PERFORMANCE OF ASPHALT CONCRETE USING 'SUPERPAVE' AGGREGATE GRADATIONS

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Abstract : The Strategic Highway Research Program in the USA has developed a new specification for Asphalt mix gradation that is called Superpave. This paper describes a laboratory investigation of asphalt concrete binder course mix containing five different aggregate gradings, all within the envelope specified by Superpave for a 19mm nominal maximum size aggregate; one grading passed through the restricted zone. In addition mix prepared to the median of the Indonesian Bina Marga specification specified for the material was also investigated. Marshall analysis showed that the optimum bitumen content was lowest for the Bina Marga gradation (5.5%) and highest for the mix prepared at the lower (coarser) limit of the Superpave gradation (5.9%). All of the mixes satisfied the Bina Marga criterion for resistance to water damage. Mixes prepared at optimum bitumen content were tested for resistance to permanent deformation in the wheel tracking and static indirect tensile strength tests, meanwhile the creep test was not evaluated for mixes performance assessment.

Key Words : superpave, asphalt concrete, marshall analysis, bitumen content, deformation.

1. INTRODUCTION

Construction of new roads and betterment of existing roads has increased at a rapid rate in Indonesia over the past number of years. Problems were observed on the roads constructed with asphalt concrete and there was increased use of Hot Rolled Asphalt Mix. The principal problem with asphalt concrete was premature cracking that was attributed to the poor durability of the mix under Indonesia conditions. Hot Rolled Asphalt Mix can accommodate a higher bitumen content and hence is considered to be more durable. However the mix tends to be susceptible to rutting and roads constructed with the material were observed to have deformed significantly after only a relative short period in service.

The Strategic Highway Research Program (SHRP) in the United State of America has developed a new specification for asphalt mix gradation that is called Superpave (Superior Performing Asphalt Pavement). The Superpave system is applicable to virgin and recycled, dense graded, hot mix asphalt, with or without modification. It can be used when constructing new surface, binder and base layers, as well as overlays on existing pavements. Through materials selection and mix design, it directly addresses the reduction and control of pavement deformation and fatigue cracking. The objective of this investigation were then :

a. to evaluate the laboratory performance of an asphalt concrete binder course conforming to selected aggregate as specified in Superpave Series No. 2-1996 (The Asphalt Institute, 1996).

b. to compare the performance of the Superpave gradations with that of a mixture graded to the median of the Bina Marga envelope Type V (SNI 03-1737-1989) that is specified for binder course mix.

2. BITUMINOUS MIXTURES

The binder course, sometimes called the base course, is the asphalt layer immediately below the wearing or surface course. There are two reasons that a binder course is used in addition to the wearing course. First the bituminous surfacing is frequently too thick to be compacted in one layer, so it must be placed in two layers. Second, the binder course generally consists of larger aggregates and less asphalt and does not require to be of as high a quality as the surface course, so replacing a part of the surface course by the binder course results in a more economical design (HUANG, 1993). In Indonesia, Asphalt Concrete is known as LASTON and eleven aggregate grading envelopes are given in the Indonesian Specification called Bina Marga Specification (SNI 03-1737-1989). Grading Type V is used for wearing and binder course layers.

2.1. Properties Required of Bituminous Mixtures

SHELL BITUMEN (1990) states that bituminous mixtures should have the ability to resist permanent deformation, resist fatigue cracking, be workable during laying (enabling the material to be satisfactory compacting with the available equipment), be impermeable (to protect the lower layers of the road from the water), be durable (resisting abrasion by traffic and the effects of air and water), and contribute to the strength of the pavement structure, be easily maintained, and most importantly, this must be cost-effective. The specific requirements of bituminous mixture are therefore stability, flexibility, durability, workability, economical, impermeable and sufficient stiffness.

