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Effect of Aggregate Gradation on Moisture Susceptibility and Creep in HMA

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***Abstract*—**The present study explains the effect of aggregate gradation on moisture damage in bituminous mixes. Three types of aggregate gradation and two types of binder; VG-30 and Polymer modified bitumen (PMB-40) are used. Moisture susceptibility tests like retained stability and tensile strength ratio (TSR) and static creep test are conducted on Marshall specimens. The creep test was also conducted for conditioned and unconditioned specimens to observe the effect of moisture on creep behaviour. The results indicate that Marshall stability value is higher in PMB-40 mix than VG-30 mixes. Moisture susceptibility of PMB-40 mixes is low when compared with mix using VG-30. The reduction in retained stability, and indirect tensile strength and increase in creep are evaluated for finer, coarser and normal gradation of aggregate to observe the effect of gradation on moisture susceptibility of mixes. The retained stability is least affected when compared with other moisture susceptibility parameters

***Keywords*—**Aggregate gradation, Creep ratio, Retained stability, Stripping, Tensile strength ratio.

I. Introduction

THE asphalt pavement failures are typically classified as stability (load) or durability related failures. Moisture damage is signified by loss of strength or durability in an asphalt pavement due to the effects of moisture and may be measured by the asphalt mixture's loss of mechanical properties [10]. Moisture susceptibility is defined as the weakening and/or eventual loss of the adhesive bond between the aggregate surface and the binder in HMA mixture due to the presence of moisture. Often called stripping, it can also occur in the presence of moisture due to the loss of the cohesive resistance of the binder film that coats the aggregate [8]. Moisture can weaken the binder matrix, subsequently lowering HMA mixture stability and load-carrying capacity. The results of stripping can manifest themselves as rutting, shoving, and fatigue cracking. The main causes of stripping are aggregate gradation, aggregate type, binder type and inadequate compaction. Other causes of stripping are the presence of a dust and/or clay coating on the aggregates, inadequate aggregate drying, the presence of weak and friable aggregates, and inadequate pavement drainage. When the aggregate is coated with dust and/or clay, the binder-aggregate bond is reduced and channels are formed where moisture can penetrate. If aggregates are not properly dried before the HMA is mixed, inadequate adhesion occurs between binder and aggregate.

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II. Objectives

The present study was taken up with the following objectives:

1) To compare and correlate the results of different moisture susceptibility tests on bitumen concrete (BC) mixes.
2) To evaluate the effect of aggregate gradation on moisture susceptibility and creep behaviour of bituminous concrete mixes.

III. Background Literature

Moisture damage is a serious problem worldwide and has been responsible for millions of dollars in reconstruction and maintenance costs since the implementation of the Superpave specification [5]. Usually, stripping starts at the bottom of the HMA layer and cannot be observed at the surface until the problem is critical [7]. Current and past studies have been done to identify the effect of aggregate gradation on moisture susceptibility and permanent deformation of hot mix asphalt (HMA). Pan and White (1999) observed that fine aggregate could be a major factor in the loss of adhesion of asphalt binder film. They also observed that maximum aggregate size and mixture gradation have a significant effect on rutting resistance, and that the presence of crushed sand may help to reduce moisture damage. Kandhal (1992) indicated that stripping of fine aggregate is more critical. Brown and Bassett (1989) evaluated five HMA mixes with different maximum aggregate sizes of crushed limestone used in preparing the specimens. The asphalt content of all mixes was selected to produce 4 percent air void. Specimens were evaluated using the Marshall, indirect tensile strength, creep, and resilient modulus tests. The creep test results indicated that the permanent strain of 15 cm. specimens decreases with an increase in the maximum size of aggregate. It has been widely held that a coarser gradation produces a more rut resistant HMA mixture. However, some studies have found that finer-graded mixtures present lower rut potential [5]. Abo-Qudais and Haider (2007) found that conditioning of HMA specimens has a significant effect on the creep deformation. Aggregate gradation and asphalt type also have considerable effect on creep deformation. Also, for conditioned specimens, the creep deformation of mixes prepared using 80/100 asphalt was more than that for mixes prepared using 60/70 asphalt and tested at the same temperature. In another study, Abo-Qudais (2007) observed the effect of using different evaluation techniques on the predicted stripping of 24 different HMA combinations prepared using different mix parameters. The stripping evaluation techniques include percent reduction in indirect tensile strength, Marshall stability and percent increase in creep. The study indicated that the percent increase in creep was the only one among the methods used that was able to determine the effect of asphalt and aggregate gradation on stripping of HMA.

