Influence of Variation in the Aggregate Gradation Range on Mix Design Properties of Bituminous Concrete (BC) Mixes used as Wearing Course

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***Abstract*—India is one of the countries having the largest road network where majority of the roads are paved with bitumen-based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course. Bituminous roads are mainly composed of naturally available aggregates and hot bitumen/asphalt, where aggregate makes up 90-95 percent by weight of Hot Mix Asphalt (HMA). Among the various type of bituminous paving mixes in India, Bituminous Concrete (BC) mix having dense grading specification (as per Ministry of Road Transport and Highways (MoRTH))has been used as a wearing course in a pavement structure to distribute stresses caused by heavily trafficked loading and to protect underlying unbound layers from the effects of water. Therefore, designing a bituminous mix to meet the desired requirements of a particular paving project requires careful selection of the compatible aggregate source, aggregate gradation and bitumen grade to sustain till its design life. Hence, is important to analyze that how the variation in aggregate gradation within the specified limits can affect the essential mix design properties of bituminous mix.**

The present study was taken up with the objective of evaluating the properties of HMA mixtures designed using bituminous concrete (BC)1 and 2 gradation. For the preparation of bituminous mixes, three aggregate gradation limits (upper limit, mid-point range and lower limit) for both BC grading 1 and 2 were used and evaluation is doneby using Marshall Method of mix design.By evaluating the volumetric and Marshall properties of the bituminous mixes with different gradations, results indicate that the performance of mixes made with mid-point value of gradation range shows higher Marshasll Stability value than other mixes while the optimum binder content (OBC) increases form coarser gradation to finer gradation for both the grading specifications. However in both the grading specifications, value of void filled with bitumen (VFB) is in the marginal range for upper and lower limit gradation and the value of voids filled with asphalt (VFA) is above the specified minimum value and the overall resultshows satisfactory performance with the variation in aggregate gradation limits.

Keywords*— *Bituminous concrete, Marshall method of mix design, wearing course, hot mix asphalt.

I. INTRODUCTION

Today, road transport is the major leading mode of transportation in India and by any reckoning it proves to be the lifeblood of India's economy because of the industrial developments and economic benefits associated with a road development project. Due to these motives, development of a modern road network has become one of the vital agendas of various countries. India is currently having a road network of 4.69 million kilometers [1], where the total road length of India has increased more than 11 times during the 60 years between 1951 and 2011. From 3.99 lakh kilometer as on 31 March 1951, the road length has increased to 46.90 lakh kilometers as on 31 March 2011 [2].

Majority of roads in India are flexible pavements having primarily bitumen-based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course [3] and Hot Mix Asphalt (HMA) is widely used bituminous material from many years for construction of flexible pavements. Bituminous material are mainly composed of naturally available aggregates and hot bitumen, where aggregate makes up 90-95 percent by weight of HMA [4]. Bituminous mixes are mainly used to provide structural strength, facilitate subsurface drainage and surface friction especially when the pavement surface is wet. Likewise, among the various type of bituminous paving mixes in India, bituminous concrete (BC) mix having dense grading specification as per Ministry of Road Transport and Highways (MoRTH) [5]has been used as a wearing course in a pavement structure to distribute stresses caused by heavily trafficked loading and to protect underlying unbound layers from the effects of water [6].

Designing a bituminous mix to meet the desired requirements of a particular paving project requires careful selection of the compatible aggregate source, aggregate gradation and bitumen grade to sustain till its design life. Basically in a batch mix or in a drum mix plant, aggregates and binder are added in designated amounts to make up one batch, where the aggregates are obtained from the nearest quarry. In a quarry, the gradation of each stock pile aggregate material is determined first and then gradations are analyzed to determine in what proportion the aggregates from different stock piles can be combined to produce a specific gradation [7] which lies with the specified gradation limit of MoRTH.These variation in gradation limit tends to affects almost all the vital properties of HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance and resistance to moisture damage [8]. Therefore, it is important to analyze that how the variation in aggregate gradation of Indian bituminous paving mixes (Bituminous Concrete) can affect the essential mix design properties within the specified limits of Ministry of Road Transport and Highways (MoRTH)-(Fifth Revision) 2013.

