Superpave Mix Design (Rutting Behavior - Permanent Deformation of Flexible Pavement)

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Abstract— This paper contains an extensive study on the "Super Pave Mix Design" method which is used in the "Advanced Pavement Design" Technique. It helps in study and characterization of asphalt mixtures which are used as road pavement materials. By using the state of art laboratory test equipment and the technical literature obtained from the different information sources the several aspects of asphalt concrete mixtures has been expressed. This paper is divided into various parts. In Part one the detailed analysis of performance characteristics of asphalt concrete mixtures and design procedure is present with analytical method of aggregate blending which is used to design the aggregate structures. In part two the comparison between the Superpave and Marshall Stability hot asphalt mix designs have done. Various materials like: Coarse aggregates, fine aggregates, Bitumen etc. are considered for the Selection of materials on the basis of their properties. Such that the aggregates are selected on the basis of their various properties like strengths, soundness and shapes etc. On the basis of gradation aggregates sizes of 12.5mm and 20mm were designed for high traffic level whereas, 10mm were designed for low traffic level. There are different type of binders have been selected according to the traffic mixtures, PG 76-22M was selected for heavy traffic volume mixtures and PG 70-22M has been selected for low traffic volume mixtures. As it was given as PG-T1-T2 where T1 is considered as the maximum temperature value in degree Celsius and T2 is considered as the minimum temperature value in degree Celsius. After the selection of the suitable materials the design mixes have been prepared (Superpave Mix and Marshall Mix Designs) and further analysis has been done on the basis of following tests: Indirect Tensile Modulus Test, Uniaxial Loading Strain Test (Creep Test), Dynamic Modulus Test. The result of this paper suggests that dense aggregate structures provides good resistance to rutting behavior and maintained the adequate levels of durability. Such that this kind of mixes have to be developed to increase the resistance towards permanent deformation and to increase the durability.

Key words: Superpave, Rutting, Permanent deformation, Hot Mix Asphalt, Pavement, Flexible pavement

I. INTRODUCTION

An efficient transportation system plays a vital role for the development of any country. The rutting behavior of pavement is the accumulation of permanent deformation in all or a portion of the layers in a pavement structure that results in a distorted pavement surface. The rutting or permanent deformation in flexible pavements is not a new problem. As long as the flexible pavement has been used the recognition of rutting behavior takes place as a primary distress mechanism and a primary design consideration. In fact, the 1986 AASHTO Guide for Design of Pavement structures is based on performance models developed at the AASHO Road Test where tire inflation pressures were nominally 80 psi. Asphalt pavement design concepts are based on providing sufficient pavement structure (rutting resistant materials) to reduce stresses in the subgrade to the point where rutting will not develop, and on providing asphalt quality and thickness to resist fatigue cracking [1]. The Superpave (Superior Performing Asphalt Pavements) mix design method was developed at a great extent which provides excellent performance under worst conditions like diverse temperature changes and heavy traffic loading. It provides a better platform to the highway agencies, contractors and engineers such that they can improve the condition of roads. Superpave implementation varies by state like pressure, temperature etc. It depends upon the nature of load acting and environmental conditions. Due to use of light motor vehicles and heavy motor vehicles at high rate increased the traffic volume and heavy loads on the pavement surface which leads to the initiation of use of qualitative mix designs Marshall or Hveem methods during mid-1990s. As increase in the traffic volume and load it was required for the Strategic Highway Paper Program (SHRP) to take initiative in 1988 and after lots of efforts around five years a new designed mix was introduced i.e. Superior Performing Asphalt Pavements (Superpave). After the involvement of Superpave Mix Design method for the construction of flexible pavement the Marshal Mix design method is no longer in use because the Superpave Mix Design method fulfill all the needs of flexible pavement by considering the factors that are responsible for the typical distresses on flexible pavements: permanent deformation, thermal cracking and temporary loss of strength. The transformation system played a vital role in the development of business and lifestyle of people such that safe and comfortable facilities are provided to the people. It involves various things for the development like expertise, professionals, workers and a large part of public investment. For the development of roadways there is a need of materials and methods which are economical as well as have high durability and suitable for the field conditions. The methods should be executed in a proper manner for the better quality of highway layer and for that there is requirement of good quality of materials such that proper selection of materials like aggregates, bitumen and additive should be done [2].