IV. Materials

One type of aggregate and two types of binder were used in this study. The crushed stone aggregate (coarse, fine and filler) of limestone type was used to prepare the bituminous mix specimens. The bituminous concrete (BC) mix as specified in Ministry of Road Transport and Highways (MoRTH-2001) specifications in India was evaluated. Three aggregate gradations as described below were selected:

1) Gradation U: Upper limit of gradation range given in MORTH-2001 specifications. The nominal size of this gradation is 9.5 mm.
2) Gradation M: Mid point of gradation range given in MORTH-2001 specifications. The nominal size of this gradation is 13.5 mm.
3) Gradation L: The lower limits of gradation range given in MORTH-2001 specifications. The nominal size of this gradation is 13.5 mm.

Fig. 1 shows the aggregate size distribution of three grading of bituminous concrete mixes used in the present study, the notation B is used to describe BC mix and U, M and L to describe upper, middle and lower gradation in the mix respectively.

Two types of asphalt binders, VG-30 (viscosity grade 30) and PMB-40 (polymer modified bitumen) are used to prepare the HMA specimens. These two binders extensively are used for preparation of HMA in India. The physical properties of two binders were evaluated as per IS 73-2006 and IS: 15462 -2004 and all test values are found within permissible limit. The notation P is used to describe (PMB-40) and V to describe (VG-30).

V. Experimental Program

Bituminous Concrete (BC) mix is used throughout this study. The following tests were conducted.

A. Optimum Binder Content (OBC)

The Marshall method of mix design as laid in ASTM D1559 was followed to determine optimum binder content (OBC) of different mixes. Three specimens were prepared at 5%, 5.5%, 6.0%, and 6.5%, and these were tested for stability, flow, air voids, unit weight, and voids in mineral aggregate (VMA). The OBC was calculated as the average of asphalt content for maximum stability, maximum unit weight, and 4.0% air voids. Table I shows the results of optimum binder content for all mixes.

B. Moisture Susceptibility Tests

Retained stability test and tensile strength ratio (TSR) test as per AASHTO T-283 were conducted on Marshall specimens for different mixes at their OBC. TSR is the percentage of average indirect tensile strength (ITS) of the conditioned (wet) specimens to the average ITS of the unconditioned (dry).

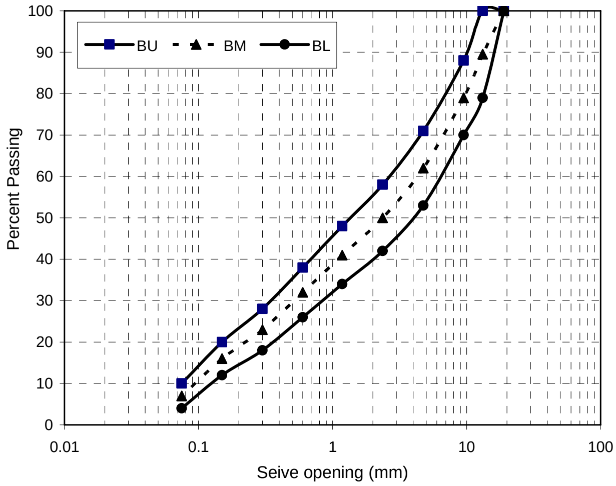

Fig. 1 Aggregate gradation for bituminous concrete (BC) mix

TABLE I
OPTIMUM BINDER CONTENT FOR ALL MIXES

Mix type	Gradation	Asphalt type	Mix ID	O.B.C %
Bitumen Concrete	Lower	PMB-40	**BLP**	5.15
		VG- 30	**BLV**	5.20
	Middle	PMB-40	**BMP**	5.43
		VG- 30	**BMV**	5.50
	Upper	PMB-40	**BUP**	5.64
		VG- 30	**BUV**	5.70