II. OBJECTIVES OF THE PRESENT STUDY

In flexible pavements for the non HMA layers, the optimum additive content is that which produces maximum density, whereas for HMA layers, the design binder content is the one that produces 4% void in compacted mixes in the laboratory. Therefore, the present study was taken up with the objective of evaluating the influence of variation in aggregate gradation range on mix design parameters of Bituminous Concrete grading (1 and 2), where the optimum binder content was calculated asthe average of asphalt content for maximum stability,maximum unit weight, and 4.0% air voids by Marshall method of mix design.

III. EXPERIMENTAL PROGRAMME

In this research one type of aggregate, one type of binder and two types of mixes (Bituminous Concrete (BC) Grading-1 and 2)were used. Extensively, the properties of three aggregate gradationslimit (upper limit, mid-point range and lower limit)for both grading were studied to signify the influence of variation on the mix design properties of bituminous mixes using Marshall Method of mix design. Further, verification of aggregate and binder specification is done according to MoRTH-2013 (Fifth revision) and IS: 73-2006 [9].

A. Aggregate Characterization

To prepare the bituminous mix specimens crushed coarse aggregate, fine aggregate and mineral filler were procured from a Pachami stone quarry near Mohammad Bazar at Birbhum district in the state of West Bengal.Initially, the physical properties of aggregates were evaluated and verified according to MoRTH-2013 and are shown in Table 1. From the test results, it was found that the properties of aggregates are within the specified limits.

TABLE-1: PHYSICAL REQUIREMENTS FOR COARSE AGGREGATE FOR BITUMINOUS CONCRETE AND THEIR RESULTS

Property	Test	Specification	Result (%)	Test Method
Cleanliness	Grain Size Analysis	Max.5%passing0.075 mm	1.14	IS 2386 Part 1[10]
Particle Shape	FlakinessandElongation Index	Max. 35% Combined	24.67	IS 2386 Part 1[10]
Strength	Los Angeles Abrasion	Max. 30%	19.34	IS 2386 Part 4
	AggregateImpact Value	Max. 24%	12.28	IS 2386 Part 4[12]
Water Absorption (W.A)	W.A of Coarse Aggregate	Max. 2%	0.55	IS 2386 Part 3[11]
	W.A of Fine Aggregate		1.61	
Stripping	Stripping Test	Min. Coating 95%	>95	IS 6241[13]

Three aggregate gradations for each type of grading are designated and illustrated in Table 2 and 3 respectively and Figure 1and 2 shows the aggregate size distribution curve for both the gradations used in the present study.

TABLE-2:AGGREGATE GRADATION SPECIFICATIONS AND DESIGNATION EMPLOYED FOR INVESTIGATION

Sl.No.	Gradation Specification of Bituminous Concrete (BC) Mix	Gradation Designation
1	Lower limit of BC Grading 1	BCL1
2	Middle limit of BC Grading 1	BCM1
3	Upper limit of BC Grading 1	BCU1
4	Lower limit of BC Grading 2	BCL2
5	Middle limit of BC Grading 2	BCM2
6	Upper limit of BC Grading 2	BCU2

TABLE-3: DIFFERENT AGGREGATE GRADATION USED IN THIS STUDY AS PER BC-1 & 2 GRADING

Designation	BCL 1	BCM1	BCU1	BCL 2	BCM2	BCU2
Nominal Maximum Aggregate Size (mm)	19	19	13.2	13.2	13.2	9.5
IS Sieve Size (mm)	Cumulative % by weight of total aggregate passing					
26.5	100	100	100	-	-	-
19	90	95	100	100	100	100
13.2	59	69	79	90	95	100
9.5	52	62	72	70	79	88
4.75	35	45	55	53	62	71
2.36	28	36	44	42	50	58
1.18	20	27	34	34	41	48
0.6	15	21	27	26	32	38
0.3	10	15	20	18	23	28
0.15	5	9	13	12	16	20
0.075	2	5	8	4	7	10
R^2	0.95	0.92	0.87	0.85	0.80	0.73

