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Feasibility Study for Using Industrial Waste as Filler in Bituminous Concrete

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Abstract

Due to the problems related to excessive waste generation, the need of recycling and reusing of waste material is arising for achieving the sustainability in construction activities. The present study focuses on the utilization of industrial waste as a filler material in flexible pavement. Four types of fillers were taken from different industries i.e. Ceramic Dust (CD) from ceramic industry, Crumb Rubber (CR) from automobile industry and Marble Dust (MD) from marble industry and Stone Dust (SD) from stone crusher. To check the suitability of these industrial wastes as filler in bituminous concrete, Marshall Specimens were prepared by adding filler in different doses i.e. 2%, 5% and 8%. Marshall Tests were conducted on prepared specimens and optimum filler content (OFC) and optimum bitumen content (OBC) for particular filler was obtained by comparing various Marshall Parameters. Retained stability tests were also performed on samples prepared on obtained OFC and OBC for particular filler. The results indicate that marble dust and ceramic dust can be effectively used as filler in bituminous mixes. The OFC of the ceramic dust, marble dust and stone dust comes out to be 5%. The crumb rubber does not perform satisfactorily performance when used, as filler as the stability and flow value does not meet the specified criteria as set by MORTH.

Keywords: Industrial Waste; Mineral Filler; Marshall Test; Retained Stability Test; Bituminous Concrete

List of abbreviations: CD: Ceramic dust; CR: Crumb rubber; MD: Marble dust; SD: Stone dust; MT: Metric ton; BC: Bituminous concrete; OBC: Optimum binder content; DBM: Dense bituminous macadam; RCA: Recycled concrete aggregate; MORTH: Ministry of Road Transport and Highways; VMA: Voids in mineral aggregates; VFB: Voids filled with bitumen; OFC: Optimum filler content

Introduction

Industrial waste is one such type of solid waste, excessive generation of which is creating various environmental and economic problems. India has a large network of industries located in different parts of the country and many more are planned for the near future. The amount of waste generated from industrial waste is estimated to be 12 to 14.7 million tons per annum [1]. Most of the industrial wastes such as fly ash, stone dust, marble dust, end of life tires, granite dust, ceramic dust, blast furnace slag, construction waste etc. are non-biodegradable. The common method used for waste disposal is landfilling which results in contamination of ground surface and groundwater sources. The availability of suitable land for waste disposal is becoming a challenge for urban areas. Several types of industrial waste are generated from different industries such as ceramic dust (CD) from ceramic industry, crumb rubber (CR) from automobile industry, marble dust (MD) from marble industry and stone dust (SD) from stone crusher. Marble powder is one such waste material, which is obtained from marble processing plants during the cutting, shaping and polishing of marble tiles. During this process, about one-fourth of the marble is turned into marble powder. The Indian ceramics industry, which is comprised of wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials and ceramic materials for domestic and others use is producing approximately 15 to 30MT per annum waste. Out of total waste, 30% goes as waste in and dumped the powder in open space. Ceramic waste is considered as non-hazardous solid waste and possesses pozzolanic properties. Therefore, after recycling can be reuse in different construction application. Discarded tires are another industrial waste, the disposal of which presents a serious environmental problem [2]. Crumb rubber is the name given to any material derived by reducing scrap tires or other rubber into uniform granules with the inherent reinforcing materials such as steel and fiber removed along with any other type of inert contaminants such as dust, glass, or rock. Hence, there is a need to look for the reuse of these waste materials. It is important to test the waste materials and to develop a methodology for their effective utilization in road construction and other applications. There is great pressure on different construction sectors of India including highway sector to explore the possibility of using these waste materials in construction works, to preserve the natural resources and to mitigate the environmental problems and land fill issues related with these wastes. The use of waste as an alternative to aggregate in highway construction would produce two major benefits; firstly, the natural aggregate quarry life can be extended. Secondly, the consumption of industrial space or productive land for dumping such waste may be reduced.

In this study, these industrial wastes are used in Bituminous Concrete (BC) as a filler material. Filler comprises of the mineral grains which passes through 0.075 mm sieve as specified in MORTH 2013 [3]. Filler particles fills the voids of the mix present within them and reduce its permeability. The performance of bituminous mix also depends on amount of filler in the mix. Similarly, the chemical behavior of fillers influences their agglomeration with bitumen and hence affects the performance of mixes when it exposed to the moisture.

