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Partial Replacement of Fine Aggregates in SDBC Mix with China Clay Waste

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ABSTRACT: For construction of roads and highways, a large amount of aggregate is needed. Because the natural aggregate resources are limited, the demand for the use of alternative aggregates has increased. Every year India produces over 300 million ton industrial and agricultural waste. Globally various researches have been conducted by Scientists and Engineers to understand the use of this waste material in road construction with the key objective of effective disposal of these materials to save the environment. China clay waste is a product obtained after purification of china clay from their ore, which is one of the major waste material. In order to produce one ton of china clay, 8 to 9 ton of waste gets generated. Semi dense bituminous concrete is the upper bituminous layer of the road subjected to moderate traffic loads. The pavements and roads that are constructed and designed for extreme weather conditions and heavy duty traffic need specially prepared bitumen grades for enhanced performance. The proper incorporation of waste materials in pavement construction along with modified bitumen in a useful way will lead to a sustainable pavement technology. Partial replacement of fine aggregate using china clay waste in semi dense bituminous concrete (SDBC) along with viscosity grade-30 as well as modified bitumen NRMB are planned to be conducted in this project.

KEYWORDS: China clay waste, SDBC, VG-30, NRMB, Marshall property, Stability and Flow.

I. INTRODUCTION

The ever increasing economic cost and lack of availability of natural material have opened the opportunity to explore locally available waste. If industrial waste materials can be suitably used in road construction, the pollution and disposal problems may be partially reduced. China clay waste is one of the alternatives that can be used to replace aggregates in preparing a flexible pavement.

China clay (Kaolin) waste is a product after purification of china clay from their ore. To produce one ton pure china clay, eight to nine tons of waste gets generated. Kaolin is an important raw material in various industrial sectors. However the kaolin mining and processing industry generates large amounts of waste. The kaolin industry, which processes primary kaolin, produces two types of wastes. The first type derives from the first processing step (separation of sand from ore). The second type of waste results from the second processing step, which consists of wet sieving to separate the finer fraction and purify the kaolin. The waste materials that can be used to replace fine aggregate in flexible pavement construction can be derived from first processing step.

In roadway transportation system, highway can be differentiated functionally and structurally. According to functional classification it may be National Highways, State Highways, Major District Road, Village Road etc and according to structural classification it is rigid and flexible. Rigid pavements are constructed by using cement concrete while flexible pavements are constructed by using bitumen as a binder. The major portion of highway in our country is flexible.

Semi dense bituminous concrete (SDBC) is used as a wearing course and shall not be laid directly over WBM or any other granular base. SDBC mix consist of mineral aggregate and appropriate binder mixed in a hot mix plant and laid with a paver on a previously prepared base in accordance with the specifications and conforming to the lines, grades and cross sections.

Bitumen is a thermoplastic material and its stiffness is dependent on temperature. Viscosity Grade-30 bitumen (VG-30) is primarily used to construct extra heavy duty bitumen pavements. Natural rubber modified bitumen (NRMB) is special type of bitumen obtained which is prepared for improving the properties to make the material resistant to

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temperature variations, weathering and high traffic loads. Replacement of aggregates in normal as well as modified bituminous concrete mixes are quite inevitable due to the limitations in the availability and increased cost of natural aggregates.

II. LITERATURE REVIEW

Megha Nema (2014) et.al. conducted a study on the use of china clay waste in semi dense bituminous concrete. The main purpose of this paper is to evaluate the suitability of china clay waste as a fine aggregate in semi dense bituminous concrete. The optimum binder content for the specimen containing china clay waste was estimated to 5.07% and that for sample containing stone dust was 5.4%. This indicates that with the use of china clay waste in SDBC mix can reduce the quantity of bitumen. The percentage of aggregate replaced with china clay waste was 30%. The constituent particles of china clay waste as well as the range of percentage of replacement were obtained from this journal. The similarity in properties of china clay waste with that of primary aggregates were determined by analyzing the constituent particles.