Evaluation of specific gravity by means of expressing the weight-volume characteristics of material are essentially important in manufacturing pavement mixtures because the aggregate and asphalt in a bituminous mix are proportioned by weight. Even in a bituminous mix, specific gravity values of aggregate provides an essential information for calculating effective specific gravity, bitumen absorption in percentage by weight of aggregate andvoids in mineral aggregate. However, the bulk specific gravity and apparent specific gravity of coarse aggregate, fine aggregate and filler evaluated as per IS: 2386 (Part 3) [11] andthe results are given in Table 4 **.**

TABLE-4: SPECIFIC GRAVITY TEST RESULTS OF AGGREGATES, FILLER AND BITUMEN

	Type	Coarse Aggregate	Fine Aggregate	Filler
Specific Gravity	Bulk	2.86	2.44	2.47
	Apparent	2.90	2.53	

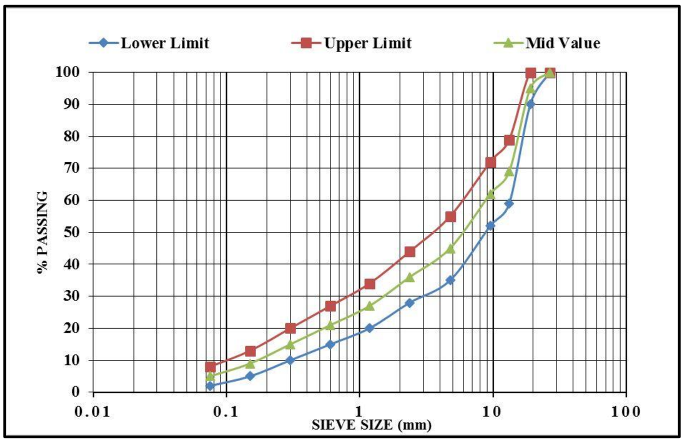

Fig. 1 Aggregate Gradation of Bituminous Concrete (BC)-1 Mix

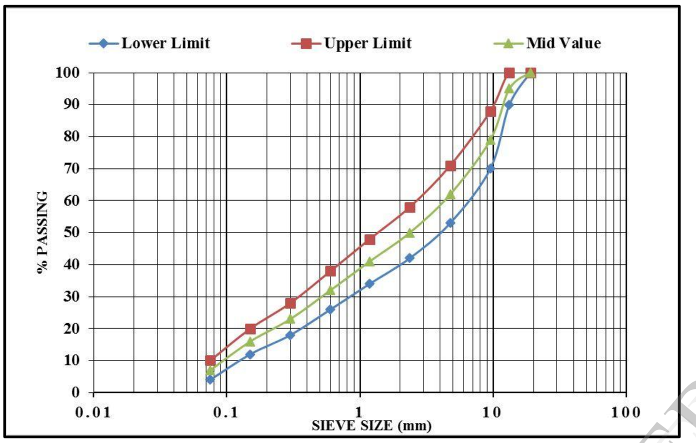

Fig. 2 Aggregate Gradation of Bituminous Concrete (BC)-2 Mix

B. Bitumen Characterization

In flexible pavement, bitumen plays the important role of binding the aggregate together by coating over the aggregate and hence it is preferred to be of good quality.In this study, the grade of bitumen used is of viscosity grade (VG) 30 andbased on the selection criteria of climatic condition as shown in Table 5, majority of regions in India lies in the temperature range of more than 30°C and -10°C.The obtained results of VG 30 binder are shown in Table 6 and were verified according to IS 73:2006: Indian Standard: Paving Bitumen Specification [9].

TABLE-5: SELECTION CRITERIA FOR VISCOSITY GRADE PAVING BITUMEN BASED ON CLIMATIC CONDITION [5]

Lowest Daily Mean Air Temp., °C	Highest Daily Mean Air Temperature		
	Less than 20°C	20-30°C	More than 30°C
More than -10°C	VG 10	VG 20	VG 30
-10°C or Lower	VG 10	VG 10	VG 30