Many researchers have carried out researches on the utilization of industrial waste as filler in bituminous mixes [4-9]. Sutradhar investigated the effects of using the fly ash, marble powder, rubber powder, and petroleum-contaminated soil as filler materials instead of stone powder in the bituminous concrete [10]. The results showed that marble powder and fly ash could be used as filler materials instead of stone powder in the bituminous concrete pavement. Chandra, *et al.* [11] studied the possible use of industrial wastes such as marble dust, granite dust and fly ash, along with hydrated lime and conventional stone dust from quartzite, as filler in bituminous concrete. The results suggested that marble dust, granite dust, and fly ash could be effectively used as filler in bituminous mixes. Among these industrial wastes, marble dust was found to be the most promising filler, as the results of mixes with marble dust have the lowest optimum binder content (OBC). Karasahin, *et al.* [12] investigated the use marble dust as filler in bituminous concrete. The results showed that limestone and marble dust gave almost the same performance. The value of marble dust in the mixes had higher values of the plastic deformation. In another study by Giri, *et al.* [9] the performance of DBM mixes prepared by the fillers i.e. cement dust and stone dust, was evaluated after using recycled concrete aggregate and pre-treated recycled concrete aggregate (RCA) with bitumen emulsion. Performance of DBM mixes with pre-treated RCA and cement dust as filler was observed as better. Fatima, *et al.* [13] studied that the suitability of ceramic waste as a filler material in semi-dense bituminous concrete. Results shows that the stability values and other parameters of samples containing ceramic wastes were improved in comparison to conventional mineral filler.

Hence, by going through literature, it was found that a limited amount of researches have been carried out to check the effect of using industrial wastes such as marble dust, fly ash, ceramic dust etc. But studies on the utilization of crumb rubber as a filler in bituminous mixes has not been carried out till date. This paper presents the influence of industrial waste used as filler in Bituminous Concrete (BC) mixes. To study the effect of different industrial wastes as a filler on the bituminous mix, conventional filler (stone dust) was replaced with 2%, 5% and 8% of crumb rubber, ceramic dust and marble dust (by weight of aggregates) and Marshall test were conducted at 4%, 5%, 6% and 7% bitumen content. Retained stability test was conducted to determine the moisture susceptibility of the bituminous mixes.

Materials

Bitumen

In present study, locally available binder corresponding to 80/100 penetration grade (viscosity grade 10) was used which was obtained from Pmd Petrocem India Pvt Ltd, Mohali, India. Important physical properties of the bitumen such as penetration value, softening point, ductility and specific gravity etc. were determined and are shown in Table 1.

Test	Results	IS 73:2013 Specifications	Test Procedure
Penetration at 25 °C	89	80 (Min)	IS 1203:2004
Softening Point (°C)	45.1	40 (Min)	IS 1205:2004
Ductility at 25 °C (cm)	87	75 (Min)	IS 1208:2004
Flash Point (°C)	262	220(Min)	IS 1209:2004
Fire Point (°C)	309	----	IS 1209:2004
Specific Gravity at 27 °C	1.02	----	IS 1202:2004

Table 1: Properties of bitumen

Aggregates

The aggregate used in the present study was taken from the nearby stone crusher from Chandigarh, India. The performance of bituminous mixes is primarily affected by the properties of aggregates. Characterization of aggregates is required to determine their suitability for using them in particular course. In characterization process, various aggregate properties such as Aggregate impact value, Aggregate crushing value, Los Angeles abrasion value, combined flakiness and elongation index, Water absorption etc. were evaluated and the results are shown in Table 2 [14].

The natural aggregates were sieved into individual fractions and recombined to produce the gradation specified by MORTH for bituminous concrete. Grading 1 was adopted for preparing bituminous concrete mixes for 50mm thick wearing course as per the MORTH specifications for roads and bridges which is shown in Table 3.