D.Sakthibalan (2013) conducted a study on the influence of aggregate flakiness on dense bituminous macadam & semi dense bituminous concrete mixes. The presence of flaky aggregates is considered as undesirable in bituminous mixtures because of their tendency to breakdown under loading. Based on the Marshall stability test conducted they concluded that the parameters such as stability, flow, voids filled with bitumen and tensile strength ratio decreases with increase in proportion of flaky aggregate for both DBM and SDBC mixes. Flakiness index up to 30% for DBM and 33% for SDBC can be permitted without compromising the specification requirements. Hence we limited the value of flakiness index within the range in our work.

Deepesh Kumar Singh Lodhi & R.K Yadav (2016) conducted a study on the effect of gradation of aggregate on Marshall Properties of SDBC mix design. In this study five gradations which include lower grade, lower middle grade, middle grade, higher middle grade, and higher grade of grade 2 were used with 4.5%, 5% and 5.5% bitumen content. Based on the observation they concluded that the conventional practice of designing semi dense bituminous concrete mixes at mid point gradation does not result in the best mix. In the design of SDBC mix most of the Marshall properties are superior at lower middle gradation of MoRTH specification. Since the aggregate gradation have greater influence on the Marshall properties, we selected the lower middle grade gradation of grade 2 in our work.

Mithul Patel et al. (2014) conducted a study on properties of VG-30 paving mix with and without warm mix additive. Warm mix additives are used in order to reduce the mixing temperature of bitumen with aggregate. Lower temperatures result in reduced fuel usage, fume exhausts, green house gas emission, reduced wear and tear, enhancement of worker health and safety conditions during pavement construction and reduction in construction prices while maintaining the quality of work of pavement. Laboratory investigations to determine physical properties of VG 30 grade bitumen reveals that dosage of 2% of water mix by additive, by weight of asphalt is acceptable for road construction according to the MoRTH specification. Stability value of 2% dosage of warm mix additive is found to be higher at 120°C. The findings obtained from this journal are follows. VG 30 takes care of both low and high temperature susceptibility. Hence it is most suitable for pavements in India where there are higher temperature variations. It possesses excellent adhesive and bonding properties with aggregates, excellent water proofing properties and resistance to mild acids and alkali.

Krishnapriya M.G (2015) conducted study on performance evaluation of natural rubber modified bituminous mixes. The binders used for the study are PB 80/100 and NRMB 60/70. The performance characteristics with respect to common failure like fatigue, cracking, rutting and moisture susceptibility of the natural rubber modified bituminous mix are obtained by conducting different performance test. Based on the study she concluded that the overall performance of NRMB mix is better compared to that of ordinary bituminous mix. The optimum moisture content of NRMB based on performance test was found to be 5% and it has excellent rut resistance.

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III. MATERIALS COLLECTED

1. Mineral aggregates

Crushed aggregates are obtained from Palal aggregates Tiruvankulam. Mineral aggregates include the size ranging from 12.5mm to .075mm. Mechanical properties of coarse aggregates are utmost important for achieving long life pavements and sustaining heavy traffic loads. The laboratory investigations fulfill the criteria as laid down in MoRTH.

2. Filler

Aggregate passing through 0.075 mm IS sieve is called as filler. Function of filler is to fill up the voids in the mixes. By using of filler, bitumen mixes can be made harder and stiffer. This will cause least possible of deformation occurs due to traffic load. In bituminous mixes different types of fillers were used like limestone dust, cement, stone dust, brick dust, silica fume, fly ash, marble dust cement etc. For the study limestone dust is used as filler.

3. Viscosity Grade (VG-30) Bitumen.

Bitumen is defined as the tarlike mixture of hydrocarbons derived from petroleum naturally or by distillation. The primary use of bitumen is in road construction, where it is used as the glue or binder mixed with aggregate particles to create bitumen concrete. Bituminous materials are very commonly used in highway construction because of their binding and their water proofing properties. VG-30 bitumen has a penetration grade of 60/70. It is primarily used to construct extra heavy duty bitumen pavement that need to endure substantial traffic loads. VG-30 bitumen is suitable for hot climate. For the study VG-30 is obtained from Bharat petroleum Ltd.