C. Static Creep Test

The static creep test is considered important to obtain the data for estimating potential deformation of the vehicle wheel path. The static creep test is conducted by applying a static stress of 100 kPa in one cycle of one hour loading and one hour unloading that provides information on asphalt mixture response characteristics (elastic/plastic). Specimens were prepared using two types of binder and three types of gradation. The original height of the specimens was measured before testing, while the axial deformation was measured during the creep test using the linear vertical displacement transducers (LVDTs). Accumulated microstrain was calculated as the ratio between the measured deformation and the original specimen height. In order to observe the effect of moisture on elastic response of a mix, the test was conducted on two groups of specimens. One group was tested in dry condition at 25°C (normal specimens) without moisture conditioning and the other group was moisture conditioned before the test. The moisture conditioning was done by placing the specimen in water bath at 60°C for 24 hrs and then the specimen was transferred from the hot water bath to another water bath at 25°C for 2 hrs before testing. The stripping effect on creep behaviour was evaluated based on the creep ratio as defined in (1):

$$Creep\ Ratio = \frac{Permanent\ deformation\ in\ conditioned\ specimen}{Permanent\ deformation\ in\ unconditioned\ specimen} \quad (1)$$

VI. Test Results and Discussion

A. Retained Stability

The retained Marshall Stability calculations for all mixes are shown in Table II and Fig. 2. These results indicate that the mixes with PMB-40 have better performance than those with VG-30. The mixes with upper gradation (finer) show better durability than mid point gradation and the lower gradation (coarser) for all mixes. It is because the retained stability is a measure of water susceptibility of a mix and the dense graded hot mix provides better moisture resistance. In general, the coarser aggregate gradations are more prone to premature stripping because these mixes are more permeable to water when compared to fine aggregate gradations. As per Indian specifications in force, the minimum requirement of retained stability for a bituminous mix is 70 percent and here all mixes pass the test.

TABLE II
Retained Stability for Different Mixes

Mix ID	Stability (kN)		Retained Stability %
	Soaked	Standard	
BLP	19.9	21.3	93.4
BLV	14.2	16.2	87.4
BMP	18.3	19.2	95.5
BMV	13.6	15.1	90.4
BUP	18.1	18.4	98.5
BUV	13.7	14.4	94.8

B. Tensile Strength Ratio (TSR)

Table III and Fig. 3 show the tensile strength ratios for different mixes. Like retained stability, the mixes with PMB-40 had better performance than those with VG-30. It was expected also as the viscosity of the asphalt plays a significant

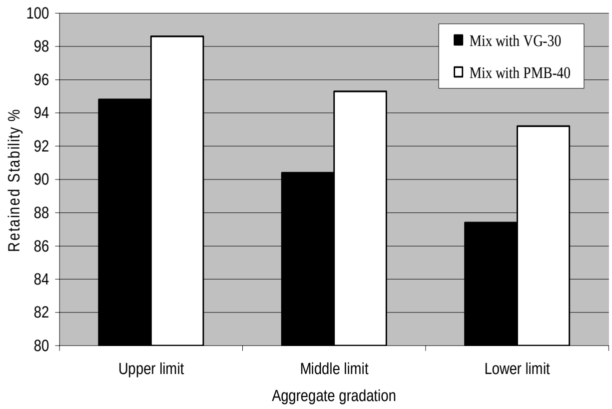

Fig. 2 Retained stability values for different mixes

role in the stripping behaviour of the asphalt mix. High viscosity asphalt resists displacement by water and provides a better retention of asphalt on the aggregate surface. The mixes with upper limit (fine) gradation showed better TSR than mixes with middle or lower gradation. This is also understandable as the water susceptibility of a mix depends on its gradation and the dense graded mix provides better moisture resistance. Also, coarser aggregate gradation has low amount of materials passing # 200 sieves (75 µm). Since material finer than 75 µm tends to fill voids and increase density, the reduction in material finer than 75 µm also affected the TSR in coarser graded mixes. Breaking of larger particle size aggregate in coarser aggregate gradation during compaction also leads to uncoated surface which absorbs the water more than the other particles and then leads to stripping Fig. 4.