Tests	Results	MORTH Specification, 2013	Test Procedure
Aggregate Impact value (%)	13.22	24	IS 2386 (Part 4):1963
Aggregate Crushing Value (%)	21.46	----	IS 2386 (Part 4):1963
Los Angeles Abrasion (%)	21.34	30	IS 2386 (Part 4):1963
Combined Flakiness and Elongation Index (%)	19.29	35	IS 2386 (Part 1):1963
Apparent Specific gravity of Coarse Aggregate	2.72	----	IS 2386 (Part 3):1963
Bulk Specific Gravity of Coarse Aggregate	2.62	----	IS 2386 (Part 3):1963
Water Absorption of Coarse Aggregates (%)	1.20	2	IS 2386 (Part 3):1963
Apparent Specific gravity of Fine Aggregate	2.71	----	IS 2386 (Part 3):1963

Table 2: Properties of aggregates

Cumulative percentage passing				
Sieve size (Mesh)	Specification Limits	Grading A	Grading B	Grading C
	(Grading 1)	(2% Filler)	(5% Filler)	(8% Filler)
26.5 mm (1.06 in.)	100	100	100	100
19 mm (3/4 in.)	90-100	95	95	95
13.2 mm (0.53 in.)	59-79	69	69	69
9.5 mm (3/8 in.)	52-72	62	62	62
4.75 mm (#4)	35-55	45	45	45
2.36 mm (#8)	28-44	36	36	30
1.18 mm (#16)	20-34	27	27	26
600 µ (#30)	15-27	21	21	23
300 µ (#50)	10-20	14	15	20
150 µ (#100)	5-13	8	9	13
75 µ (#200)	2-8	2	5	8
Pan	0	0	0	0

Table 3: Gradation of aggregate used

Mineral filler

In this study, four types of mineral fillers: crumb rubber, stone dust, ceramic dust and marble dust were used. The crumb rubber was obtained from Publix India Incorporation, Ludhiana, India. The Ceramic Dust and Marble Dust were obtained from Shri Sai Cutting Edge, Sultanpur, and Delhi. The stone dust was obtained from local stone crusher in Chandigarh, India. All fillers were sieved through 75µ sieve and the passing fraction of the material was used as filler in BC mixes. The specific gravity of the fillers is shown in Table 4.

Specific gravity of fillers	Results	Test procedure
Ceramic dust	2.710	IS 2386 (Part 3):1963
Marble dust	2.592	
Stone dust	2.540	
Crumb rubber	0.820	

Table 4: Specific Gravity of mineral fillers

Experimental Design and Procedure

Marshall test

Laboratory investigations were made by performing Marshall Test on bituminous concrete mixes. The standard size of Marshall

Specimen was 63.5mm (2½ in.) height by a 101.6mm (4 in.) diameter. Approximately 1200g of aggregate and filler required for each test specimen. The aggregates and bitumen were blended together after heated separately at their corresponding mixing temperatures. The mix is placed in a preheated mould and compacted by giving 75 blows on each face with a 4.54kg hammer using a free fall of 457mm (18 in.), representing heavy traffic conditions. Specimens were then removed from the mold and allowed to cool overnight. Samples were immersed in a water bath at 60 °C for 30±5minutes. Samples (Figure 1a) are removed from the water bath and placed immediately in the Marshall loading head as shown in (Figure 1b).

Figure 1(a): Marshall Samples

(b): Marshall loading head

Marshal stability and flow value: Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25mm is called the Marshall Flow value of the specimen.

For Marshall Test, the optimum binder content was evaluated by determining the engineering properties of bituminous mixes in terms of Marshall stability, bulk density, flow value, air voids, Voids in mineral aggregates (VMA), voids filled with bitumen (VFB) etc. Marshall Tests were performed in accordance with AASHTO T245 Asphalt Institute MS-2 Manual (AI, 2014) [15] was adopted for the determination of optimum binder content. It recommends choosing the bitumen content at the median of the percent air voids limit, which is 4%.