4. Natural rubber modified bitumen (NRMB)

Proper blending of bitumen with natural rubber in a fixed proportion confers good elastic recovery to the blend. Incorporation of 2-4 percent natural rubber into bitumen thus improves the properties of the later substantially and rubberized bitumen is found to be an excellent binder for rubble and sand. The rubberized bitumen formed minimizes permanent deformation due to overload on the road. This bitumen is unaffected by changes in atmospheric temperature and improve skid resistance due to increased aggregate retention and elimination of bleeding. Rubber increases the resistance to flow of bitumen at high temperature and improves the resistance to brittle fracture at low temperature. The above properties increase the service life of rubberized roads. For the study NRMB is obtained from Bharat Petroleum Ltd.

5. China clay waste

China clay waste is the spoil resulting from the production of china clay. It is largely produced in the Kutch district of Gujarat region of India, for every tone of china clay produced an average of 9 tons of waste are produced. China Clay by-products have properties similar to primary aggregates. In particular the better quality stent has properties not dissimilar to crushed granite. In this research the source of china clay waste is Kerala Ceramics Ltd Kundara.



Fig. 1 (a) Stone aggregate (b) China clay waste

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Table1. Gradation of aggregates

IS Sieve in mm	Percentage passing by weight (Grade 2)	
	Range	Lower mid grade
13.2	100	100
9.5	90-100	92.50
4.75	35-51	39.00
2.36	24 -39	27.75
1.18	15 -30	18.75
0.3	9-19	11.50
0.075	3-8	4.25

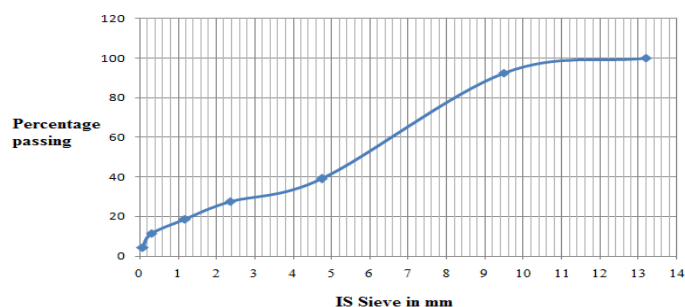


Fig 2. Gradation curve

IV. MATERIALS TEST RESULTS

Table 2. Aggregates test results

Description of test	Specification as per IRC95-1987	Test result
	(maximum)	Observed
Aggregate Impact value(%)	30	28.75
Aggregate crushing value(%)	40	34.40
Water absorption(%)	1	0.30
Specific gravity	N/A	2.75
Stripping(%)	25	0.00
Flakiness index	30	18.75
Elongation index	15	13.85

Table 3. Test results of VG-30

Description of test	Specification as per IS:73-2006	Test result observed
Viscosity	60-140 Seconds	67 Seconds
Specific Gravity	0.97-1.02	1
Softening Point	>47°C	55°C
Ductility	Min. 40 cm	95 cm

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Table 4. Test results of NRMB

Description of the test	Specification as per IS:15462-2004	Test result observed
Viscosity	60-140	120 Seconds
Specific Gravity	-	1
Softening Point	55 ⁰ C	55 ⁰ C
Ductility	Min. 40 cm	70 cm

V. EXPERIMENTAL PROGRAMME

Marshall Method was introduced by Bruce Marshall of the Mississippi State Highway Department. In general, the Marshall Method is applied with penetration bitumen or viscosity grade bitumen. The mixes should contain aggregate with size less than 25mm. It requires the preparation and evaluation of a series of tests with different bitumen content of each other. The Marshall test uses standard cylindrical test moulds that are 10.2 cm diameter by about 7.5cm high. The specimens are prepared using a prescribed procedure for heating, mixing and compacting the bitumen-aggregate mixtures. The two principle features of the Marshall method of mix design are a density-voids analysis and a stability flow test of the compacted test specimens. The stability test is a type of unconfined compressive strength test in which the test specimen is compressed radially at a constant rate of strain of 50mm per minute at 60⁰C. The Marshall stability of each test specimen is the maximum load resistance in Newton that the specimen develops, while the Marshall Flow value is the total movement or strain occurring in the specimen between no load and maximum load during the stability test. The optimum binder content then selected for design is essentially a compromise value which meets specified requirement for stability, deformation and void content.