II. LITERATURE SURVEY

The Superpave mix design method contained all the qualities of the mix design and was introduced to replace the Marshall mix design methods. For this a large number of papers have reviewed to get an optimum binder content which depends upon the VMA (Void Mineral Aggregates). For Superpave mix design method it was analyzed that for an optimum binder content which depends upon the VMA and seems to cover a range a range of air void content from 2% to 5%. As the rutting problem occur in flexible pavements the air void content reaches to 2% or less. If the air void content percentage in the constructions of flexible pavement is very low then it shows that there is less potential to resist from the rutting or permanent deformation. So, it is required that the air void content for a suitable mix may varies from 3% to 5% [3].

By Huber and Heiman (1987) it was studied that the permanent deformation occurs due to lateral movement of soil subgrade and due to laying of week layers of HMA (Hot Mix Asphalt). It is the result of acting repeated loads which increase the pressure on road due to increase in traffic volume and cause movement of materials used in the pavement layers [4].

III. Objective and Scope of Study

A. Objective:

- Critical analysis of the available information relating to permanent deformation of bitumen asphaltic concrete.
- Characterization of the available materials such as fine and coarse aggregates and asphalt binder according to Superpave mix design criteria.
- To compare the Marshall Mix with Superpave Mix design by evaluating the rutting behavior of pavements designed.
- Evaluation of the performance of Superpave, and Marshall Tests using Indirect Tensile Modulus Test, Uniaxial Loading Strain Test (Creep Test) and Dynamic Modulus Test.

B. Scope of Work:

- This specification for a superpave volumetric mix design uses aggregates and mixture properties to produce a hot mix asphalt (HMA).
- This standard specifies minimum quality requirements for binder, aggregates, and hot mix asphalt for superpave volumetric mix design.
- The selection of the materials for both the mix designs have done separately.
- The test samples have been prepared for testing by considering the optimum content for the suitable mix designs.
- The performance based evaluation of prepared samples have been done using various tests like Indirect Tensile Modulus Test, Uniaxial Loading Strain Test (Creep Test) and Dynamic Modulus Test.
- The data obtained from various tests were analyzed to provide recommendations for use of Superpave Mix design as an alternative to Marshall Mix design.

IV. Requirement of Work

One of the problems faced during implementation of the Superpave mix design method is requirement of maintaining minimum void mineral aggregates (VMA). The Superpave gyratory compactor played a great role in maintaining the minimum void mineral aggregates to increase the compactness of design mix and this increased the use of coarser aggregates asphalt mixes which has the gradation below the restricted zones. There were many highway agencies which made their asphalt mixes gradation above the density line such that in the majority parts of the United States used the coarser asphalt mixes especially for high volume roads to meet the Superpave VMA requirements. It was done so to increase the durability of the pavements which is directly related to the thickness of the asphalt film. Therefore, it was known that the minimum void mineral aggregates should not be based upon the minimum asphalt content rather it directly based on the desirable thickness of the asphalt film. The evaluation of material's performance includes the following steps which are as follows:

- Determination of properties of the materials
- Selection of materials to be used like aggregates and binders
- Selection of test procedures and equipment to be used according to the field conditions
- Comparison between Superpave and Marshall Mix designs methods on the basis of outcomes.

V. Analysis and Findings

By Huber and Heiman (1987) it was studied that the permanent deformation occurs due to lateral movement of soil subgrade and due to laying of week layers of HMA (Hot Mix Asphalt). It is the result of acting repeated loads which increase the pressure on road due to increase in traffic volume and cause movement of materials used in the pavement layers [4]. In this the American Association of State Highway Officials (AASHO) Road test report (1962) has given the main idea that due to lateral movements of subgrades permanent deformation occurs [5]. The report present in the study of joint paper that permanent deformation is caused due to traffic volumes, axle loads and tyre pressure. It was commented that hot mix asphalt is considered as the visco-elastic material because it has both elastic and viscous property [6].