TABLE III
Summary of Tensile Strength Ratio for Different Mixes

TSR %	ITS (kPa)		Mix ID
	conditioned	Unconditioned	
84.3	875	1039	BLP
77.9	767	985	BLV
89.6	871	972	BMP
81.4	712	875	BMV
97.1	879	905	BUP
88.1	630	715	BUV

C. Static Creep Test

1. Accumulated Strain

Accumulated strain is the ratio of measured deformation to the original specimen height at certain time during the test duration. Table IV and Fig. 5 show the accumulated strain with time for different types of mixes in a normal creep test (unconditioned specimens).

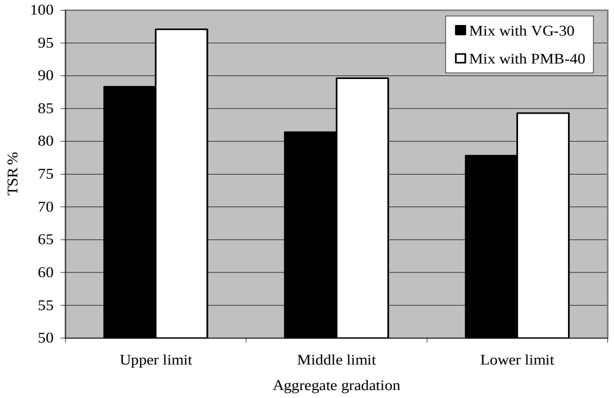

Fig. 3 Tensile strength ratio for different mixes

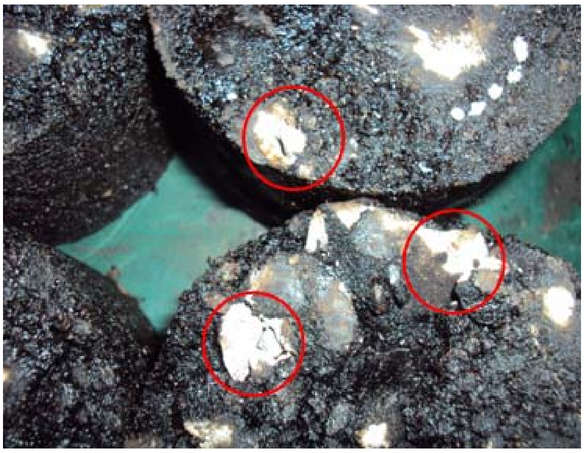

Fig. 4 Broken aggregates during compaction

As may be seen, the mixes with PMB-40 showed better performance than mixes with VG-30. It is again attributed to the viscosity of the asphalt as increased resistance to rutting is offered by stiffer (high viscosity or low penetration) binder [13]. Also, the mix prepared with upper gradation had the highest deformation followed by the mix prepared with middle aggregate gradation. The mix prepared with lower gradation shows the lowest creep deformation. It can be explained on the basis of difference in gradation. The aggregate size zone from 4.75 mm or 2.36 mm to 0.30 mm sieve is considered undesirable in a mix gradation [4]. This zone limits the inclusion of large amounts of rounded particle [11]. However, this zone is available in upper gradation more than that in the middle and lower gradation. Also, the coarser aggregates have higher shear resistance than the finer aggregates and the rutting occurs in mixtures with low shear resistance.

2. Rebound (Recovered) strain

The percent rebound strain was determined by dividing the total rebound strain by the maximum deformation at 60 minutes and results are given in Table IV and Fig. 6. The trend is similar to that observed for permanent strain. The mixes with PMB-40 showed higher percent rebound strain when compared with mixes of VG-30. Also, the rebound strain in mix prepared with upper gradation is more than in the mixes with middle and lower gradation for both types of binder (VG-30 and polymer modifier.