1. Preparation of Test Specimen.

1. Measure 1200 grams of aggregates which has been blended in the desired proportions.
2. Heat the aggregates in the oven to the mixing temperatures.
3. At the mixing temperature, add bitumen at various percentages.
4. The materials are then mixed in a heated pan with heated mixing tools.
5. Mixture is then returned to the oven and reheated to the compacting temperature.
6. Place the mixture in a heated Marshall mould with a collar and base and then the mixture is spaded around the sides of the mould.
7. Place a filter paper under the sample and on top of the sample.
8. The mould is then placed in a Marshall compaction pedestal
9. Compact the material with 75 blows of the hammer.
10. The sample is then inverted and compacted on the other face with number of blows.
11. After compaction, invert the mould, with collar on the bottom. The base is removed and the sample is extracted by pushing it out the extractor.
12. The sample is allowed to stand for the few hours to cool.
13. Record the mass of the sample in air and when submerged, as this is used to measure the density of specimen, so as to allow, calculation of the void properties.
14. Determine the bulk density of each specimen.
15. Calculate the percentage of air voids in each compacted specimen.
16. For each specimen, calculate the percentage of voids in the compacted mineral aggregate framework.

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2. Test procedure

1. Specimens should be heated to 60°C, either in a water bath for 30-40 minutes or in an oven for minimum of 2 hours.
2. Remove the specimens from the water bath or oven and place in lower segment of the breaking head. The upper segment of the breaking head of the specimen should be placed in position and the complete assembly is placed in position on the testing machine.
3. The flow meter should be placed over one of the posts and is adjusted to read zero.
4. Load should be applied at a rate of 50 mm per minute until the maximum load reading is obtained.
5. The maximum load reading in Newton is observed. At the same instant the flow as recorded on the meter in units of mm was also noted.
6. Correct the measured stability values and prepare separate graphical plots for binder content versus each of the following:
 - Stability,
 - Flow value,
 - G_m (Bulk sp. Gravity),
 - Voids in mineral aggregates (VMA),
 - Air voids,
 - VFB (voids filled with bitumen).
7. Determine the optimum bitumen content.

VI MARSHALL TEST DATA

Table 5. Average Marshall properties of samples with VG-30 as binder

China clay Waste percentage	Bitumen content (%)	Bulk density(g/cc)	Air voids (%)	VFB (%)	Stability (kN)	Flow (mm)
0%	5.00	2.372	4.944	70.630	13.500	2.950
	5.50	2.384	3.670	78.140	11.140	3.900
	6.00	2.393	2.602	84.660	15.010	4.650
	6.50	2.377	2.565	85.810	9.170	5.050
25%	5.000	2.361	5.131	69.700	12.150	3.400
	5.500	2.375	3.774	77.600	13.340	3.650
	6.000	2.369	3.330	81.020	15.380	4.350
	6.500	2.364	2.853	84.340	11.510	5.500
30%	5.000	2.334	6.266	65.060	13.510	2.650
	5.500	2.366	4.116	75.970	15.110	3.500
	6.000	2.364	3.482	80.290	16.870	4.600
	6.500	2.356	3.147	82.950	12.820	5.300
35%	5.000	2.280	8.732	56.630	12.090	2.560
	5.500	2.308	6.674	65.600	14.050	3.450
	6.000	2.356	3.800	78.860	11.030	4.500
	6.500	2.350	3.301	82.230	9.030	5.450

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Table 6. Average Marshall properties of samples with NRMB as binder

China clay waste percentage	Bitumen content (%)	Bulk density (g/cc)	Air voids (%)	VFB (%)	Stability (kN)	Flow (mm)
0%	5.000	2.280	8.732	56.630	12.090	2.560
	5.500	2.308	6.674	65.600	14.050	3.450
	6.000	2.356	3.800	78.860	11.030	4.500
	6.500	2.350	3.301	82.230	9.030	5.450
25%	5.000	2.392	4.075	74.583	13.749	2.600
	5.500	2.397	3.143	80.754	14.535	3.550
	6.000	2.421	1.401	91.202	15.644	4.500
	6.500	2.406	1.347	92.074	7.840	6.000
30%	5.000	2.382	4.202	73.933	10.777	2.400
	5.500	2.398	2.800	82.500	13.096	3.700
	6.000	2.419	1.219	92.252	14.578	4.400
	6.500	2.412	0.782	95.248	10.073	5.950
35%	5.000	2.363	4.913	70.760	11.788	3.800
	5.500	2.367	4.001	76.515	12.975	4.900
	6.000	2.374	2.983	82.686	14.227	5.400
	6.500	2.366	2.624	85.426	9.707	6.300