Retained stability test

Retained stability tests were conducted in accordance with ASTM D1075 specifications to examine the performance of bituminous mixes against the moisture-induced damage. The Marshall specimens were considered conditioned when they have been immersed in water at 60 °C for 24h, and are unconditioned when they have been immersed in water at 60 °C for a half hour. Retained stability was calculated by taking the ratio of Marshall Stability of conditioned specimen to the Marshall stability of unconditioned specimen. For determining the resistance of mixes to moisture damage, the retained stability was obtained by using the equation.

$$\text{Retained stability}(\%) = \frac{\text{Marshall stability of Conditioned specimen}}{\text{Marshall stability of Unconditioned specimen}} \times 100$$

Results and Discussion

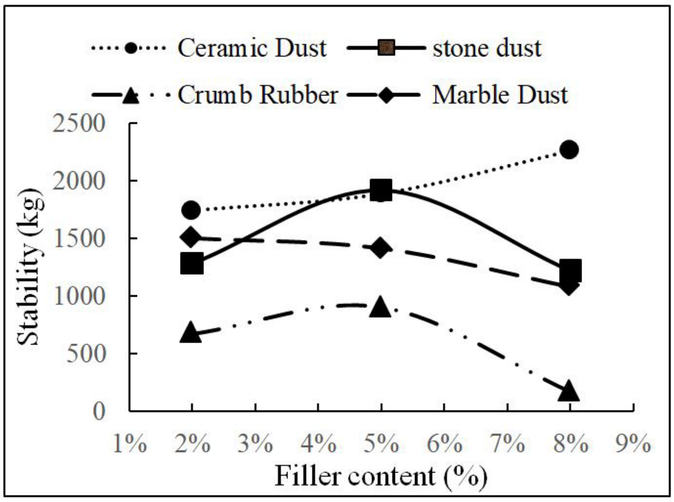
Marshall Test

The determination of mix design parameters is necessary in order to predict the performance of mix. Stability ensures resistance to deformation under sustained or repeated loads. Marshall Flow value is an important parameter in order to ensure the sufficient flexibility to withstand deflection and bending without cracking. Sufficient air voids are necessary to provide space for additional compaction under traffic loading in the total compacted mix. VMA is the volume of inter-granular void space between the aggregate particles of a compacted paving mixture. VFB represents the volume of the effective bitumen content in the mix. In the present study, the effect of utilization of different types of fillers on mix properties has been evaluated. Four types of mineral fillers viz. ceramic dust (CD), stone dust (SD), crumb rubber (CR) and marble dust (MD) have been investigated for use in bituminous concrete (BC). Each type of filler has been tested at 2%, 5% and 8% proportion by weight of mineral aggregates. Marshall Mix design was conducted and results of mix design parameters corresponding to optimum bitumen content (OBC) for each type of filler and filler content are tabulated in Table 5.

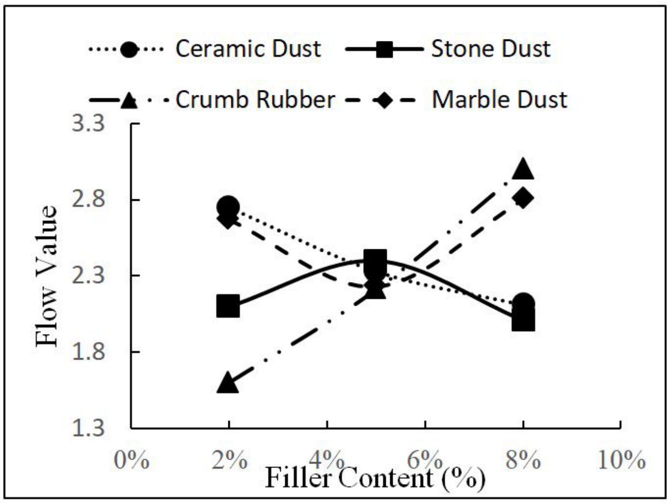
Type of filler	Filler content (%)	OBC (%)	Marshall Stability (kg)	Flow value	VMA (%)	VFB (%)	Density (kg/m³)
CD	2	5.80	1744.80	2.75	17.17	77.01	2389.60
	5	5.27	1889.00	2.33	15.54	74.06	2414.87
	8	5.35	2261.50	2.11	16.40	75.50	2403.60
SD	2	5.41	1284.60	2.10	16.48	76.21	2398.12
	5	5.30	1919.30	2.40	16.24	74.15	2394.53
	8	5.65	1221.90	2.01	15.90	76.73	2397.11
CR	2	5.45	673.20	1.60	16.04	74.10	2307.03
	5	4.60	905.50	2.21	13.70	71.86	2202.71
	8	4.00	171.20	3.00	12.20	67.92	2098.47
MD	2	5.55	1502.30	2.67	16.72	76.02	2395.00
	5	5.22	1416.00	2.23	15.88	75.43	2405.23
	8	5.25	1081.40	2.80	15.85	74.61	2399.20
MORTH, 2013	----	5.20 (Min)	900 (Min)	2-4	11-13 (Min)	65-75	----

