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The Effect of Aggregate Gradation on Design Mix using Modified Bitumen

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Abstract:

Pavements undergo different type of stresses through out there life. Out of which rutting and fatigue are major distresses. To combat these problematic aspects of roads we have to deal from the root level of design mix (BC) and find a suitable cure for it.Aggregates are most important building component used in the construction as well as in the pavement industry. It is the reason for which aggregate characteristics and gradation greatly affect the performance of asphalt pavements and should be studied carefully. For preparation of mixes two types of gradation are considered i.e., Dense gradation and Open Gradation as per MORT&H (5th Revision) specifications. The mix with modified asphalt (CRMB 55) is evaluated under Marshall Test to obtain the optimum binder content and also the strength factor of the mix is evaluated by the test. After finding out the OBC, Indirect Tensile Strength test and Texas Boiling Test are carried out to investigate the preferability of the mixes. The research program also provides a comparative study on using neat binder and modified binder. The results brought a conclusion that open gradation super pasts dense gradation in every aspects and also gives a good result with CRMB as compared to neat bitumen.

Keywords: Bituminous Concrete (BC), Open Gradation, Dense Gradation, CRMB, Marshall Properties, Indirect Tensile Strength, Texas Boiling Test

1. Introduction

Pavement design and Design mix are two important factors which come into play when we consider flexible pavements. The study is mainly related to improve the mix design so that the failure to which the pavements are prone to can be diagnosed. With the increasing traffic the deterioration of the road is simultaneously growing. Researches focus on strengthening the road networks with economical ways so as they provide longevity in their life and less amount of deterioration. To achieve the desired roads, we need some adulteration in the old conventional mix. The adulterations improve different properties of a mix and hence reducing their proneness towards failure. This research inclines towards the arrangement of aggregate i.e., aggregate gradation in the mix which may be a root cause of its performance. Binder is the constituent in this research which is considered for some modifications and indirectly increases the strength of the road.The main and foremost objective of the study is to study the changes in properties of the design mixes which uses modified bitumen as binder by changing the gradation of the aggregate.

2. Background

In this research we will be dealing with flexible pavements. Flexible pavements support the loads from traffic through bearing rather than flexural action. It comprises of different layers of selected materials which gradually distribute the loads from pavement surface to the underneath layers by soil-to-soil contact. The design is so ensured that the load transmitted to each layer does not reach the layer's maximum bearing capacity. A study on bituminous mix by [35]Animesh Das has brought a distant comparison in evaluation of bituminous mix in past and present. With the increasing traffic, the requirement of a good mix design has been changing time to time. These properties of the aggregate should be checked to ensure a good quality of bituminous mix and simultaneously a strong pavement.Numbers of tests have been recommended in the codes and specifications to judge the properties of the aggregates, e.g. strength, hardness, toughness, durability, angularity, shape factors, clay content, adhesion to binder etc. **In NCHRP report 539 (2005)** on aggregate properties and their performance on superpave-designed hot asphalt mix, mineral aggregates make up between 80% to 90% of the total volume or 94% to 95% of the mass of HMA. That is the reason why it is important to maximize the quality of the mineral aggregates to ensure the proper performance of the national roads. The new gradation limits included definitions for nominal maximum and maximum size of aggregates, control points for various maximum aggregate sizes and the restricted zones. [5]**Karim et al. (1997)**, in an assessment presented some of the findings from a laboratory study of certain polymer modified binders as well as asphalt mixes using polymer modified binders and from his findings it was found that the use of polymer modified binders in asphalt mixes would continue to be a better choice especially when a high performance type bituminous pavement is required.[1]**Suresh et al. (2009),** investigated on the effect of various binders on the performance and durability of porous friction course (PFC) mixes by taking three different modified binders and neat bitumen for three different aggregate gradations and came down to a result that the use of modified binders is more appropriate for PFC mixes with coarser gradations.[14]**PrestiD. L. (2013)** reviewed the use of recycled tyre rubber modified bitumen for road asphalt mixtures. Though asphalt pavement provides several benefits, RTR-MBS technologies should be given a first option to be used in road pavement. Further research can be done on evaluation of pavement performance as well as properties which concerns environment.[9]**Golipourr et al. (2012)** investigated the impact of aggregate gradation variation on rutting characteristics of asphalt concrete mixtures by using materials like asphalt bitumen 60/70and crushed limestone with two broken faces. Test methods included Marshall Test & dynamics creep test. He concluded that gradation bands placed in upper limit of asphalt mixture design show the best performance. We can extend this study by investigating the impact by changing the type of aggregate and bitumen type.[10]**Sridhar et al. (2007)** investigated the effect of gradation and compactive effort on the properties of dense bitumen macadam mixes where bitumen was obtained from Mathura and aggregate from Delhi followed by Marshalltest. Gradation bands placed in the upper limit of asphalt mixture design gradation chart show the best performance against rutting while lower bands have the highest amount of permanent deformation. Gradation bands placed in the upper limit of asphalt mixture design gradation chart show the best performance against rutting while lower bands have the highest amount of permanent deformation. Compaction efforts for different types of aggregate and binder type can give a further scope to the study.[15]**Sangsefidi et al. (2015)**, aimed to select the best configuration of material in order to achieve mixture fabricating purposes by studying the effect of aggregate gradation limits consideration on performance properties and mixture design parameters of hot asphalt mixes. A kind of crushed aggregate and mineral filler, both manufactured from limestone, have been used as the aggregate skeleton and 60/70 penetration grade paving bitumen has been used as the binder. The moisture sensitivity of these mixes was evaluated using two commonly used test methods: AASHTO T-283 and ASTM D3625 and the dynamic creep test were carried out. It is predicted that a gradation coarser than gradation L (outside the considered band) may produce better result. The studies of aggregate gradation have seen a various attempts in literature. Even the modification of bitumen especially with rubber modification has been a recent trend in the research world. The combination of both is yet a question finding its answer. Modification in bitumen and the effective gradation can be a double advantage. Moreover, this would solve the problem of solid waste management to a great extent and at the same time help in exploring the new possibility of using a non conventional waste material in a typically non conventional mix.