TABLE-6: TEST RESULTS & SPECIFICATIONS OF VG30

Property	Specification	Result	Method of Test
Penetration at 25°C. 0.1 mm, 100g, 5 Sec.	50-70	56	IS 1203[14]
Softening Point,°C	Min. 47	50.5	IS 1205[15]
Ductility at 27°C, cm	Min. 40	>100	IS 1208[16]
Flash Point, COC, °C	Min.220	310	IS 1209[17]
Specific Gravity, g/cm^3	Min.0.99	1.02	IS 1202[18]

C. Marshall Method of Mix Design For the Determination of Optimum Binder Content (OBC)

Indian specifications recommends the use of Marshall Method for design of bituminous mixtures by using standard cylindrical test specimens of 2.5 inch height and 4 inch diameter. The procedure for Marshall Test has been standardized by American Society for Testing and Materials, ASTM D-1559 [19] to determine the OBC of different mixes. Three specimens were prepared at 4.5%, 5%, 5.5% and 6.0%, for BC-1 grading mixes while again three specimens were prepared at 5%, 5.5%, 6.0% and 6.5% for BC-2 grading mixes. The selected mixing and compaction temperatures of bituminous mixes using VG 30 were 160°C and 140°C respectively which lies in the considerable range (mixing temperature: 150-165°C and compaction temperature: 140°C) viscosity grading bitumen as per the IRC 111:2009 guidelines [20]. After the batching of aggregate as per their respective binder content, it is then placed in oven to attain the temperature of +10°C above the mixing temperature. Then mixing is done and the loose bituminous mix is placed in temperature controlled oven at the compaction temperature for 2 hours as conditioning time. After conditioning, the loose mix is compacted in manual Marshall Compactorby applying 75 blows on either side of the specimen and then, after 24 hours of curing, the samples are extracted from the mould and are tested for Bulk Density (Gmb) and Air Void (Va) analysis. After Bulk Density and Air Void analysis the samples were tested for stability and flow.

IV. ANALYSIS OF MIX DESIGN PARAMETERS

The values of effective specific gravity of aggregate (Gse) for a respective mix gradation is shown in Table 7 and mainly this Gse includes all void spaces in the aggregate particles except those that absorb asphalt. Then the maximum specific gravity (Gmm) of bituminous mixes with different bitumen content is evaluated for each mix by considering the Gse value as constant. Afterwards, the volumetric property of the compacted bituminous mix were evaluated by calculating the air voids (Va) in the sample, voids in the mineral aggregate (VMA) and voids filled with bitumen (VFB) by using the following equations.

$$\mathrm{Va} = \frac{\mathrm{Gmm} - \mathrm{Gmb}}{\mathrm{Gmm}} \mathrm{X}\ 100 \qquad (1)$$

$$\mathrm{VMA} = 100 - \frac{\mathrm{Gmb}\ \mathrm{x}\ \mathrm{Ps}}{\mathrm{Gsb}} \qquad (2)$$

$$\mathrm{VFA} = \frac{\mathrm{VMA} - \mathrm{Va}}{\mathrm{VMA}} \mathrm{X}\ 100 \quad (3)$$

TABLE-7: EFFECTIVE SPECIFIC GRAVITY OF DIFFERENT AGGREGATE GRADATIONS

Gradation Designation	BCL 1	BCM 1	BCU 1	BCL 2	BCM 2	BCU 2
Effective Specific Gravity	2.756	2.722	2.689	2.698	2.634	2.666

To decide the optimum bitumen content or the design bitumen content, we follow the National Asphalt Pavement Association (NAPA) method by calculatingaverage of the asphalt content for maximum stability, maximum bulk density and 4.0% air voids and correspondingly, the values of other parameters were checked if they meet the requirements or not as shown in Table 8 andTable 9 shows the obtained results of OBC for the sixdifferent types of mixes.