Table 5: Marshall Mix design parameters corresponding to OBC at different filler contents

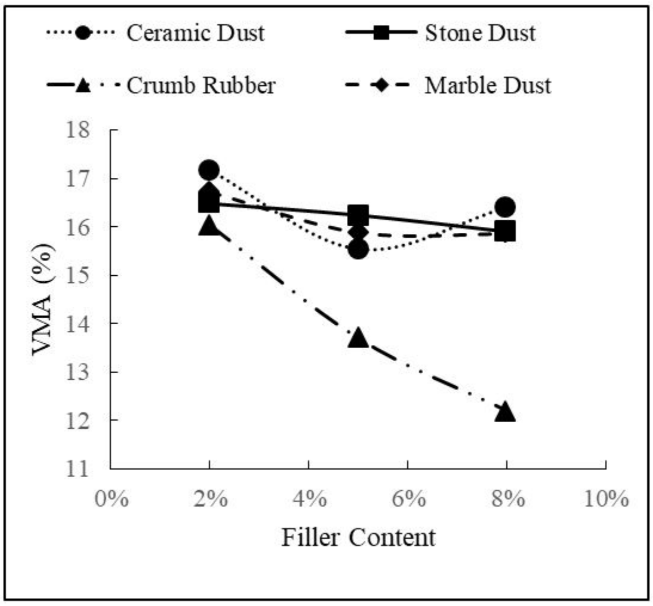
Graphs of Marshall Design parameters with different fillers at different filler contents at their OBC values are shown in Figure 2.



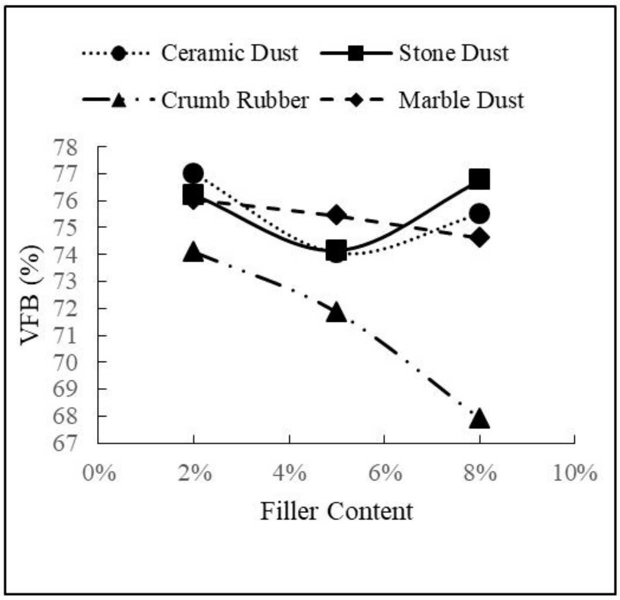
(a)



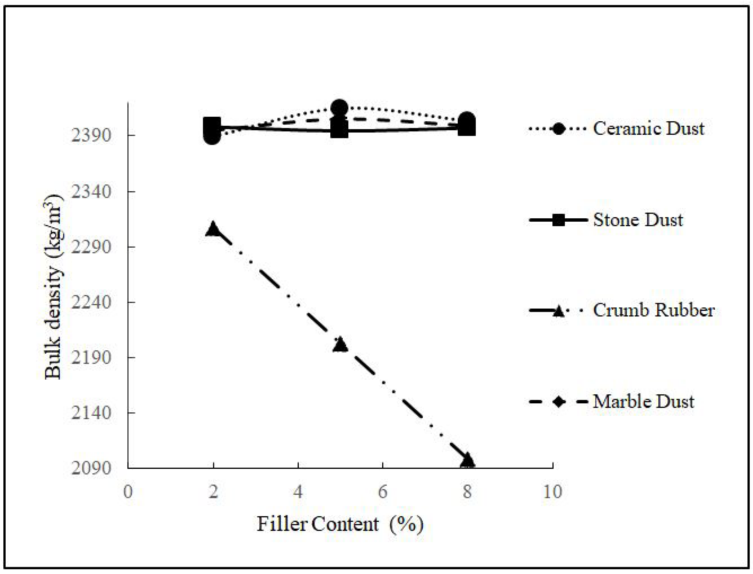
(b)