3. Experimental Program

Materials

The binder types (BT) studied includes, neat bitumen (NB),polymer modified bitumen of crumb rubber modified bitumen (CRMB 55). These binders obtained from suitable sources in India were tested inaccordance with the Indian Standards (IS). The grading requirementsfor these binder types were also evaluated and found to be satisfactory. The test results arepresented in Table 1. The crushed bauxite stone aggregates obtainedfrom local stone-crushing plants were used in this study.The results of physical properties of aggregates tested are givenin Table 2.

Table 1:Properties of Neat Bitumen and CRMB 55

Characteristics	IS Test Methods	Properties of Neat Bitumen (VG 30)	Properties of CRMB 55
Penetration at 25 C (mm)	IS : 1203-1978	56	42
Softening Point (C)	IS : 1203-1978	50	62
Specific gravity	IS : 1203-1978	1.05	1.15

Table 2

Properties of Aggregate

Property	Test value	MORTH Specification	Test Method

Aggregate Impact Value (%)	22.6	Max 30%	IS: 2386 (P IV)
Aggregate Crushing value (%)	25		IS: 2386 (P IV)
Aggregate Abrasion Value (%)	26	Max 30 %	IS: 2386 (P IV)
Flakiness and Elongation Index (%)	28.20	Max 30%	IS: 2386 (P I)
Water Absorption value (%)	0.5	Max 2%	IS: 2386 (P III)
Specific Gravity	2.76	2.6_2.9	
Stripping Value	2.5	5	

Laboratory Test

Marshall Mix design is a common laboratory method, rather than Heevem test which is adopted worldwide for determining the strength and flow characteristics of all type of bituminous paving mixes. The Marshall properties such as stability, flow value, unit weight and air voids were studied to obtain the optimum binder contents (OBC). The mix volumetric of the Marshall samples such as unit weight, air voids were calculated by using the procedure mentioned by Das and Chakroborty (2003)[23]. Strength is measured in terms of the 'Marshall's Stability' of the mix following the specification ASTM D 1559 (2004), which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. In this test compressive loading is applied on the specimen until it is broken. Normaly, the temperature of 60°C is considered as the weakest condition for a bituminous pavement. The flexibility of the specimen is measured in terms of the 'flow value' which is measured by the deformation in diameter of the sample to the original, in the direction of load application within the start of loading and at the time of maximum load. During the loading, a dial gauge is attached which measures the specimen's flow value (deformation) due to the loading. The associated flow value of specimen at material failure is considered to be final. The density- voids analysis is done using the volumetric properties of the mix.