TABLE IV
SUMMARY OF STATIC CREEP TEST ON DIFFERENT MIXES

Mix ID	Total Deform -ation (mm)	Rebound Strain microstrain	Permanent strain microstrain	Rebound strain %
BLP	0.837	1873	10777	14.8
BLV	0.971	2051	12808	13.8
BMP	1.015	2492	12933	16.2
BMV	1.093	2488	14611	14.9
BUP	1.177	3867	14484	21.1
BUV	1.189	3224	15577	17.6

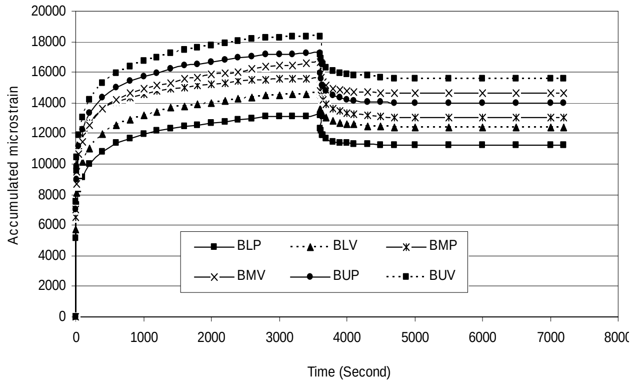

Fig. 5 Creep behaviour of BC mixes

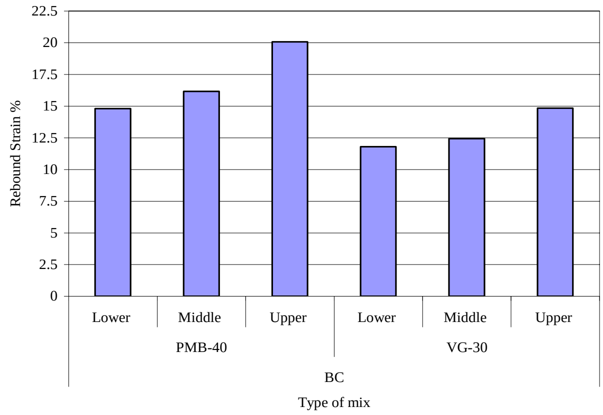

Fig. 6 Rebound (recovered) strain percent for different mixes

3. Creep Test on Conditioned Specimens

As mentioned earlier, static creep test was also conducted on specimen after conditioning them for 24 hrs at 60 °C. The creep behaviour of conditioned specimen is presented in Fig. 7. Here also, the mixes with PMB-40 showed better performance. However, the performance of conditioned specimens is substantially different from that of unconditioned specimens. The most effected are the mixes prepared with VG-30. The mix prepared with upper gradation had the lowest creep deformation and the mix prepared with lower gradation shows the highest creep deformation. Fig. 8 compares between the conditioned and unconditioned specimens based on their rutting potential.