(c)



(d)



(e)

Figure 2: Effect of different types of filler and filler contents on **(a)** stability, **(b)** Flow value, **(c)** VMA, **(d)** VFB, **(e)** Bulk density

Effect of filler content on optimum bitumen content (OBC) of mix: As observed from Table 5, all the values of optimum bitumen content (OBC) for different types of fillers at different percentages of fillers were satisfying the minimum criteria specified by MORTH (i.e. 5.2%) for BC mixes. In case of BC mixes containing stone dust (SD) as filler, the minimum value of OBC was observed at 5% filler content. For the case of crumb rubber (CR) as filler, maximum OBC of 5.45% was obtained at 2% CR. On increasing the percentage of CR, OBC value decreased and the minimum value of OBC was obtained as 4% at 8% CR. For the case of ceramic dust (CD), the maximum OBC value of 5.8% was obtained at 2% CD. Ceramic and marble dust followed the same trend of OBC values as the conventional filler i.e. stone dust. On increasing the filler content, the OBC value of CR and MD first decreases and then increases.

Effect of filler content on Marshall Stability value: In case of BC mixes containing stone dust (SD) and crumb rubber (CR), as the filler content increased, increase in Marshall Stability value was observed upto certain content and then it began to decrease. Marshall Stability values of BC mixes containing 2% and 8% CR were not satisfying the required specifications as per MORTH, 2013 [3] given in Table 5, whereas mixes containing 5% CR were satisfying the minimum criteria for Marshall Stability value. Lesser stability values in case of mixes containing CR in comparison to other fillers could be attributed to the softening of agglomerate. The increase in Marshall Stability value of mixes containing ceramic dust (CD) as filler with the increase in filler content was observed and the mixes containing marble dust (MD) as filler showed opposite trend as also observed by Karasahin, *et al.* [12] and Fatima, *et al.* (2014) [13]. In case of mixes containing CD, the very high stability value (2261.50kg) was obtained at 8% CD as shown in Figure 2(a). This could be due to the reason that high content of CD results in stiffened specimen as observed during compaction process while preparing the specimen.

Effect of filler content on flow value of mix: All the fillers, except crumb rubber (CR) at 2%, were satisfying the required specifications for Marshall Flow value given by MORTH, 2013. With increase in filler content of CD, there was decrease in flow value resulting in stiffer mix. In case of mixes containing CR, there was significant increase in flow value with increase in filler content as shown in Figure 2(b). There was uneven variation of flow value with filler content observed in case of MD and SD.

Effect of filler content on bulk density of mix: For all the samples, the compacted density of the mix was almost same (in the range of 2389-2415 kg/m^3) except samples containing CR. The bulk density of mixes containing CD and MD were similar to that for mixes containing SD. The mixes containing CR showed the continuous decrease in the bulk density with increase in filler content as shown in Figure 2(e). This could be attributed to the lower specific gravity of CR as compared to other fillers.

Effect of filler content on voids in mineral aggregates (VMA) of mix: VMA is an important parameter, which influences the durability characteristics of mix. As it can be seen from Table 5, VMA values were satisfying the permissible requirements in all cases. With increase in filler content, the decrease in VMA values was observed in all cases except for mixes containing CD, in which VMA firstly decreased and then increased as shown in Figure 2(c).

Effect of filler content on voids filled with bitumen (VFB) of mix: VFB represents the volume of effective bitumen content of the mix. In case of the mix of CD and SD, the VFB value first decreases and then increases whereas in case of the mix of CR and MD, the VFB value decreases continuously. At 2% and 8% of the mix of CD and SD, the VFB values were observed more than the permissible limits as shown in Figure 2(d). The higher value of VFB could be used in normal traffic conditions.