Indirect tensile test is used to determine the indirect tensile strength (ITS) of bituminous mixes. In this test, a compressive load is applied on a cylindrical specimen (Marshall Sample) along a vertical diametrical plane through two plane strips which is compatible with the specimen. The specimens are water bathed at two different conditions. Firstly, the dry specimen is put into waterbath for half an hour at 25°C and then tested. Secondly, the wet specimen is bathed for 24 hours in water at 25°C. A test called splitting test in which uniform tensile stress is developed perpendicular to the direction of applied load and along the same vertical plane the specimen fails by splitting is carried out to compute tensile strength ratio (TSR).

ITS = $\left(\frac{2P}{\pi \cdot t \cdot D}\right)$

where, D= Specimen's diameter, mm

ITS = Tensile strength, Pa

P= Maximum load, Newton

t= Specimen thickness, mm

$$\text{TSR} = \frac{ITSwet}{ITSdry} \times 100$$

where,

ITSdry= Average tensile strength of dry subset

ITSwet = Average tensile strength of conditioned subset

Higher the value of this ratio, greater is the resistance to moisture damage.

The Texas boiling test procedure was developed by Kennedy et al. (1982; 1984). This procedure has been standardized as ASTM D3625.This test is used to evaluate the stripping of bitumen from loose specimens. Here the specimen of 250g is taken as per the gradation used in Marshall specimen. Bitumen required to prepare this mix is the OBC for the mix. The binder is to be cooked in such a manner so that, all the aggregates are coated properly and no excess bitumen is left on the pan.The loose specimen is prepared by heating the dry aggregate of 250g at 160°C for 1 to 2 hour and the binder at 160°C for 24 to 26 hours and then mixing them at a heated condition. The loose mixture was allowed to cool down to room temperature for at least 2 hours and was placed in 500ml boiling water (distilled) for maximum 10 minutes and after every 3 minutes the mix was stirred for 10 seconds using a glass rod. Then the mix was removed from the water and placed on a white surface to determine, the percent of areas coated by asphalt by visual inspection. The percent reduction in the coating of the aggregate surface area by asphalt due to conditioning in the boiling water was used as an indicator of environmentaldamage occurrence that can occur when pavement is allowed to exposure. The reduction in HMA aggregate- coated areas is calculated according to the following equation after image analysis through MATLAB:

where,

$$X\% = \frac{A\% - B\%}{A\%} \times 100\%$$

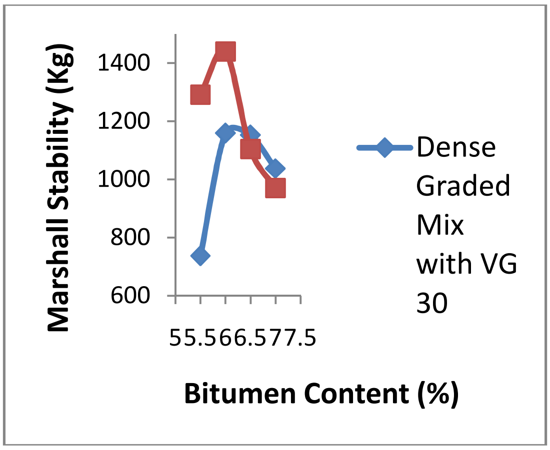
A= Coated area in unconditioned specimens
B= Coated area in conditioned specimens
X= Reduction in areas coated by asphalt
The algorithm used for image analysis is as follows:
A=’<Specify the Folder and Image location’>;
B= imread (A, ‘<image bitmap file>’);
figure (1), imshow(B);
C=rgb2gray(B);
figure (2), imshow(C);

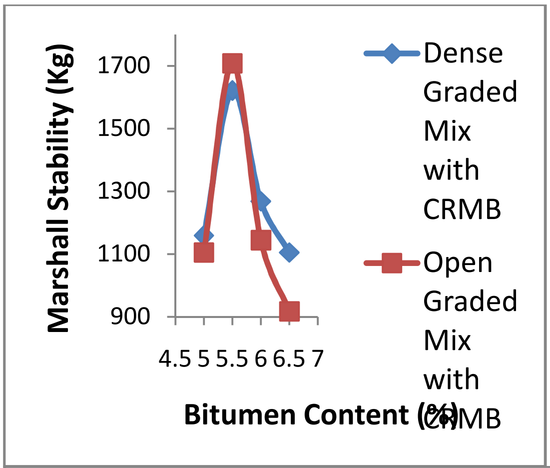
The percent reduction in the surface area of aggregate that retain its original coating after conditioning in the boiling water is estimated by graphical evaluation of the greyscale image.
This standard is based on the researcher accuracy in conducting the experiment and image analysis. This observation is a helpful method to check moisture related adhesion failure.