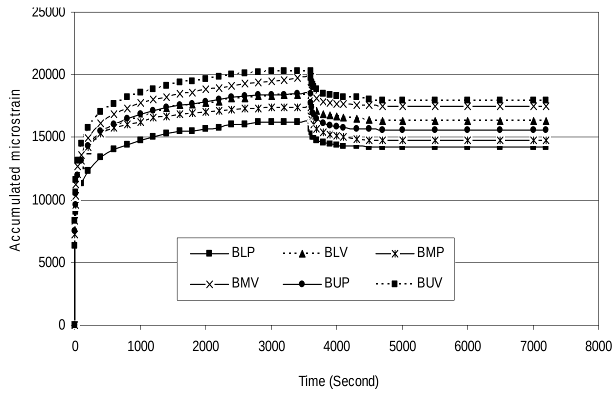

Fig. 7 Conditioned creep behaviour of bitumen concrete (BC) mixes

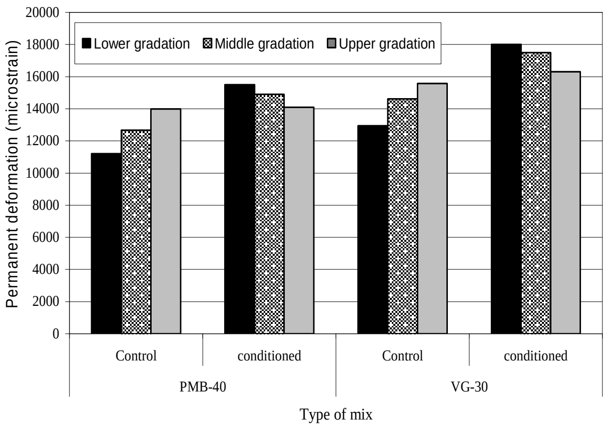

Fig. 8 Permanent deformation after 60 minutes of static loading for different mixes

In order to quantify the effect of conditioning on rutting (permanent deformation) potential of a mix, a parameter called Creep Ratio (CR) is introduced in this study. It is defined in a manner similar to tensile strength ratio and is as defined earlier in (1). The CR values for the different mixes are shown in Fig. 9. The CR value will always be more than one but larger value indicates that the mix is more sensitive to moisture damage. The mix prepared with upper gradation (finer) and PMB-40 has lowest value of CR but the mix prepared with lower gradation (coarser) and VG-30 has the highest value of (CR).

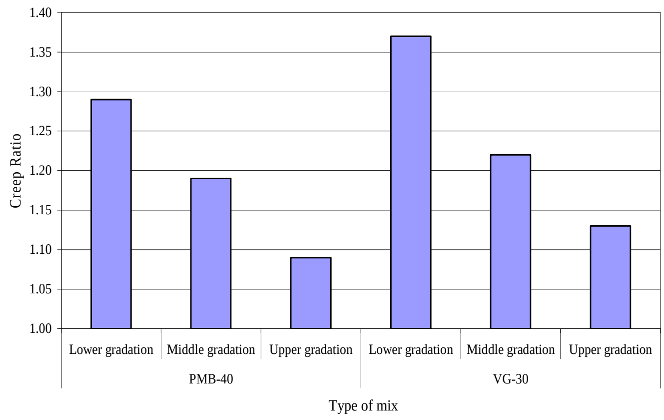

Fig. 9 Creep ratio for different mixes

D.Comparison between Moisture Evaluate Tests

To quantify the effect of conditioning on moisture susceptibility of a mix, three parameters are used in this study. These are percent reduction in ITS, Marshall Stability and percent increase in static creep. As given by following Equations:

$$\%\ Reduction\ in\ ITS = \frac{Unconditioned\ value - Conditioned\ value}{Unconditioned\ value} * 100 \quad (2)$$

$$\%\ Reduction\ in\ stability = \frac{Unconditioned\ value - Conditioned\ value}{Unconditioned\ value} * 100 \quad (3)$$

$$\%\ Increase\ in\ creep = \frac{Conditioned\ value - Unconditioned\ value}{Conditioned\ value} * 100 \quad (4)$$

The effects of the method of evaluation on the moisture damage in mixes prepared using different aggregate gradation and binders are shown in Fig. 10. This figure indicates that the retained stability is least affected by the aggregate grading but the creep is most sensitive to moisture susceptibility in case of modified binder while the ITS is more in case of unmodified binder. In general, the percent change in creep, stability and ITS due to conditioning of specimen in PMB-40 is less than VG-30. This can be explained by the fact that the binder with high viscosity is more resistance to stripping and the amount of absorbed asphalt in mixes prepared using high viscosity binder is higher than in mixes prepared with low viscosity binder [2]. The higher amount of absorbed asphalt in case of PMB-40 improved the mechanical bond between asphalt and aggregate, and hence improved the environmental damage resistance leading to less increase in creep deformation. Another reason behind better stripping resistance of HMA prepared using PMB-40 asphalt is the higher softening point of PMB-40 which enables the asphalt to keep better adhesion with the aggregate as the mix is exposed to high temperature during conditioning [1].

