, specimens were taken out from the water bath and tested for Marshall Properties. Retained Marshall Stability is calculated using the ratio of Average Marshall Stability value of conditioned specimen to that of dry specimen. The results pertaining to Retained Marshall Stability of conventional BC mix and optimized ceramic added BC mix are tabulated in Table 7.

Table 7. Ratained Marshall Stability for BC mix

State	Marshall Stability, kN	Retained Marshall Stability, %
Conventional mix		
Controlled	17.88	87.5%
Conditioned	15.64	
Optimized ceramic mix		
Controlled	21.15	89.04%
Conditioned	18.83	

4.1 Repeated Load Test or Fatigue Test

Fatigue characteristics of asphalt affect the structural design. Fatigue cracking generally initiate at the bottom of the layer and propagate upward to the surface layer. In order to avoid the fatigue bottom up cracking, Fatigue resistant mixes are preferred to provide in the bottom of bituminous layer. Fatigue test is carried out for bitumen specimens of dia 100mm and height 70mm. The specimens are prepared similar to ITS specimens. It is carried out to determine the condition of material where material fails due to repeated stress application. The stress level decided and fixed on the load carried by the ITS specimens (Conditioned state). Fatigue life of BC mix is determined based on definition of failure. Specimen fails when 3mm deformation is reached either on horizontal or vertical LVDTs. The results are presented as number of cycles that specimen can withstand. The equipment is designed and developed by SPRANKTRONICS Bengaluru.

Specimens are prepared with 29 numbers of blows on both sides. It is carried out for both conventional BC mix and optimized ceramic added BC mix. The results obtained based on 20% stress level of ITS conditioned state specimens for conventional BC mix and optimized ceramic added BC mix are tabulated in Table 8.

Table 8: Mixture Details

BC mix	Load amplitude, Kg	Deformation, mm	Number of cycles
Conventional	100	3	1731
Optimized ceramic mix	110	3	2164

Graphical representation of fatigue behavior of conventional and optimized ceramic mix is shown in Fig. 9.

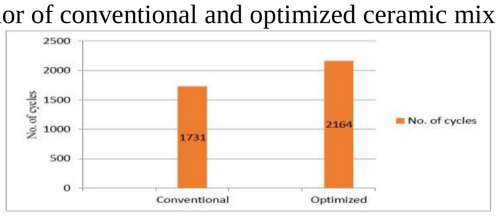

Fig. 9. Representation of Fatigue behavior of BC mixes

V. RESULTS AND DISCUSSIONS

5.1 Marshall Stability Test

Marshall Parameters corresponding to BC mixes with different proportions of ceramic waste are discussed below.

5.2 Optimum Binder Content

The obtained Optimum Binder Content values for ceramic added BC mixes are higher than the conventional BC mix. There is no much difference in OBC for ceramic BC mixes at 2.5%, 5% and 7.5%. There is increase in OBC for ceramic BC mixes at 10% and 12.5%. The higher requirement of binder in mixes with ceramic waste as filler might be due to the larger surface per unit volume and greater absorption of binder by ceramic waste. From the results, it is observed that increase in ceramic content results increase in OBC of BC mixes. OBC of ceramic BC mixes is shown in Fig. 10.

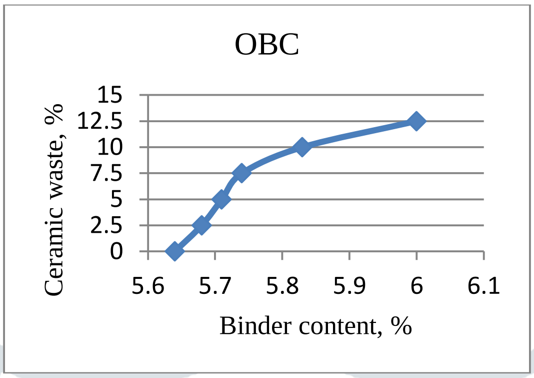

Fig. 10 Optimum Binder Content of BC mixes

5.3 Marshall Stability

Marshall Stability values are higher for ceramic filler mixes at 2.5%, 5% and 7.5% than the conventional BC mix. Further addition of ceramic waste results decreases in Marshall Stability of mixes. Marshall Stability value at 7.5% ceramic filler mix is higher than other ceramic mixes. Fig. 4.11 shows Marshall Stability values for ceramic filler mixes.