A. Types of Rutting in Asphaltic Concrete:

It was determined that asphalt flow is the cause of rutting behavior in pavements. Also, it was found that the post compaction and plastic flow in the asphalt layers considered as the reason behind the deformation of pavement. The post compaction is defined as the continued compaction which is caused due to the repeated traffic loads. At constant volume conditions and results which is caused due to the movement of mix laterally away from the wheel path due to shear strain the plastic flow usually occurs. It was also determined that the permanent deformation may also be due to low bearing capacity of asphalt layers and quantity which is not be able to fulfill a requirement of compaction of asphalt layers. As the number of load applications increases the permanent deformation increases gradually which results in the formation of longitudinal depression in the wheel path in addition to small upheavals to the sides. The permanent deformation is most common in the areas where the climate is very warm and the traffic rate of heavy vehicles is very high, approaches to intersection and climbing lanes [7].

B. *Rutting Due To Densification:*

It was found that the densification is caused due to the additional loads in the underlying layers that may be base course, sub-base course and surface course. When the road is open to traffic then the repeated loads act on it which results in the permanent deformation by densification. At the time of construction of the flexible pavements when there is insufficient compaction takes place then it results to the permanent deformation when these roads came under contact with traffic loading. In the initial stage the void content in the bitumen asphalt concrete is about 7% to 8% and as the further compaction takes place for the stabilization of asphalt concrete it is expected hopefully reduced at about 4%. Rutting occurs when the densification cause due to traffic loading but also when the proper drainage system is not provided at the time of pavement design then it results in the permanent deformation of pavement surface [4].

C. *Rutting Due To Shear Failure:*

It was studied and reported about the mixtures of asphalt concrete that the shear deformation may be developed in the asphalt mixture when it is subjected to the repeated traffic loading. At this time the air void content of the mixture is very low about 4%. Along the shear plane the lateral displacement of pavement materials shows the sign of mixture instability. These shear failure in the mixture can be occurred in transverse and longitudinal directions. The permanent deformation occurred in the pavement can be visible in such a way that there will be formation of ridges takes place along the edges of the wheel path and depression appears in the loaded portion of pavement. As a result the resistance to the shear stress generated in the pavement surface due to the tyre pressure is reduced [4].
Material Selection:

D. *Aggregate Selection:*

It can be specified in 3 ways are as under:

1) Aggregate gradation: Based on the gradation specifications.
2) Physical Properties: Based on shape like angularity, flakiness, and elongation particles.
3) Source Properties: The source properties considered as the soundness of the aggregate materials. As the sodium or magnesium sulphate soundness test is done then the loss of percentage of materials from the aggregate is considered as the soundness. By this test we can determine the aggregate resistance towards deterioration. This test is performed by taking sodium or magnesium sulphate solution and the aggregate material is immersed in it. After that dry these aggregate material in oven heating. The resistance of aggregate to in-service deterioration is determined by using this test. Then repeat it again and again such that salt precipitates formation takes place in the aggregate permeable void space during drying period and due to the repeatedly immersion forms the hydrates having internal expensive forces which is same as the expansive force of freezing water. This process of immersion and drying is called soundness cycle. In this soundness is obtained by the total percentage loss for required number of cycles over various sieves intervals. [8].

The sample of aggregates were tested for their suitability are as given below:

S.No.	Parameters	20mm	10mm	MORT and H-Limits
1	% Abrasion Value	25.9	36.3	Max. 40
2	% Impact Value	22.1	22.8	Max. 30
3	% Flakiness and Elongation	17.5	24.8	Max. 30
4	% Water Absorption	0.56	0.61	Max. 2