VII. EXPERIMENTAL RESULTS

1. TEST PROPERTIES CURVE FOR BITUMINOUS MIX BY MARSHALL METHOD

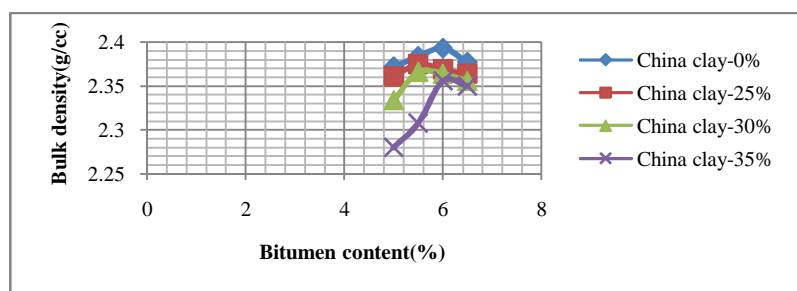


Fig. 3 Combined graph of Bulk density Vs Bitumen content (VG-30)

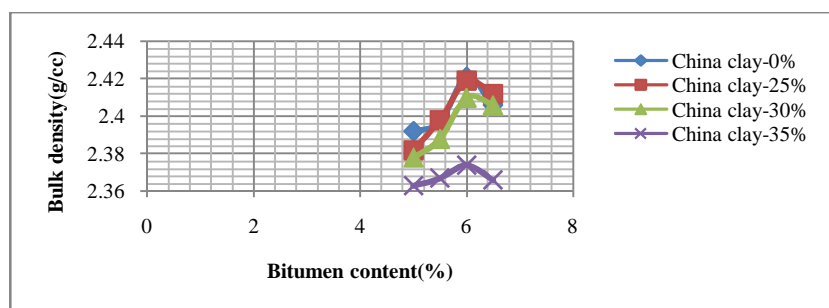


Fig. 4 Combined graph of Bulk density Vs Bitumen content (NRMB)

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Fig. 3 shows variation of bulk density with varying percentage of binder content for VG-30 with and without china clay waste replacement. For VG-30 maximum bulk density is obtained for conventional mix ie, 2.393 and the bulk density decreases with increase in percentage of china clay waste in the mix. Fig. 4 represents variation of bulk density for NRMB with various percentage of china clay waste. For NRMB also maximum bulk density is obtained for conventional mix ie, 2.42 and the bulk density decreases with increase in percentage of replacement. This may be due to the reason that China clay waste has less specific gravity when compared to natural aggregates.

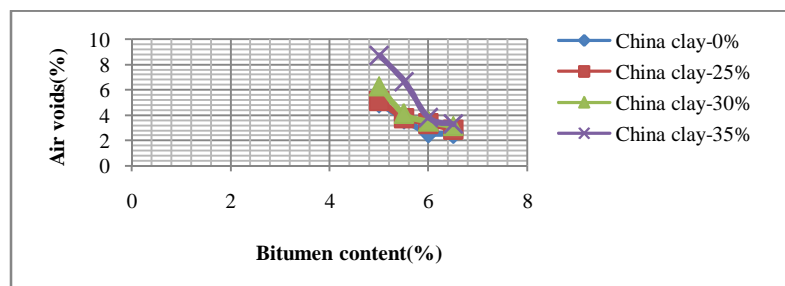


Fig. 5 Combined graph of Air voids Vs Bitumen content (VG-30)