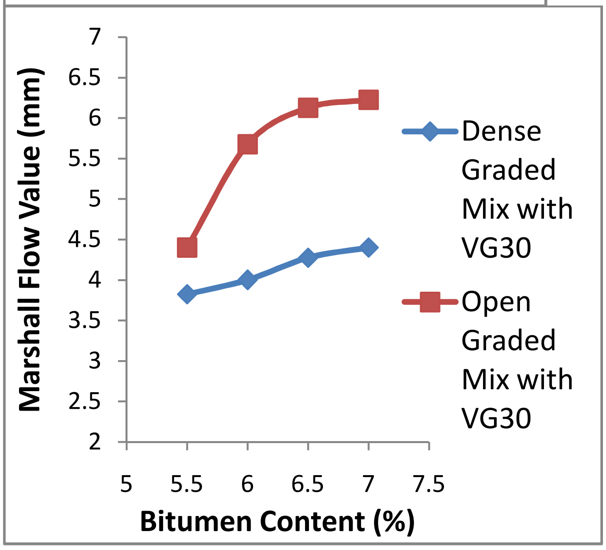
4. Results and Discussion

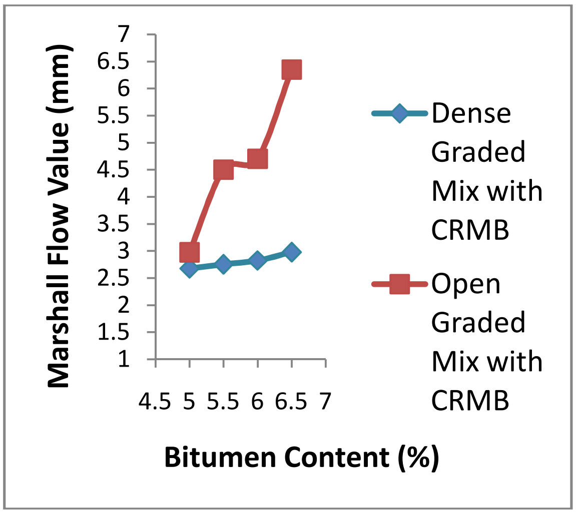
This section is divided into different parts dealing with parameter used for analysis, calculation of Optimum binder Content (OBC) of BC for two type of gradation used in the mixes and evaluates the effect of gradation difference, calculation of OBC for Modified Bitumen and analyse the effect of it on the mixes, calculation of tensile strength of the specimen with different gradation and different binder type, results of Texas boiling test.The calculation mainly depends on the volumetric properties of the mix as per Das A. and Chakroborty P. (2010).