2.2. The Principles of Mix Design

The design of bituminous mixtures is largely a matter of selecting and proportioning material to obtain the desired properties in the finished construction product. The overall objective for design is to determine a cost-effective blend and gradation of aggregates and asphalt that yields a mix having :

a. Sufficient asphalt to ensure a durable pavement
b. Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
c. Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of asphalt expansion due to temperature increase without flushing, bleeding, and loss of stability.
d. A maximum void content to limit the permeability of the mix to harmful air and moisture
e. Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance.
f. For surface mixes, proper aggregate texture and hardness to provide sufficient skid resistance in unfavourable weather conditions.

The design of bituminous mixtures involves the choice of aggregate type, aggregate grading, bitumen grade and determination of the bitumen content will optimise the engineering properties in relation to the desire behaviour in service. SHELL BITUMEN (1990) mentions that the objective of mix design is to produce an economical material, making full used of local resources that meet engineering requirements for optimal service and economic performance.

2.3. Superpave Asphalt Mix Design

The Superpave mix design system integrates material selection and mix design into procedures based on the project's climate and design traffic. Superpave specifies aggregate gradation by adding two features : control points and restricted zone. Control points function as master ranges between which the gradation must pass. The restricted zone forms a band through which the gradation can not pass. This gradation often results in a mixture that poses compaction problems during construction, is very sensitive to asphalt content and can easily become plastic with even minor variations in asphalt content (The Asphalt Institute, 1993).

Superpave defines five aggregate gradations by their nominal maximum aggregate sixe recommended for the design of paving mixes for base, binder, and surface courses. The principle feature of the Superpave Asphalt Mixture Design procedure is laboratory compaction, which is accomplished using a Superpave Gyratory Compactor. A loading mechanism presses against the reaction frame and applies a load to the loading ram to produce a 600 kPa compaction load on the sample. It has an inside diameter of 150 mm and the base rotates at a constant 30 revolution per minute during compaction with the mould positioned at a compaction angle of 1,25 degrees. For compacted samples that will be used in Superpave mix design, the sample size is 150 mm diameter by 115 mm height and requires approximately 4700 grams of aggregate.

The Superpave Gyratory Compactor is used to produce specimens for volumetric analysis, and it also records data to provide a measure of specimen density throughout the compaction procedure. As with other mix design procedures, asphalt mixtures are designed at a specific level of compactive effort. In Superpave this is a function of the design number of gyrations, N_{des}. N_{des} is used to vary the compactive effort of the design mixture and it is a function of climate and traffic level. N_{ini} is the initial number of gyrations; N_{max} is maximum number of gyrations. The ranges of values for number of gyrations are shown in Table 1. The sample is compacted using the maximum number of gyrations, continually monitoring the height of the samples during the compaction process. Once the design aggregate structure is selected, a minimum of five bitumen contents is investigated and at each bitumen content a minimum of two samples is prepared. The mixture properties are then evaluated to determine a design bitumen content according to The Asphalt Institute Superpave design criteria, shown in Table 3. The volumetric properties are calculated at N_{des} for each trial bitumen content. From these data points, the designer generates graphs of VIM, VMA, VFB and unit weight of total mix versus bitumen content. The optimum bitumen content is established at 4.0% air voids (VIM).

2.4. Marshall Method of Mix Design

The most commonly used method of bituminous mix design is the Marshall method. All of the calculated and measured mix properties at each bitumen content are evaluated by comparing them with mix design criteria. In the Marshall procedure specimens 4 inches in diameter and 2.5 inches high are prepared by compacting the mix in a mould using a hammer

Table 1 The Asphalt Institute Superpave Mix Design Criteria

1 Superpave Design Gyratory Compactive Effort

Design ESAL (millions)	Average Design High Temperature											
	< 39°C			39 – 40°C			41 - 42°C			43 – 44°C		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3 – 1	7	76	117	7	83	129	7	88	138	8	93	146
1 – 3	7	86	134	8	95	150	8	100	158	8	105	167
3 – 10	8	96	152	8	106	169	8	113	181	9	119	192
10 – 30	8	109	174	9	121	195	9	128	208	9	135	220
30 – 100	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	143	235	10	158	262	10	165	275	10	172	288