TABLE-8: REQUIREMENTS FOR BITUMINOUS MIX USING VISCOSITY GRADE PAVING BITUMEN

Properties	Viscosity Grading Paving Bitumen
Compaction Level at 75 blows on each face of specimen	
Marshall Stability (kN) at 60°C	9
Marshall Flow (mm)	2-4
Air Voids, %	3-5
VFA, %	65-75
% Voids in Mineral Aggregate	
Nominal Maximum Aggregate Size (mm)	**Min % VMA related to designed 4 % Air Void**
9.5	15
13.2	14
19.0	13

TABLE-9: MARSHALL MIX DESIGN PARAMETERS FOR DIFFERENT BITUMINOUS MIXES

Mix ID	OBC %	Gsb	VMA %	VFB %	StabilitykN	Flow mm
BCL1	5.11	2.444	14.75	75	16.31	2.97
BCM1	5.33	2.392	15.61	73.1	17.18	3.24
BCU1	5.68	2.367	15.74	75	16.04	3.37
BCL2	5.41	2.382	15.62	75	17.70	2.89
BCM2	5.63	2.335	16.34	73.1	16.94	3.10
BCU2	5.93	2.312	16.43	75	16.21	3.4

V. RESULTS AND DISCUSSION

Marshall Stability and flow values are independent parameters, but the values of VMA, Va, and VFBof a bituminous mix would be dependent on each other. Even ifthey are dependent, but there is a possibility that if one of them is satisfied within the givenrange, the others may not.Yet, results indicate that the performance of mixes made with mid-point gradation range shows higher stability value than other mixes (as shown in Figure 3)but all the mixes are having higher stability values than the minimum value of 9kN and the optimum binder content increases form coarser gradation to finer gradation for both types of grading (as shown in Figure 4).Generally, the optimum binder content of a mix is highly dependent on aggregate characteristics such as gradation and absorption.The finer the mix gradation, larger the total surface area of aggregate and higher amount of bitumenis required to uniformly coat the aggregate particles,while coarser mixes have less total aggregate surface area and it demand less amount of bitumen. Similarly, the Marshall Flow value (as shown in Figure 5) also increases from coarser to finer gradation but for all the samples its value is within specified range of (2-4 mm). However, the mixes that have very low flow value and abnormal high Marshall Stability value are considered too brittle and rigid for pavement service and those mixes with high flow values are considered as too plastic mix and is having a tendency to distort easily under traffic loads [4].