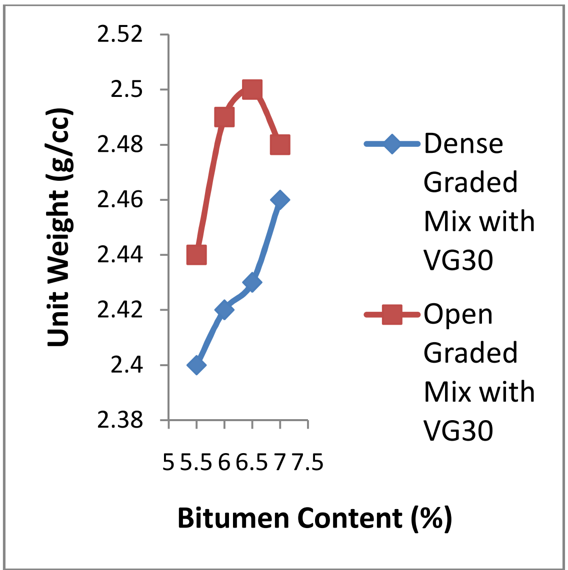
Effect of Gradation on Design Mix

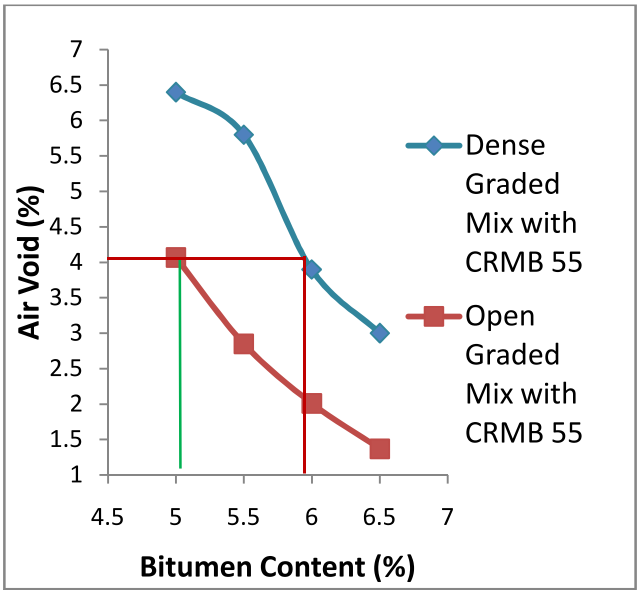


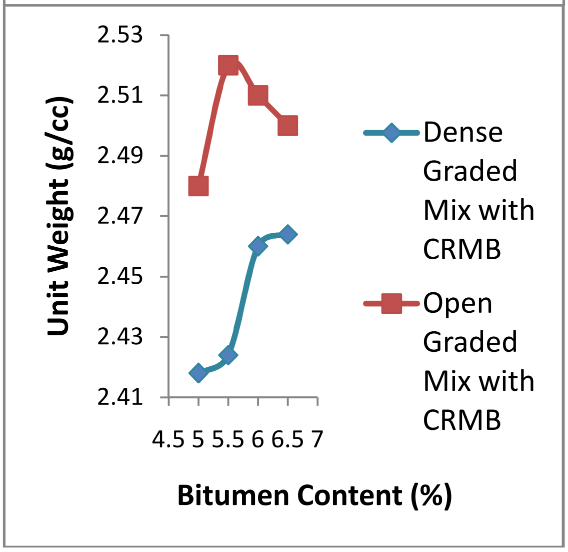


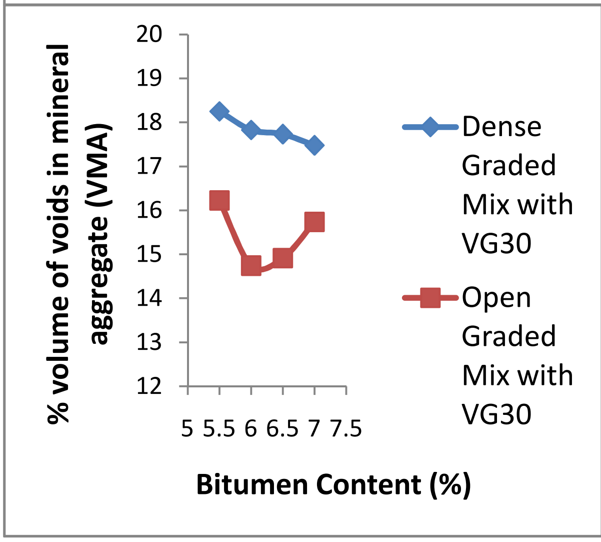


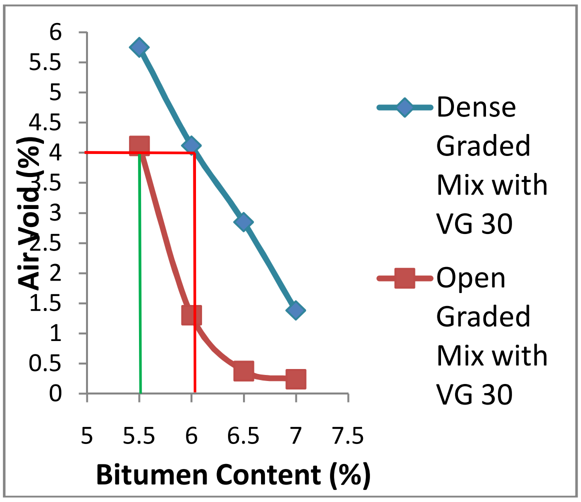


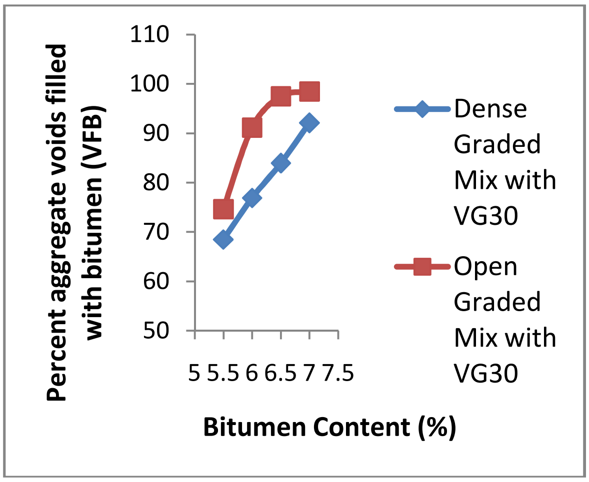

Unit Weight (g/cc)
2.52
2.5
2.48
2.46
2.44
2.42
2.4
2.38
5 5.5 6 6.5 7 7.5
Bitumen Content (%)
Dense Graded Mix with VG30
Open Graded Mix with VG30

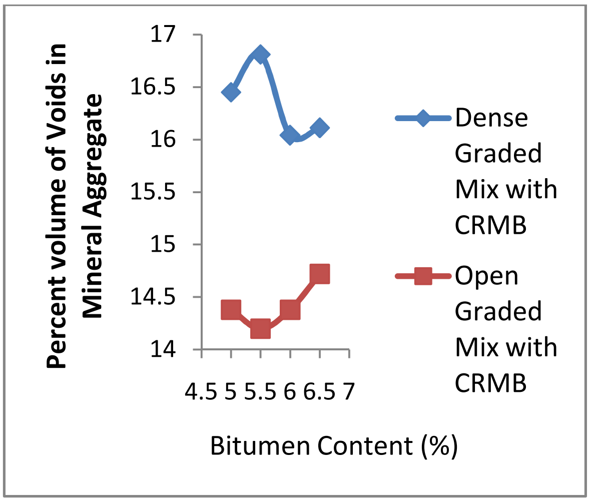

Air Void (%)