2 Voids in Mineral Aggregate (VMA) Criteria

Nominal Max. of Aggregate Size	Minimum VMA Percent
9.5 mm	15.0
12.5 mm	14.0
19.9 mm	13.0
25.0 mm	12.0
37.5 mm	11.0

3 Voids Filled with Bitumen (VFB) Criteria

Traffic, millions ESAL	Design VFB, Percent
< 0.3	70 - 80
< 1	65 - 78
< 3	65 - 78
< 10	65 - 75
< 30	65 - 75
< 100	65 - 75
> 100	65 - 75

4 Maximum Theoretical Specific Gravity

% Gmm @ Nini	< 89 %
% Gmm @ Nmax	< 98 %

Source : The Asphalt Institute, 1996

of 10 lbs weight with a free fall of 18 in. Depending upon the design traffic, 35, 50 or 75 blows of the hammer are applied to each face of the sample. The mixes are usually made with bitumen content at increments of 0.5% by weight and not less than four bitumen contents are investigated. After overnight curing the density and air voids content are determined. The sample is then heated in a water bath for 30 minutes at a temperature of 60°C for the stability and flow test. The sample is placed in a cylindrical shaped split-breaking head and is located at a rate of 2 inches/minute. The maximum load and corresponding flow are registered during the test. The maximum load is called the Marshall Stability and the ratio of stability to flow is called the Marshall Quotient. Six graphs are plotted; stability, flow, unit weight of total mix, VIM, VFB and VMA versus bitumen content. These graphs are used to determine the design optimum bitumen content of the mix.

2.5. Marshall Immersion Test

A number of Marshall samples are prepared at optimum bitumen content. Half of the batch is tested under standard conditions and the average stability determined. The remaining samples are immersed in a water bath for 24 hours at 60°C, and the average stability then determined by testing under standard conditions. The loss of stability following immersion is a measure of resistance to water damage; the ratio of immersed stability to standard stability is called the Index of Retained Strength (IRS).

2.6. Wheel Tracking Test

The Wheel Tracking Test (WTT) is a simulation test in which a moving wheel load is passed backwards and forwards over the sample. The sample of dimensions 30cm x 30cm x 5cm, is compacted by a purpose built compactor. The compacted density of the sample should meet the degree of compacting obtained for corresponding Marshall samples within ± 2%. Prior to testing, the specimen is immersed in the water bath of the wheel-tracking machine for about 30 - 40 minutes at the specified temperature. The test is carried out with the contact pressure of the testing wheel at 6.4 ± 0.15 kg/cm^2, corresponding to a dual-wheel single-axle load of 8.16 tons. Each specimen is subjected to 1320 cycles of the wheel in one hour at a rate of 22 cycles (44 passes) per minute. The main components of the wheel-tracking test are the Wheel Tracking Compactor and the Wheel Tracking Machine. The Japan Road Association (1980) method of interpretation of the results is based on the relationship between cummulative deformation and time. From the cumulative deformation versus time graph, the period during which deformation accumulates at a linear rate is observed. From this linear portion of the graph, two parameters, the Dynamic Stability and the Rate of Deformation are calculated.

2.7. Indirect Tensile Strength (Static Load) Test

The indirect tensile strength test is conducted by loading a cylindrical specimens with a single compressive load acting parallel to and along the vertical diametrical plane. This loading configuration develops a relatively uniform tensile stress perpendicular to direction of the applied load and along the vertical diametrical plane, with ultimately causes the specimen to fail by splitting along the vertical diameter. The indirect tensile strength test is performed after the sample has been brought to the specified temperature. The samples is loaded, using a 12.7 mm wide curved stainless steel loading strip, at a constant rate of 51 mm per minute (2 in. per minute). The loading strip is utilised in order to change the horizontal stress along the vertical diameter from tension to compression near the points of load application. The Marshall compression machine is utilised to conduct the test and two guide rods are used to prevent any eccentricity in loading. Vertical deformation is measured using a linear transducer, fixed at the upper loading strip and touching the upper side of the guide rod. Mechanical dial gauges held against the left and right sides of the sample by magnetic attachments may be used to measure horizontal deformation. The data required for calculations are the height of the sample, the maximum load at fracture and the horizontal and vertical deformation.