E. *Binder Selection:*

It was evaluated by grading systems with Superpave binder specifications. Grading systems were based on the empirical relationships between physical properties and the observed performance. The Superpave binder specifications are based directly on the performance and are selected on the basis of the climate in which the pavement will serve. Among various binder grades, the distinction is the specified maximum and minimum temperatures meeting the requirements. A binder classified as a PG 64 – 10 means that the binder will meet the high temperature physical property requirements up to a temperature of 64°C and the low temperature physical property requirements down to -10°C. Binder are selected based on expected pavement temperature extreme values in the area of intended use, it is recognized that bitumen from two different sources may show same physical properties at a particular temperature. In superpave only acceptable test values and not the test temperature are recommended. The temperature are determined from most prevalent maximum and minimum temperature of field at a given mobility level. A binder is designated as PG T_1T_2 where PG is performance grade, T_1 is maximum temperature limit, T_2 is minimum temperature limit under which performance of binder is tested to be acceptable for example: PG 64-16, here $T_1 = 64^0$ C and $T_2 = -16^0$C [9]. The sample of bitumen were tested for their suitability as per IS: 73:2000 specification given below:

S.No.	Parameters	Result	IS: 73 : 2000
1	Flash Point ^{0}C	314	Mini. 220
2	Penetration at 25 ^{0}C	57	Between 30-70
3	Softening Point ^{0}C	48	Mini. 47

VI. TESTING OF MATERIALS

Flexible pavements involves the performance based testing which is further to predict the permanent deformation of the desired pavements. Here we have considered two mix designs to compare with each other which we can use in formation of pavements i.e. superpave mix design and marshall mix design. Following tests were performed to evaluate the comparative performance of asphalt mixes;

- Indirect Tensile Modulus Test
- Uniaxial Loading Strain Test (Creep Test)
- Dynamic Modulus Test

For every test proper test conditions have been made so that we get an appropriate test results. Each test has been described with sample preparation, testing conditions, test procedure, test results in tabular form.

A. Indirect Tensile Modulus Test:

This test was performed using UTM – 5P (Universal Testing Machine – 5 Pulses). In this test the specimen is subjected to diametric loading force and then total recoverable diametric strain is measured at axes form the applied force which is present 90^0 to it. The poisson's ratio value maintained is 0.4 and it is used as constant. As we have considered the controlled temperature testing, the transducers are used to estimation of the specimen's skin and core temperatures. These transducers inserted in dummy specimen and located near the specimen under testing. As per the procedure in the tests jigs the specimen were mounted as described by the manual (Manual UTM-5P) and the results were stored in the computer database as given in tables [10].

Indirect Tensile Modulus Test		
Mix Type	Temparature^{0}C	Indirect Tensile Modulus Test
Marshall	25	Test pulse period= 1000micro seconds, Pulse Width= 400micro seconds, Peak loading force= 500N
Superpave	55	

Testing conditions for Indirect Tensile Modulus Test

Temparature^{0}C	**Resilient Modulus (MPa)**	
	Marshall	**Superpave**
25	**4950**	**7990**
55	215	525

Resilient Modulus for Marshall and Superpave

B. Uniaxial Loading Strain Test (Creep Test):

This test was performed by using UTM – 5P (Universal Testing Machine – 5 Pulses). With the help of this machine we can apply uniaxial loadings in repeated manner at different temperatures. In this test a static conditioning stress is applied to the specimen and then measure the strain develop and also conditioning time as 100 seconds. In this the heavy loading is applied having the loading pulse period of 2000 micro seconds and having pulse width of around 500 micro seconds in continued manner. The total strain develop were measure with the help of two linear variable displacement transducers during both conditioning and pulse loading. For each test, the temperature has been maintained inside the testing cabin at the desired value before the test carried out. In order to attain a uniform temperature for the specimen to be tested was kept inside the temperature controlled chamber for around two hours.