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
4.5 5 5.5 6 6.5 7
Bitumen Content (%)
Dense Graded Mix with CRMB 55
Open Graded Mix with CRMB 55

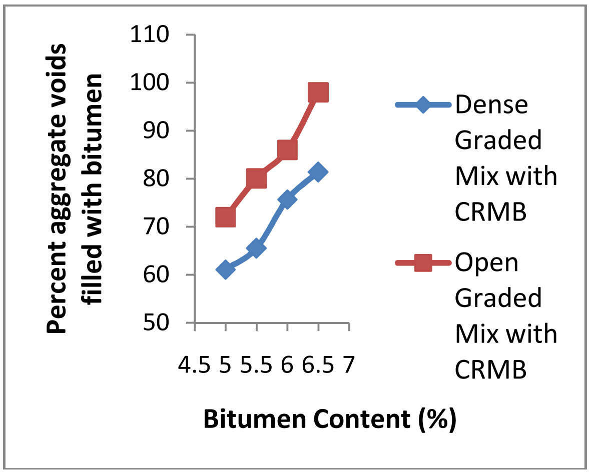

Unit Weight (g/cc)
2.53
2.51
2.49
2.47
2.45
2.43
2.41
4.5 5 5.5 6 6.5 7
Bitumen Content (%)
Dense Graded Mix with CRMB
Open Graded Mix with CRMB

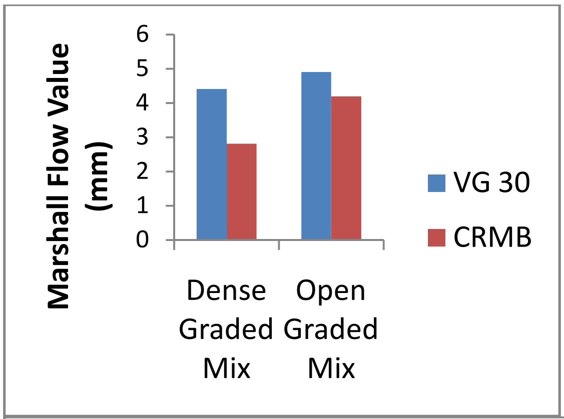

% volume of voids in mineral aggregate (VMA)
20
19
18
17
16
15
14
13
12
5 5.5 6 6.5 7 7.5
Bitumen Content (%)
Dense Graded Mix with VG30
Open Graded Mix with VG30