3. LABORATORY TEST

The test methods utilised conformed generally to the Indonesian National Standards (SNI), other standard methods, e.g. American Association of State Highway and Transportation Officials (AASHTO), British Standards Institution (BSI) were used when the appropriate test was not available in the Indonesian National Standards. The aggregates used in this research programme were obtained from Banjaran in Bandung Region of West Java. Coarse, fine aggregate and filler consisted of crushed stone materials. The bitumen used in this investigation was 60/70 penetration grade. The performance assessment for bituminous mixtures include Marshall properties, wheel tracking and indirect tensile strength tests but creep test was not included for the assessment.

3.1. Aggregate Grading Investigated

The bituminous mixtures investigated were an asphalt concrete binder course made with various grading of aggregate. The grading investigated were shown in Table 2 and Figure 1:

a. Specimens Type-A consisting of coarse aggregate, fine aggregate and filler in proportions that conformed to the median gradation of Indonesian Bina Marga specification Type V.
b. Specimens Type-B consisting of coarse aggregate, fine aggregate and filler in proportions that conformed to the lower limit of the Superpave gradation for 19-mm nominal maximum size.
c. Specimens Type-C consisting of coarse aggregate, fine aggregate and filler in proportions that conformed to the median of the Superpave gradation and passing through the median of the restricted zone.
d. Specimens Type-D consisting of coarse aggregate, fine aggregate and filler in proportions that conformed to the median of the Superpave gradation and passing through the upper limit of the restricted zone.
e. Specimens Type-E consisting of coarse aggregate, fine aggregate and filler in proportions that conformed to the median of the Superpave gradation and passing through the lower limit of the restricted zone.

3.2. Test on Bituminous Mixtures

a. Marshall Test

   The Marshall analysis was used to obtain the optimum bitumen content. Three samples were prepared at each of five bitumen contents for each type of grading investigated. The mix design criteria given by The Asphalt Institute were used in the analysis of the samples, and the results were compared with the Bina Marga criteria.

Table 2 Aggregate Grading Specified for Bina Marga Type-V

Sieve	Passing by weight (%)		
(mm)	Minimum	Maximum	Spec. Type A
25.00	100.0	100.0	100.0
19.00	80.0	100.0	90.0
9.52	60.0	80.0	70.0
4.76	48.0	65.0	56.5
2.38	35.0	50.0	42.5
0.59	19.0	30.0	24.5
0.279	13.0	23.0	18.0
0.149	7.0	15.0	11.0
0.074	1.0	8.0	4.5

Source : SNI, 03-1737-1989

Table 3 Superpave Aggregate Grading Investigated for a 19-mm Nominal Maximum Size

Sieve	Passing by Weight (%)			
	Controls Point		Restricted Zone Boundry	
(mm)	Minimum	Maximum	Minimum	Maximum
25.00	100.0	100.0		
19.00	90.0	100.0		
12.50	78.0	90.0		
2.36	23.0	49.0	34.6	34.6
1.18	18.0	42.0	22.3	28.3
0.60	14.0	34.5	16.7	20.7
0.30	10.0	27.0	13.7	13.7
0.074	2.0	8.0		

Source : The Asphalt Institute, 1996

Sieve	Passing by Weight (%)			
(mm)	Specimen Type B	Specimen Type C	Specimen Type D	Specimen Type E
25.00	100.0	100.0	100.0	100.0
19.00	90.0	95.0	95.0	95.0
12.50	78.0	84.0	84.0	84.0
2.36	23.0	34.6	34.6	34.6
1.18	18.0	25.3	28.3	22.3
0.60	14.0	18.7	20.7	16.7
0.30	10.0	13.7	13.7	13.7
0.074	2.0	5.0	5.0	5.0