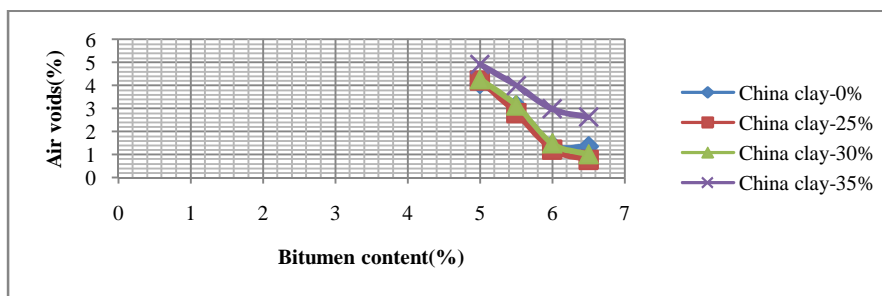


Fig. 6 Combined graph of Air voids Vs Bitumen content (NRMB)

Air voids are necessary in bituminous mixes to allow densification under traffic loads and to prevent bleeding of bitumen during hot climates. MoRTH specified air voids within the range 3-5% for SDBC mixes. At lower bitumen content air voids is higher, as the bitumen content increases percentage of air voids decreases. Fig. 5 and Fig. 6 shows variation of percentage of air voids for VG-30 and NRMB respectively. From both the graph it is clear that air voids increases with increase in fine aggregate replaced with china clay waste. This may be due to that China clay waste is more porous than conventional aggregate.

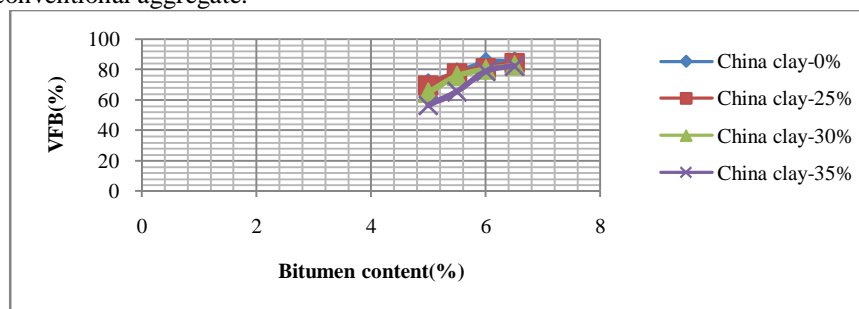


Fig.7 Combined graph of VFB Vs Bitumen content (VG-30)

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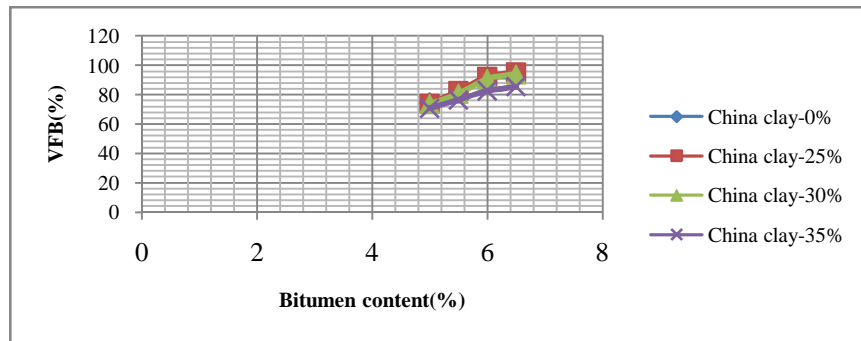


Fig.8 Combined graph of VFB Vs Bitumen content (NRMB)

Certain amount of air voids are present in the aggregate and the bitumen is expected to fill up to 67 to 75 percent of these voids. According to MoRTH Semi Dense Bituminous Concrete should have VFB within the limits 65-78%. VFB increases with increase in percent of bitumen. Based on test results it can be seen that in most of the cases it crosses the limits

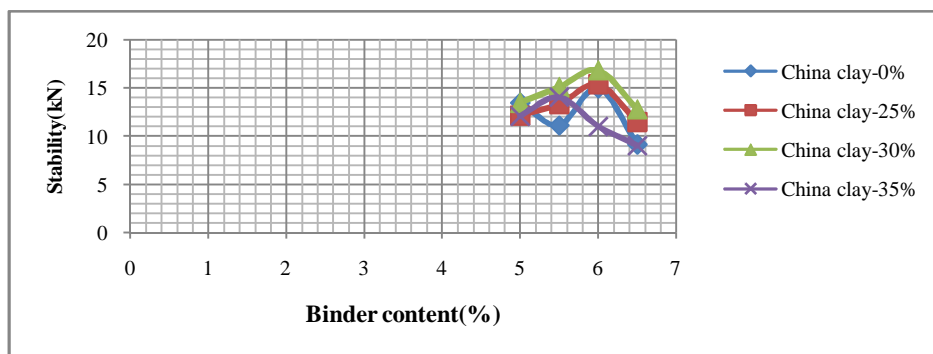


Fig. 9 Combined graph of Stability Vs Bitumen content (VG-30)