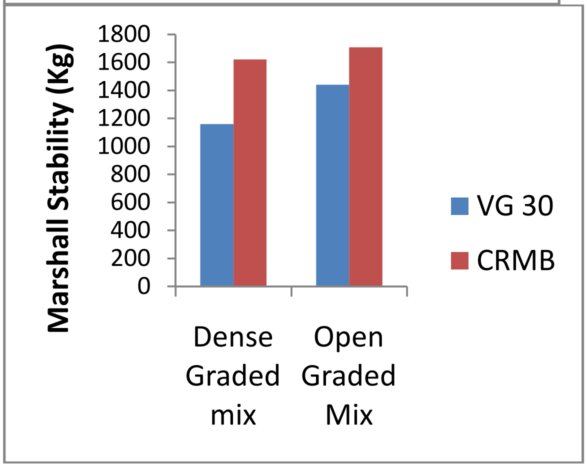

Air Void (%)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
5 5.5 6 6.5 7 7.5
Bitumen Content (%)
Dense Graded Mix with VG 30
Open Graded Mix with VG 30

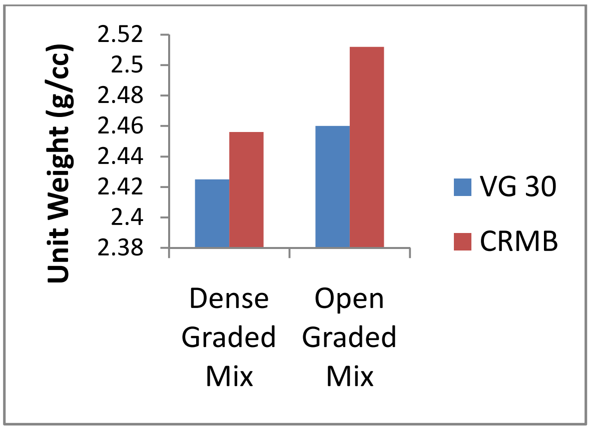

Percent aggregate voids filled with bitumen (VFB)
110
100
90
80
70
60
50
5 5.5 6 6.5 7 7.5
Bitumen Content (%)
Dense Graded Mix with VG30
Open Graded Mix with VG30