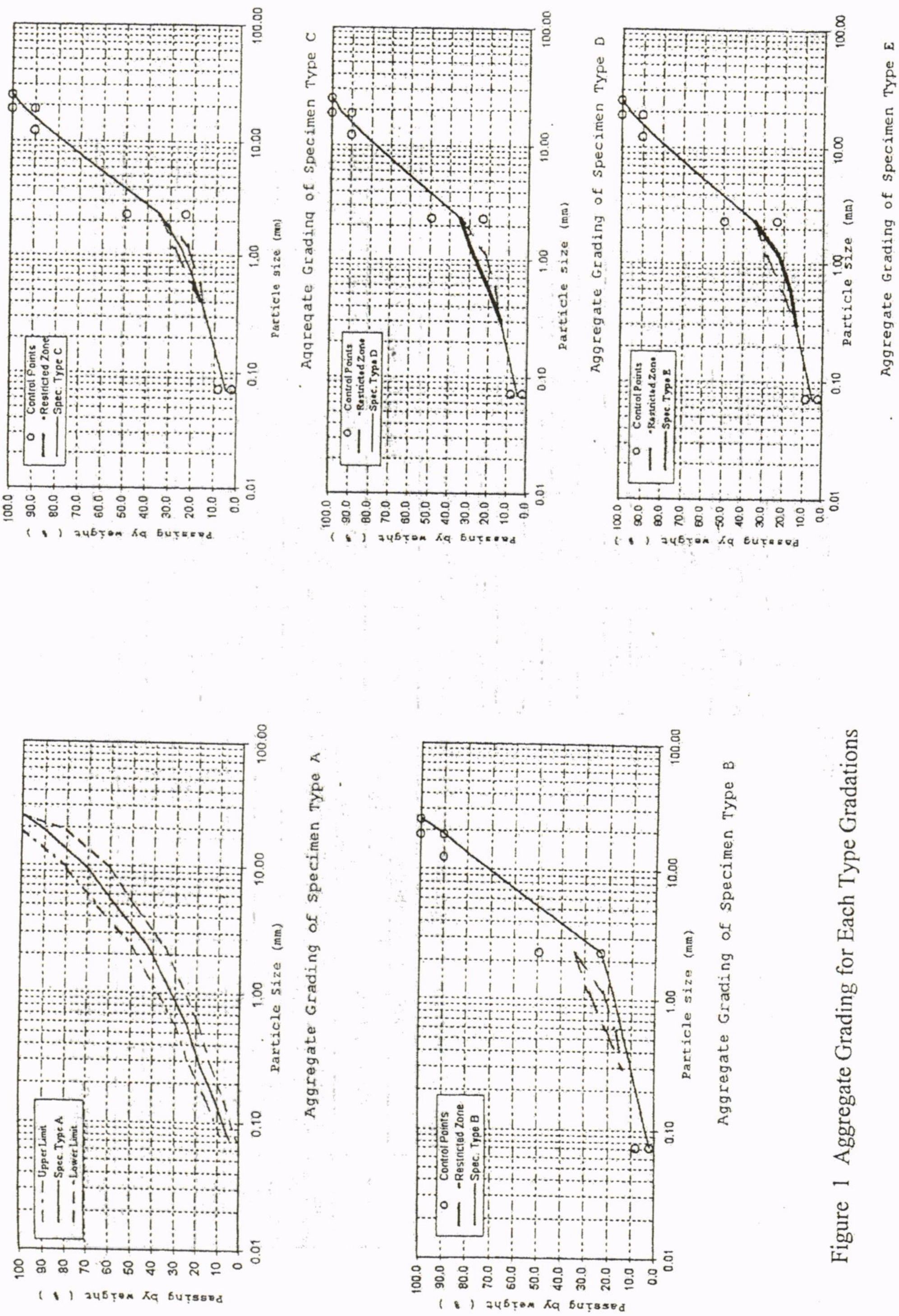

Figure 1 Aggregate Grading for Each Type Gradations

b. Marshall Immersion Test
Specimens prepared at optimum bitumen content were used to investigate susceptibility to water damage. Six samples of each mixed type were prepared at optimum bitumen content; three samples were tested under standard Marshall conditions and the three remaining samples were tested following immersion in a water bath at 60°C for 24 hours. The ratio of Marshall stability after and before immersion, expressed as a percentage, is known as the Marshall Index of Retained Strength (MRS) and provides a measure of susceptibility to water damage.