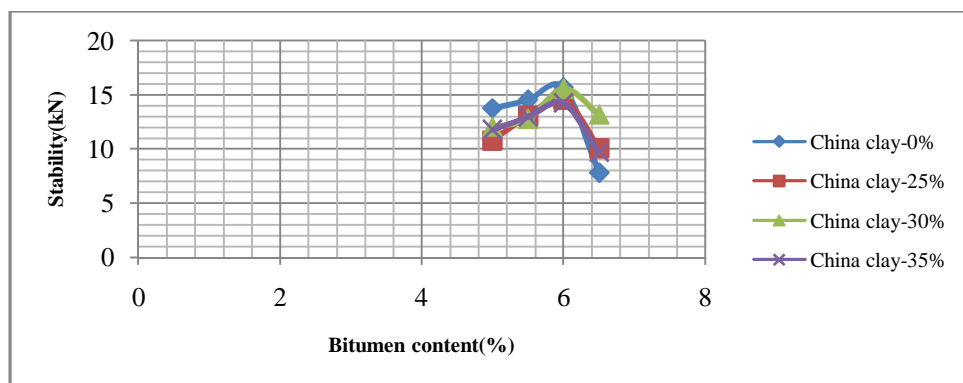


Fig. 10 Combined graph of Stability Vs Bitumen content (NRMB)

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According to MoRTH specification minimum stability for Semi Dense Bituminous Concrete pavement is 8.2 kN at 60°C. The stability values for all the test results are much higher than that of minimum value prescribed in guidelines. In this study it is observed that when bitumen percentage increased stability also increased. At a certain point after increment of bitumen percentage stability decreased.

Fig. 9 shows variation of stability at different bitumen content for the mix using VG-30. Maximum stability values were obtained from the mixes in which 30% of fine aggregate were replaced with china clay waste ie, 16.87kN which is 12.4% more than the stability value for conventional mix. Maximum stability value for conventional mix was obtained as 15.01 kN. When the replacement percentage of china clay waste was increased to 35% stability value is decreased to 14.05 kN but it is greater than the minimum stability requirement as per guidelines.

Fig. 10 shows the variation of stability at different bitumen content for NRMB. In case of NRMB it is observed that maximum stability value is obtained for conventional mix. When the fine aggregate is replaced with china clay waste maximum stability value is obtained at 30% replacement ie, 15.577 kN which is slightly less than that obtained for conventional mix.

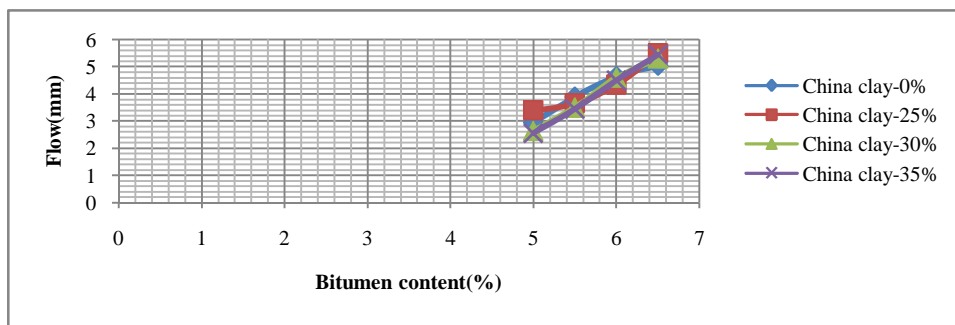


Fig.11 Combined graph of Flow Vs Bitumen content (VG-30)