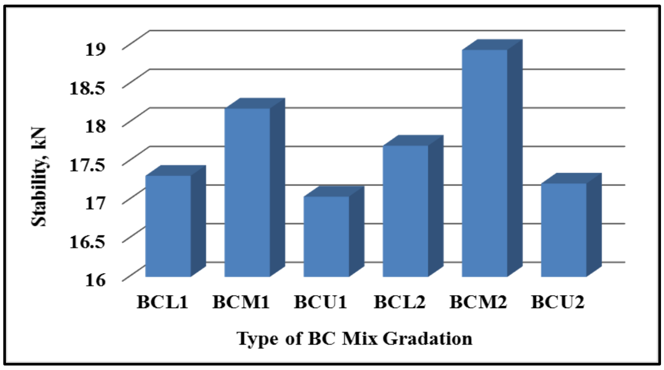

Figure-3:Marshall Stability Values for Different Mixes of BCGradation

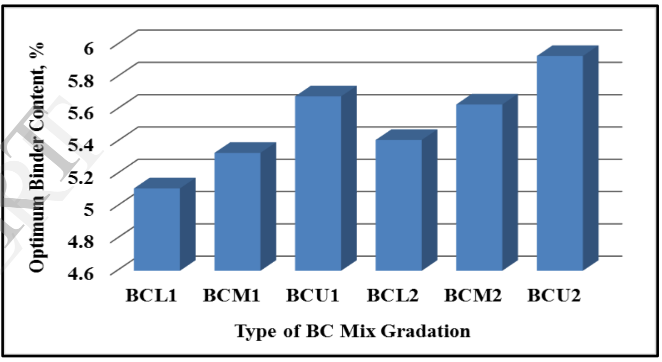

Figure-4: Optimum Binder Content Values for Different Mixes of BC Gradation

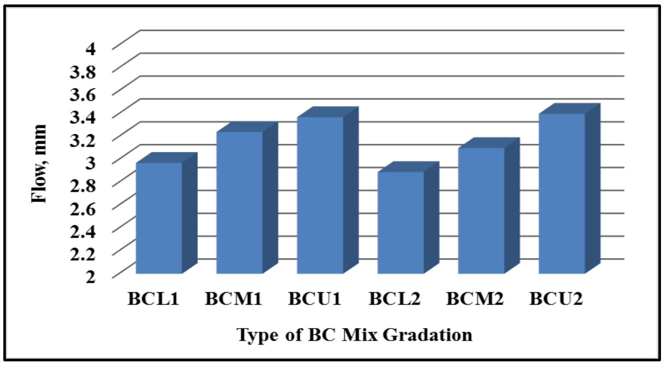

Figure-5: Marshall Flow Values for Different Mixes of BC Gradation

The results of VMA are above the specified limit as per nominal maximum aggregate size (NMAS) and the value keeps increasing from lower limit gradation to upper limit gradation in both the BC 1 and 2 mixes as shown in Figure 6 by relating the VMA value with the corresponding compositional structure of the selected gradations. Minimum VMA is necessary to achieve an adequate asphalt film thickness, which results in a durable asphalt pavement, as increasing the density of the aggregate gradation to a point where below minimum VMA values are obtained leads to thin film thickness of asphalt and a low durability mix [4]. But, in this study the VMA values are satisfactory while, the VFB values are in the marginal range for lower limit gradation and upper limit gradation (Figure7). However, the acceptable range of VFB varies depending upon the traffic level as higher traffic requires lower VFB due to mixture strength and stability and lower traffic requires higher range of VFB to increase HMA durability.

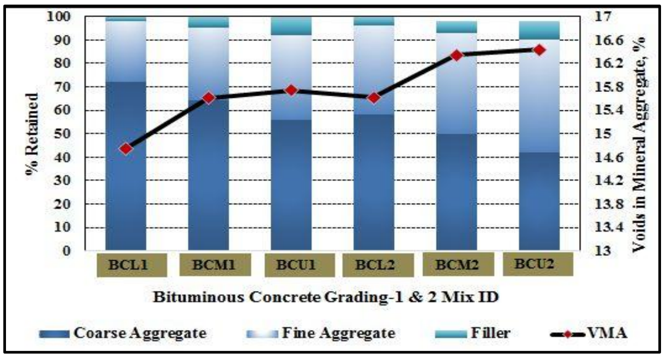

Figure-6: Marshall Flow Values for Different Mixes of BC Gradation

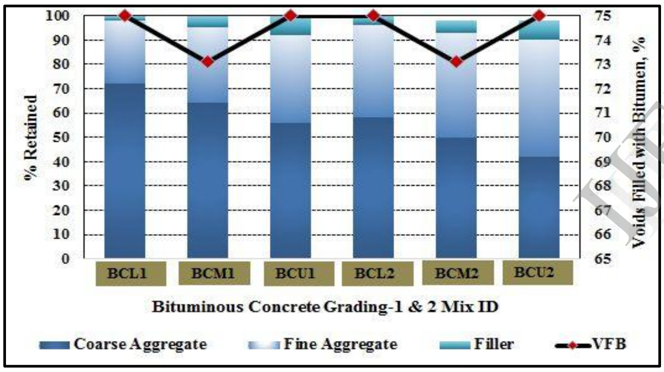

Figure-7: Marshall Flow Values for Different Mixes of BC Gradation

VI. CONCLUSION

Roads in India are performing poorly with pavement life much shorter than the expected. Thehigh traffic intensity in terms of commercial vehicles, the serious overloading of trucks andsubstantial variation in daily and seasonal temperature of the pavement have been responsible forearly development of distress on bituminous surfacing. Starting from day one after construction, a pavement starts deteriorating in quality but if proper mix design is maintained then the unfavorable effects on pavement surface can be somehow reduced to some extent. The overall objective of mix design is to determine an economical blend with the locally available natural aggregate gradation andthis research paper analyze that how the variation in aggregate gradation within the specified limits can affect the essential mix design properties of bituminous mix and gives a clear conception regarding selection of optimum binder content (OBC). This comparative analysis regarding upper, mid-value and lower gradation for both the types of mixes provides an idea that if the aggregate gradation in the field mix varies within these gradation range then what deviations can possibly occur in the mix considering the same binder grade. Overall results indicate that the aggregate gradation closer to the mid-value range have to be selected as a reference specification for the designing of bituminous mixes in order to predict other possible performance tests on the HMA mixes.

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