c. Wheel Tracking Test
The samples for the wheel tracking test were prepared at optimum bitumen content and their densities were kept as close as possible to that of the corresponding Marshall samples.

d. Indirect Tensile Strength Test
Indirect Tensile Strength was determined using the Marshall apparatus and the tests were conducted on samples prepared at optimum bitumen content. Three samples of each mix were tested for the indirect tensile strength at temperature of 45°C and 60°C.

4. DATA PRESENTATION AND ANALYSIS

The coarse aggregate, fine aggregate and filler were obtained from the crushed stone stockpile at Banjaran, and the bitumen was 60/70 penetration grade. The properties determined for these materials are discussed below.

4.1. Results of Tests on Aggregate and Bitumen

The aggregate grading investigated were based on the Bina Marga Type-V grading band, specified for asphalt concrete binder course, and Superpave gradations based on a 19-mm nominal maximum size. Individual aggregate size fractions were separated, then recombined in the proportions needed to satisfy the grading; Saybolt-Furol viscosity test was also done to obtain the temperature range of mixing and compacting. It seems that that all the quality meets The Indonesian Bina Marga requirements for material used in hot mix asphalt and the results of 60/70 pen grade bitumen show that the material also meets the Bina Marga requirements.

4.2. Results of Marshall Analysis

Parameters such as stability, flow, density, voids in the mix (VIM), voids in the mineral aggregate (VMA) and voids filled with bitumen (VFB) were obtained by the Marshall analysis. The samples were compacted and 75 blows were applied to each face of the sample. For the requirements of mixing, the aggregate and bitumen were heated to a temperature higher than that at which the viscosity of bitumen equals to 170 ± 20 centistokes and compacting temperature was based on a bitumen viscosity of 280 ± 30 centistokes. From the relationship between bitumen viscosity and temperature, it was obtained that the mixing and compacting temperatures were 150°C and 138°C respectively.

Table 4 Marshall Analysis Results for Specimen Type-A

MIX PROPERTIES	TEST RESULTS					SPECIFI - CATION *)
Bitumen Content, %	5.0	5.5	6.0	6.5	7.0	
Unit Weight, g/cc	2.329	2.360	2.377	2.382	2.374	-
VIM, %	6.35	4.42	3.00	2.10	1.72	3 - 5
VMA, %	15.39	14.75	14.57	14.86	15.61	> 14
VFB, %	58.57	70.37	79.39	85.63	89.09	65 - 75
Stability, kg	1122	1155	1163	1147	1107	> 810
Flow, mm	2.61	2.81	3.12	3.53	4.05	2 - 3.5
Marshall Quotient, kg/mm	433	410	376	330	272	-

Table 5 Marshall Analysis Results for Specimen Type-B

MIX PROPERTIES	TEST RESULTS					SPECIFI - CATION *)
Bitumen Content, %	5.0	5.5	6.0	6.5	7.0	
Unit Weight, g/cc	2.294	2.327	2.347	2.355	2.350	-
VIM, %	7.87	5.84	4.31	3.28	2.75	3 - 5
VMA, %	16.88	16.14	15.85	16.00	16.61	> 14
VFB, %	53.20	64.14	72.84	79.32	83.57	65 - 75
Stability, kg	1027	1072	1084	1063	1009	> 810
Flow, mm	2.89	3.04	3.36	3.85	4.51	2 - 3.5
Marshall Quotient, kg/mm	361	351	324	282	223	-