As shown in as given in tables:

Mix type	**Temperature (°c)**	**Creep testing parameters**
		No. of Pulse= 3600, Pulse Period= 2000ms, Pulse width= 500ms, Rest Period= 1500
		Stress Level (kPa)
Marshall	25	100
		300
		500
Superpave	55	100
		300
		500

Uniaxial Loading Strain Test Conditions

Stress Level	**T (°c)**	**Resilient Strain (%)**			
		Mix Type			
		Superpave		**Marshall**	
		Individual	**Averag-e**	**Individu al**	**Avera-ge**
100 kPa	25	0.015	0.0133	0.0055	0.017
		0.011		0.0245	
		0.014		0.022	
	55	0.021	0.0290	0.0331	0.038
		0.036		0.0101	
		0.032		0.071	
300 kPa	25	0.030	0.034	0.04	0.035
		0.035		0.037	
		0.037		0.03	
	55	0.07	0.09	0.12	0.11
		0.10		0.14	
		0.10		0.07	
500 kPa	25	0.02	0.03	0.04	0.041
		0.04		0.03	
		0.03		0.053	
	55	0.091	0.108	0.10	0.123
		0.122		0.14	
		0.112		0.13	

Uniaxial Loading Strain Test Results Showing Resilient Strain (%)

C. Dynamic Modulus Test:

Dynamic modulus testing of asphalt concrete is a type of viscoelastic test response which is developed under loading conditions having a succession of waves or curving. By this type of loading conditions the complete or pure value of stress is divided by the most extreme possible amount of strain. This test was performed by using NU-14 machine. In this an asphalt concrete specimen of cylindrical shape of 4 x 6 inch size. This test has been carried out at two different temperature conditions and six different stress levels [11].

Mix type	**Temperature (°c)**	**Dynamic Modulus Test**
		No. of cycles= 200 Frequency (HZ)= 25, 10
		Stress Level (KPa)
Marshall	25	300
		500
		700
Superpave	55	35
		50
		65

Dynamic Test Conditions

Frequency (Hz)	**Dynamic Modulus (Mpa) at 25°C**					
	Marshall			**Superpave**		
	300 kPa	**500 kPa**	**700 kPa**	**300 kPa**	**500 kPa**	**700 kPa**
25	6955	7625	7355	7700	11645	8935
10	4895	5700	5770	6290	9235	7045

Comparison of Dynamic Modulus Results for Marshall and Superpave Mix at 25°C

Frequency (Hz)	**Dynamic Modulus (Mpa) at 55°C**					
	Marshall			**Superpave**		
	35 kPa	**50 kPa**	**65 kPa**	**35 kPa**	**50 kPa**	**65 kPa**
25	375	419	430	733	740	735
10	295	323	343	555	545	569

Comparison of Dynamic Modulus Results for Marshall and Superpave Mix at 55°C

VII. FINAL DISCUSSION ON TEST RESULTS

In all the three tests carried out as mentioned in the "Analysis and Findings" we prepared the test conditions. The following test conditions were kept and result analysis was done:

A. Indirect Tensile Modulus Test:

1) Test Conditions:

We compared two mix designs Marshal Mix design and Superpave Mix design and kept the samples of Marshal Mix and Superpave Mix designs at 25^0C and 55^0 C respectively. Test pulse period = 1000ms, Pulse Width = 400ms, Peak loading force = 500N.

2) Test Result:

The void mineral aggregates (VMA) are present in the greater amount in Superpave Mix design, it makes the mix more compact and enhance the hardness, durability and capability to bear more impact, as compared to the Marshal Mix Design.

B. Uniaxial Loading Strain Test:

1) Test Conditions:

We compared two mix designs Marshal Mix design and Superpave Mix design and kept the samples of Marshal Mix and Superpave Mix designs at 25^0C and 55^0 C respectively. The creep testing parameters are: No. of Pulse= 3600, Pulse Period= 2000ms, Pulse width= 500ms, Rest Period= 1500.

2) Test Results:

We tested both the samples at different loading and took their average. It was found that Superpave Mix design showed better result than Marshal Mix design.

C. Dynamic Modulus Testing:

1) Test Conditions:

We compared two mix designs Marshal Mix design and Superpave Mix design and kept the samples of Marshal Mix and Superpave Mix designs at 25^0C and 55^0 C respectively. Test parameters are: No. of cycles= 200, Frequency (HZ) = 25, 10.

2) Test Results:

We tested both the samples at different pressures at different frequency. The pressure was varied according to the temperature of the test condition due to variation of mix design characterstics. It was found that Superpave Mix design showed better result than Marshal Mix design.