Determination of optimum filler content (OFC): After analyzing the effect of different fillers and filler content on the Marshall properties of the mix, the optimum value of filler content could be determined from the experimental results. The optimum filler contents (OFC) for ceramic dust, stone dust and marble dust were observed as 5%, for all of them, since mix design parameters corresponding to these filler contents showed better results and were satisfying the required MORTH specifications for bituminous concrete. These results are in good agreement with the research of Chandra, *et al.* [11]. BC mixes containing CR showed inferior results i.e. less stability value as compared to other fillers. Although, mix design parameters, corresponding to OBC, were satisfying the required specifications in mixes containing 5% CR, but much lesser value of OBC (4.6%) than minimum permissible limit of 5.2% and Marshall stability value (905.50kg) marginally above than minimum permissible limit of 900kg were major concerns regarding its utilization as filler. Hence for retained stability test, the OFC for CR was taken as 5%. If we go on with minimum permissible OBC value of 5.2% for use of CR as filler in BC, Marshall Stability value will further decrease (lesser than 900kg) as observed in experimental results.

Retained stability test

Retained Stability is the measure of moisture-induced striping in the mix and subsequent loss of stability due to weakened bond between aggregates and binder. The retained stability test was performed on the calculated value of optimum filler content (OFC) at their corresponding optimum bitumen content (OBC) values and the results of retained stability tests are tabulated in Table 6.

Filler used			Retained stability value (%)
Ceramic Dust	Marshall stability value of conditioned specimen (kg)	1596.77	84.53
	Marshall stability value of unconditioned specimen (kg)	1889.00	
Stone Dust	Marshall stability value of conditioned specimen (kg)	1655.20	86.24
	Marshall stability value of unconditioned specimen (kg)	1919.30	
Crumb Rubber	Marshall stability value of conditioned specimen (kg)	667.53	73.72
	Marshall stability value of unconditioned specimen (kg)	905.50	
Marble Dust	Marshall stability value of conditioned specimen (kg)	1234.61	87.19
	Marshall stability value of unconditioned specimen (kg)	1416.00	

Table 6: Retained stability test results at OBC of fillers

The optimum filler content (OFC) of fillers was obtained and the retained stability value was calculated on the OFC values. Table 6 shows that the retained stability for the mixes with Marble dust (87.19%) has higher value as compared to other three mixes. All the values of retained stability satisfied the minimum required value of 75% except crumb rubber (CR). Retained stability value for CR (73.72%) marginally falls below minimum required value. It was recommended to use of CR in normal rainfall condition. The results showed that the presence of CD, MD and SD as filler in BC mixes leads to a higher protection against water damage and could be used in heavy rainfall condition.

Conclusions

From the laboratory investigation carried out for determining the suitability of different types of fillers in bituminous concrete, the following conclusions have been made.

- Ceramic dust (CD), stone dust (SD) and marble dust (MD) used as filler in the study shows the improvement in Marshall Stability and density values as compared to crumb rubber. The higher values of Marshall Stability were achieved by using CD and SD. Marshall Stability of a mix at OBC with 2% ceramic filler was 1744.8kg and increased to 2261.5 at 8% ceramic filler.
- In case of crumb rubber (CR), the Marshall parameter showed inferior results as the minimum stability value was achieved only at 5% CR that was marginally above than the required value. Decrease in the stability values occurs due to increase of the rubber particles in the mix because of the softening of agglomerate. A decrease in the density and VMA of the mix was observed with the addition of rubber in the mix because of low density of rubber.
- Higher value of voids filled with bitumen (VFB) in case of CD and SD could be used in normal traffic flow conditions.

- The highest retained stability value was obtained by marble dust (MD) filler i.e. 87.19%. In case of CR, the retained stability value was lesser than the specified limit, so the use of CR may be restricted to normal rainfall regions with effective drainage or it may be used with anti-stripping compounds in high rainfall regions.
- Ceramic dust and marble dust satisfies the entire minimum requirement for mineral filler specified by MORTH in bituminous concrete mixes except the VMA value at 2% filler content.
- Though the experimental results concluded that MD, SD and CD can be effectively utilized as fillers in bituminous concrete for provision in wearing course, it is recommended that other mix characteristics such as durability, cracking resistance etc. needs to be investigated so as to obtain satisfactory performance of wearing course during its service life.
- Utilization of waste materials such as CD, MD etc. is not only beneficial to decrease environmental problems such as air pollution, disposal problems etc., but there are indirect benefits such as reduction in land wastage etc.

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