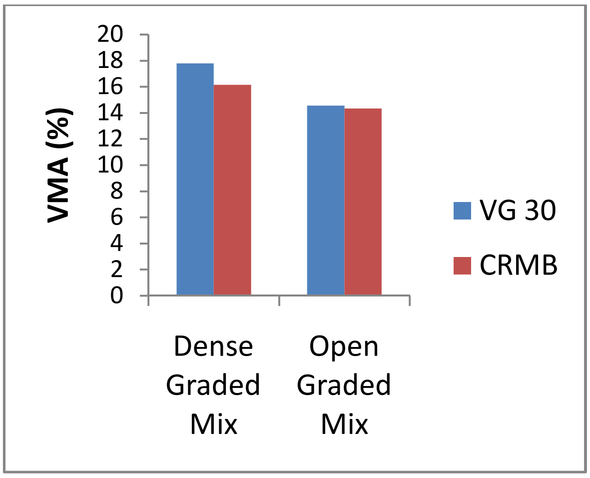


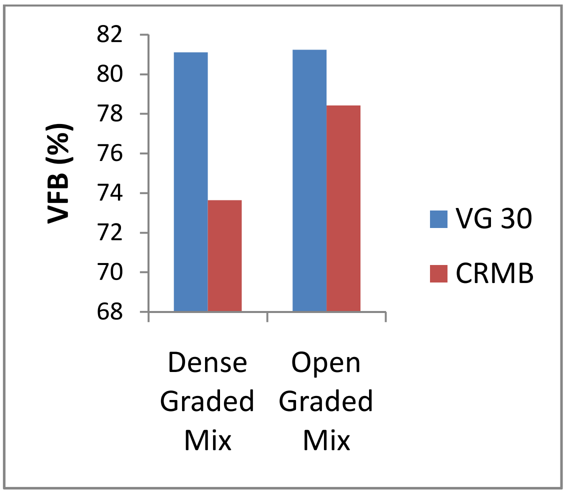




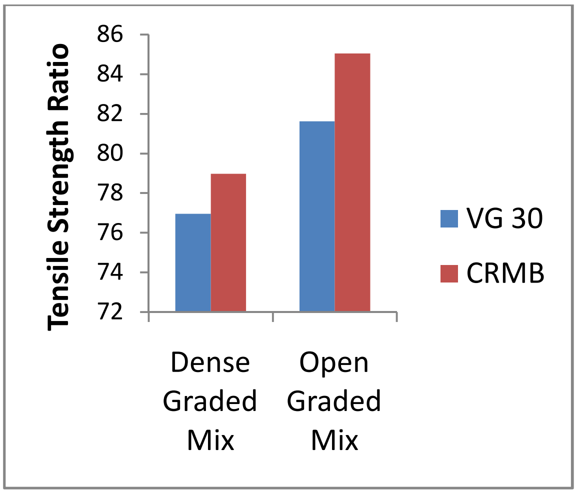
From the result we can clearly get the indication that aggregate gradation has effect on the strength criteria of a bitumen mix. May it be the neat bitumen or the modified binder, the open graded mix shows a better result than the dense graded mix. It is observed that with increase binder content flow value increases. The observations show the desired result. Due to reason that the void content in open graded is more in comparison with dense graded mix, the flow value increases in case of the latter.It is observed that unit weight increases with increase binder content up to certain binder content; then decreases. The figures represent the volume of air void at different bitumen content. We can see a downward curve showing the decrease in voids as the bitumen content increases. For calculation of optimum binder content the bitumen content at 4% air void is taken into consideration.It is observed that with increase binder content air void decreases in case of volume of air voids. VFB increases with increase binder content.

Effect of Modified Bitumen on the Design Mix





The figure shows the stability of mix when optimum binder content mix is taken into consideration. The CRMB binder exhibits good results as compared to VG 30 in case of both the gradation. The use of binder CRMB reduces the flow value of the mix in both the case of gradation mix. The unit weight increases in case of use modified binder. The result is not so effective in case of VMA because the voids reduction is not a property useful for the analysis. In figure we can clearly see a large difference in VFB in comparison. This is because the neat bitumen is more susceptible to temperature as compared to CRMB. So, it fills the voids efficiently while CRMB does not easily succumb to the temperature.



Tensile Strength

The modified bitumen is better performing than neat bitumen. The effect can be seen in both the type of gradation mix in case of Tensile strength.

Boiling Test

This test of Texas Boiling mainly evaluates the stripping property of a mix or material. It is a sub-property to moisture susceptibility. The images below show the stripping property. It is clear from the test that there is 0% stripping in case of modified binder. While for normal bitumen we see some amount of stripping.

5. Conclusion

Computing from the results of this study, a convenient selection of gradation in the process of mixture design has a great effect on performance of the mixture. Based on the clear evidence from this study, it seems the open graded mix is an appropriate aggregate gradation for BC. The strength of open graded mix shows a 5-25% better performance as compared to dense graded mix. While the gradation has evitable effect on the performance of the design mix and also greatly affects the economic aspect in particular, overall consideration signifies the open graded mix better gradation for use in pavement design. Even in the case of sustaining to load, the open graded mix show a good tensile strength of near about 8%. Modification in bitumen has somewhat contributed towards the improved performance of mix. In every test it has shown better results than neat bitumen. The stability of the mix increases to 39.79% in case dense mix while in case of open graded mix it results in a increase of 18.59% as we use the CRMB as binder. The flow value also reduces with its use. The performance in tensile strength test also gives a support to use of modified binder as the tensile strength increases to 8-15% in different gradation used in this research. Here two type of graded mix i.e. dense and open in BC mix is prepared where VG 30 and CRMB bitumen is used as binder. OBC is found out by Marshall Method of mix design. The strength criteria are evaluated by Marshall Test and Indirect Tensile Strength test. The Texas Boiling test represents the moisture susceptibility criteria. It is clear from the research that the use of open gradation as design mix in BC with CRMB as modified binder should be given a consideration and can be used in flexible pavement.Many properties of dense and open graded mixes such as Marshall properties, boiling characteristics, tensile strength characteristics have been studied in this investigation. Only one type modified binder has been taken into consideration in this investigation. However, some of the properties such as fatigue properties, resistance to rutting and dynamic creep behaviour can further be investigated. Some other type of additives can also be tried in mixes and compared. Modified binder mainly CRMB currently is not in wide range of use as it is subjected to some of disadvantages such as segregation due to its stiffness. Moreover, the branch of this evolving material, experimental stretches may be constructed differently and the periodic evolution should be taken care of.

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