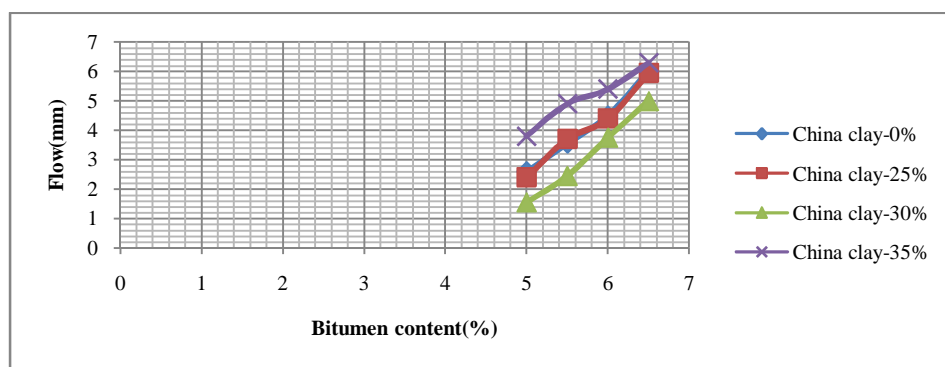


Fig. 12 Combined graph of Flow Vs Bitumen content (NRMB)

MoRTH specified the flow value in the range 2-4 mm for SDBC mix. It is obtained that as the percentage of bitumen increased flow value also increased. For VG-30 up to 5.5% of bitumen content it falls within the limits. In most of the cases flow value is more for conventional mixes. Flow value for bitumen mixes using NRMB is higher than that for mixes using VG-30. In case of NRMB also up to 5.5% of binder content flow value falls within the limits.

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2. DETERMINATION OF OPTIMUM BINDER CONTENT

Optimum binder content for the mix design can be determined by taking average value of the following three bitumen contents found from the graphs.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity (Gm)
3. Binder content corresponding to the median of designed limits of percent air voids (Vv) in the total mix (i.e. 4%)

Table 7. Optimum binder content for VG-30

Specimen	VG-30 0% replacement	VG30 25% replacement	VG30 30% replacement	VG30 35% replacement
Binder content at maximum bulk density	6	6	6	6.1
Binder content at maximum stability	5.3	5.4	5.6	6
Binder content at 4% air voids	6	5.9	5.9	5.5
Optimum binder content	5.76	5.76	5.83	5.86

Table 8. Optimum binder content for NRMB

Specimen	NRMB 0% replacement	NRMB 25% replacement	NRMB 30% replacement	NRMB 35% replacement
Binder content at maximum bulk density	6	6	6	5
Binder content at maximum stability	5	5.1	5.1	5.5
Binder content at 4% air voids	5.9	5.9	6	5.9
Optimum binder content	5.63	5.66	5.7	5.8

VIII. CONCLUSION

Marshall Stability test was conducted to evaluate the suitability of China clay waste as a fine aggregate in SDBC mix using NRMB and VG-30. Based on the test results following conclusions are made,

- Stability value of mixes with different percentage of china clay waste has shown good results satisfying the minimum requirement of 8.2 kN.
- It has been observed that the replacement is more effective in SDBC mix using VG-30.
- In case of SDBC mix using VG-30 stability value is maximum for the mix in which 30% of fine aggregate is replaced with China clay waste and maximum value was obtained as 19.59 kN which is greater than the stability value obtained for conventional mix.
- In case of NRMB stability value of conventional mix is 18.97 kN and that of mix obtained by 30% replacement of china clay waste is 16.79 kN, which is high compared to minimum requirement.
- Optimum binder content for VG-30 is slightly more than that for NRMB. This may be due to the increased efficiency of NRMB to coat over the aggregate easily imparted by its ductile property.
- Optimum binder content increases with increase in percentage of china clay waste. This may due to the increased absorption of bitumen by china clay waste.

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- Flow, VFB, air voids for the specimen casted for optimum binder content falls within the limits specified by MoRTH.
- Bulk density gets reduced when replacement is done in SDBC mix with china clay waste. This may be due to the reduced specific gravity of china clay waste.
- Air voids increased when percentage of replacement increased. The increase in air voids may be due to the porous nature of China clay waste.

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