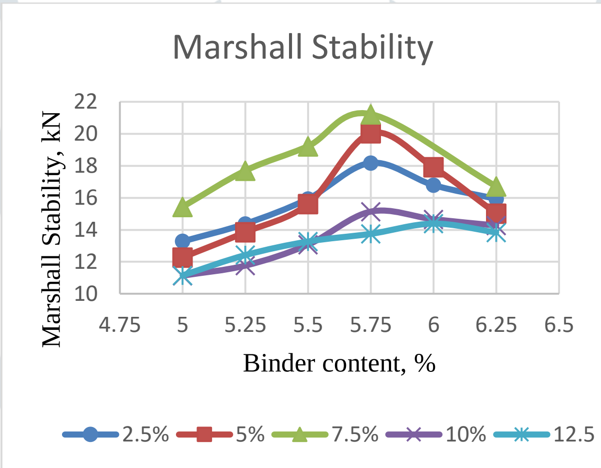

Fig. 11 Marshall Stability values of ceramic mixes

5.4 Marshall Flow

Flow values for ceramic filler mixes are found within the limit. Flow values at Optimum Binder Content are tabulated in Table 4.7. There is decrease in flow values upto 7.5% ceramic filler mixes. After addition of ceramic more than 7.5%, the flow value is increased due to increase in OBC at 10% and 12.5% mixes. Fig. 12 shows Flow values for ceramic filler mixes.

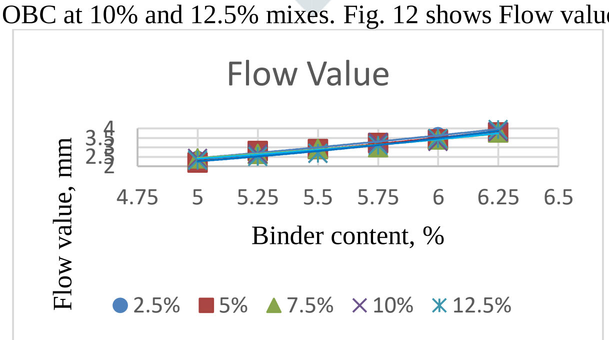

Fig. 12 Flow values of ceramic mixes

5.5 Density

Maximum density for compacted mixes is increase to its maxima at particular binder content and then decreases. Maximum density is slightly higher for conventional BC mixes than the ceramic BC mixes. Results show that maximum density of mixes decreases with increase in ceramic filler. Fig. 13 shows Density values for ceramic filler mixes

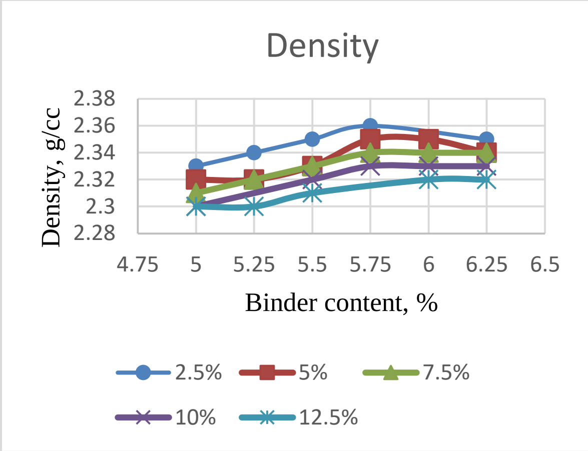

Fig. 13 Density values of ceramic mixes

5.6 Air voids

% air voids in the mix decreases as the binder content increases. % air voids in BC mixes increases with increase in ceramic filler. % air voids are within the limit for ceramic BC mixes at 2.5%, 5% and 7.5%. % air voids exceeded the limit at 10% and 12.5% ceramic filler. Hence ceramic waste can be used as filler in BC mixes by replacing 7.5% stone dust. Fig. 14 shows % air voids for ceramic filler mixes.