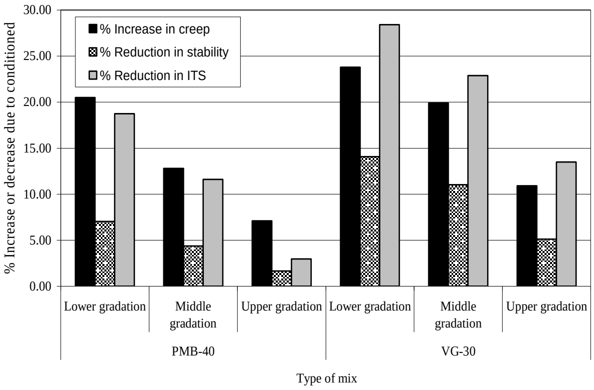

Fig. 10 Effect of test method on moisture susceptibility

VII. Conclusion

Six types of mixes made with combination of three aggregate gradation and two binders are evaluated for their moisture susceptibility. The results indicate that the mix prepared by using PMB-40 has the best performance on moisture susceptibility. Marshall Stability value for PMB-40 mix is higher than those for VG-30 mixes. The retained stability is least affected by the aggregate grading but the creep is most sensitive to moisture susceptibility in case of modified binder while the ITS is more in case of unmodified binder. It means the percent increase in creep is a better parameter to evaluate the moisture damage in mixes. Further, the mix prepared with upper gradation (finer) and PMB-40 has lowest value of creep ratio and higher value of percent rebound strain but the mix prepared with lower gradation (coarser) and VG-30 has the highest value of creep ratio and lower value of rebound strain.

References

[1] Abo-Qudais, S. A, (2007) “The effects of environmental damage evaluation techniques on the prediction of environmental damage in asphalt mixtures”. Science Direct, building and environmental journal U.K, volume 42, pp 288 – 296.

[2] Abo-Qudais, S. A and Haider Al-Shweily (2007) “Effect of Antistripping Additives on Environmental Damage of Bituminous Mixtures”. Science Direct, building and environmental journal U.K, volume 42, pp 2929 – 2938.

[3] Brown, E.R. and Bassett, C.E., (1989) "The Effects of Maximum Aggregate Size on Properties of Asphalt Aggregate Mixes", Report submitted to Highway Research Center, Harbert Engineering, Auburn University, Alabama.

[4] Cominsky, R., Leahy, R. B. and Harrigan, E. T., (1994), "Level One Mix Design: Material Selection, Compaction, and Conditioning". Report SHRP-A-408. Strategic Highway Research Program, National Research Council. USA.

[5] Eliana, P. and John E.P. (2006)," HMA Pavement Performance and Durability" Joint Transportation Research Program, School of Civil Engineering, Purdue University, USA. Pp.7.

[6] IS 73 (2006), "Paving Bitumen Specifications", Indian Standards Institution, New Delhi, India.

[7] Kandhal, P., (1992), "Moisture Susceptibility of HMA Mixes: Identification of Problem and Recommended solutions", NCAT Report No. 92-1. National Center for Asphalt Technology, pp.11.

[8] Kanitpong, K. and Bahia, H.U. (2003)," Evaluation of the Extent of HMA Moisture Damage on Wisconsin as it Relates to Pavement Performance", Final Report No. WHRP 03-07, University of Wisconsin-Madison.

[9] Kumar, P., Chandra, S. and Bose, S., (2006)," Strength Characteristics of Polymer Modified Mixes". International Journal of Pavement Engineering (IJPE), Vol. 7, No. 1, pp. 63–71.

[10] Mc Gennis, R. B., Anderson, R. M., Kennedy, T. W. and Solaimanian, M. (1994), "Background of Superpave Asphalt Mixture Design and Analysis". Report SA-95-003. Federal Highway Administration, U.S. Department of Transportation

[11] Pan, C., L., and White, T. (1999), "Conditions for Stripping Using Accelerated Testing". FHWA/IN/JTRP-97/13 HPR-2068. Indiana Department of Transportation.

[12] Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D., and Kennedy, T., (1996), “Hot Mix Asphalt Materials, Mixtures, Design, and Construction” NAPA Education Foundation, Lanham, Maryland. Second Edition, pp. 241-250.

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