VIII. CONCLUSION

The aim of present paper work was to check whether Superpave mix design method using indigenous materials, under local traffic loading conditions and prevailing temperature regime has superiority over the other mixes with respect to rutting or not. Basically two dense graded mix was studied. Dense graded mixes were prepared using Superpave and Marshall Mix Design approaches. The main conclusions drawn from the current paper work are being presented. Superpave mix showed better performance in terms of low accumulated strains (%) (Permanent deformation) as compared to Marshall mixes which is an indication of highly rut resistant mix. Accumulated strains increased with the increase in number of load repetitions, stress level and temperature but percent increase in accumulated strains (%) was more in the case of Marshall Mixes to that of Superpave. It reflects that under conditions of heavy traffic loadings and high temperatures, Superpave mix can be a better option against rutting. Superpave mix showed better performance in terms of low accumulated strains (%) (Permanent deformation) as compared to Marshall mix which is an indication of highly rut resistant mix. Accumulated strains increased with the increase in number of load repetitions, stress level and temperature but percent increase in accumulated strains (%) was more in the case of Marshall mix to that of Superpave. It reflects that under conditions of heavy traffic loadings and high temperatures, Superpave mix can be a better option against rutting. Superpave mix showed in better performance in terms of low resilient strains (%), high resilient modulus and high creep stiffness as compared to Marshall mix. During Indirect Tensile Modulus Testing, higher values of Modulus of Resilience were observed in case of Superpave mixes. Even at the maximum testing temperature (55^o C), Superpave mix performed better than the other two mixes. Dynamic moduli of Superpave mix were also relatively higher at different dynamic stress levels and temperatures as compared to Marshall. Permanent strain induced revealed that Superpave mix behaved as a more stable mix in terms of lower dynamic creep values. Dynamic creep increased with the increase in temperature for all the mixes. It reflects that rutting (Permanent deformation) is a function of dynamic loading and high temperature.

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REFERENCES

[1] Middleton, D.R., F.L. Roberts and T. Chira-Chavala, "Measurement and Analysis of Truck Tire Pressures on Texas Highways," in Transportation Research Record

1070, Transportation Research Board, Washington, D.C., 1986, pp. 1-8.
[2] Cominsky, R., R.B., Leahy, and E.T. Harrigan. Level One Mix Design: materials Selection, Compaction, and Conditioning, SHRP A-408. Strategic Highway Research Program, National Research Council, Washington, D.C., 1994.
[3] Brown, E. R. and S. A. Cross. "A National Study of Rutting in Hot Mix Asphalt (HMA) Pavements," Journal of the Association of Asphalt Paving Technologists, Vol. 61, 1992, pp. 535–573.
[4] Huber, G. A. and Heiman, G. H. 1987. Effects of Asphalt Concrete Parameter on Rutting Performance: A Field Investigation. Association of Asphalt Paving Technologists v. 56.
[5] AASHO Road Test 1962.Special Report No.73 Washington DC Publication No.1012
[6] Pomeroy, C. D. 1978. Creep of Engineering Materials. A Journal of Strain Analysis Monograph. Mechanical Engineers Publication Limited. London.
[7] Mouratidis, A. and Freitas, A. R. 2007. Assessment of Pavement Rutting due to Asphalt Flow. Advanced Characterization of Pavement and Soil Engineering Materials-Loizos, Scarpas & Al-Qadi, p. 1297-1304.
[8] American Association of State Highway and Transportation Officials (AASHTO). 2004. Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate, AASHTO Designation T104.
[9] Roberts, F. L., Mohammad, L. M. and Wang, L. B. 2002. History of Hot Mix Asphalt Mixture Design in the United States. ASCE 150th Anniversary Civil Engineers Paper. Journal of Materials in Civil Engineering v.14, no.4, p279-293.
[10] American Society for Testing and Materials (ASTM). 2004. Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures. ASTM Designation D4123
[11] American Association of State Highway and Transportation Officials (AASHTO). 2004. Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures, AASHTO Designation TP 62-03.