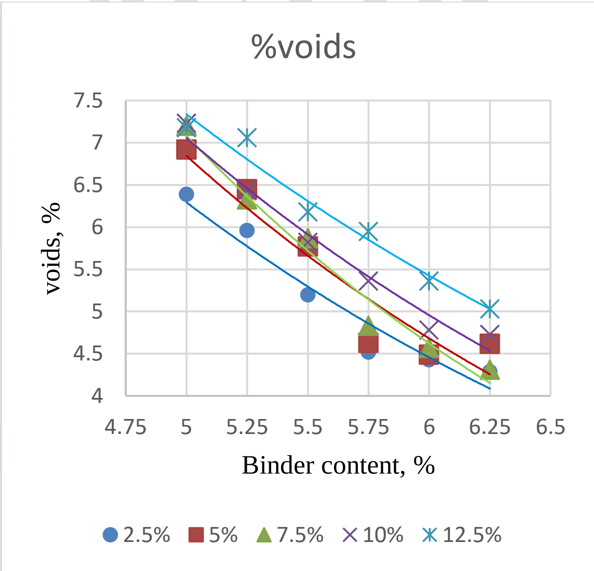

Fig. 14 % air voids of ceramic mixes

5.7 Voids filled with Bitumen

As the binder content increases, Voids filled with bitumen in mixes increases. % air voids and voids filled with bitumen are inter-related. As the % air voids increases, voids filled with bitumen in mixes decreases or vice-versa. From the results, it is observed that voids filled with bitumen values found within the limits for ceramic filler mixes. Fig. 15 shows voids filled with bitumen values for ceramic filler mixes.

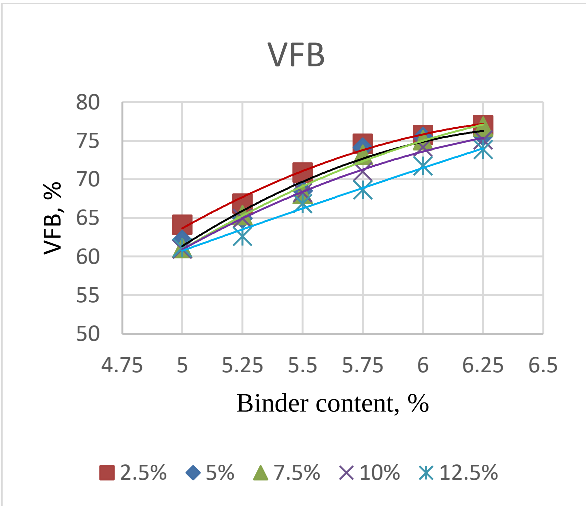

Fig. 15 VFB values of ceramic mixes

5.8 Water sensitivity test

- Tensile Strength Ratio from the Water Sensitivity test show better moisture susceptibility for both BC mixes i.e, more than 80%. BC mix with optimized ceramic waste shows better moisture susceptibility compared to conventional BC mix.
- Retained Marshall Stability of the mix is more for BC mix with optimized ceramic waste compared to conventional mix.

5.9 Repeated Load Test or Fatigue Test

- From the results, it is concluded that number of cycles required for failure is higher for optimized ceramic BC mix compared to conventional mix.

5.9.1 Cost Analysis

Cost analysis is systematic approach to achieve the benefits in preserving savings. In this chapter cost of materials required for production of both conventional BC mix and optimized BC mix are studied and discussed. Cost of materials for production of BC layer is calculated for surface course of 1km 2 lane road of 40mm thickness. Marshall Properties from the previous chapter shows that replacement of stone dust by 7.5% ceramic waste gives better results. Hence an attempt is made to compare the cost of materials required for production of conventional and optimized BC mix.

- For conventional BC mix, total cost of materials for 1 m^3 is Rs. 5,164.94. Total cost of materials for surface course of 1-km 2-lane road of 40mm thickness is Rs. 14,46,184.
- For optimized ceramic BC mix, total cost of materials for 1 m^3 is Rs. 5,168.74. Total cost of materials for surface course of 1-km 2-lane road of 40mm thickness is Rs. 14,47,247.
- For surface course of 1-km 2-lane road of thickness 40mm BC layer, cost analysis showed that the cost of materials for the production of conventional and optimized ceramic BC mix are approximately equal.

VI. CONCLUSION

Based on the laboratory experiments and analysis, the following conclusions are drawn. Marshall Parameter values for both conventional and optimized ceramic BC mix are found to be satisfactory as per the MORTH requirements. Ceramic waste can be replaced effectively upto 7.5% with stone dust in BC mix. The Tensile strength ratio for conventional BC mix and optimized ceramic BC mix are found to be more than the 80%. Hence, no anti-stripping agents are required. Retained Marshall Stability for optimized ceramic BC mix is found to be 89.04% which is 1.02 times more than the conventional BC mix. From the fatigue test, it is found that optimized ceramic mix showed higher resistance for cracking than conventional mix. Cost analysis for both conventional and optimized ceramic mixes indicates almost same cost for the materials.

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