*) The Asphalt Institute, 1993

Table 6 Marshall Analysis Result for Specimen Type-C

MIX PROPERTIES	TEST RESULTS					SPECIFI - CATION *)
Bitumen Content, %	5.0	5.5	6.0	6.5	7.0	
Unit Weght, g/cc	2.322	2.349	2.365	2.370	2.363	-
VIM, %	6.68	4.88	3.52	2.62	2.16	3 - 5
VMA, %	15.77	15.24	15.11	15.39	16.07	> 14
VFB, %	57.55	68.35	76.65	82.79	86.66	65 - 75
Stability, kg	1089	1138	1148	1120	1053	> 810
Flow, mm	2.70	2.88	3.21	3.69	4.33	2 - 3.5
Marshall Qoutient, kg/mm	409	392	359	309	244	-

Table 7 Marshall Analysis Result for Specimen Type-D

MIX PROPERTIES	TEST RESULTS					SPECIFI - CATION *)
Bitumen Content, %	5.0	5.5	6.0	6.5	7.0	
Unit Weght, g/cc	2.318	2.347	2.364	2.370	2.365	-
VIM, %	6.84	4.97	3.56	2.59	2.07	3 - 5
VMA, %	15.92	15.33	15.14	15.36	15.99	> 14
VFB, %	56.90	67.80	76.48	82.90	87.14	65 - 75
Stability, kg	1081	1128	1140	1115	1055	> 810
Flow, mm	2.75	2.93	3.26	3.71	4.31	2 - 3.5
Marshall Quotient, kg/mm	397	383	353	306	243	-

Table 8 Marshall Analysis for Specimen Type-E

MIX PROPERTIES	TEST RESULTS					SPECIFI - CATION *)
Bitumen Content, %	5.0	5.5	6.0	6.5	7.0	
Unit Weght, g/cc	2.309	2.339	2.357	2.362	2.355	-
VIM, %	7.20	5.29	3.88	2.95	2.52	3 - 5
VMA, %	16.24	15.61	15.42	15.68	16.38	> 14
VFB, %	55.58	66.38	74.83	80.95	84.73	65 - 75
Stability, kg	1028	1088	1111	1096	1044	> 810
Flow, mm	2.77	2.97	3.31	3.79	4.42	2 - 3.5
Marshall Quotient, kg/mm	376	364	337	294	235	-

*) The Asphalt Institute, 1993

Results of the Marshall test for the mixes are summarised in Tables 4 to 8. The data and the acceptable ranges in bitumen content for specified properties used to determine optimum bitumen content. Mixture properties at optimum bitumen content are summarised in Table 9 and it seems that in general, all of the mixes meet The Asphalt Institute (TAI) and Bina Marga criteria. The results of the Marshall analysis of these mixes are discussed below :

a. Optimum Bitumen Content (OBC)
The OBC determined for each aggregate grading is suitable in terms of compliance with The Asphalt Institute design criteria considering all parameters such as VIM, VMA, VFB, Flow and Stability and the OBC is determined to be 5.5% by weight of mix for mix Type-A. The OBC of specimen Type-A is lower than that of the other mixes.

b. Unit Weight
The unit weight of Specimen Type-A is consistently higher than that of the other mixes. In comparison with other mixes, this mix has also the lowest OBC, again that aggregate gradation of Specimen Type-A (continuous graded) can lead to have a higher unit weight.

c. Voids in the Mixture (VIM)
The VIM of Specimen Type-A is consistently lower than that of the other mixes. However at its OBC, VIM is lowest for Specimen Type-C. The VIM of all mix types at OBC satisfies TAI and Bina Marga criteria, both of which require VIM to be in the range 3.0% to 5.0%. When VIM is too high, brittleness, premature cracking, and stripping are possible consequences, but if too low, can lead to instability in the mix and plastic flow.

d. Voids in Mineral Aggregate (VMA)
The Asphalt Institute specifies minimum VMA values of 12%, 13%, and 14% for mixtures containing a nominal maximum aggregate particle size of 19 mm, at design air voids contents of 3%, 4% and 5% respectively. Bina Marga specifies a minimum VMA value of 14% for mixture containing a nominal maximum aggregate particle size of 19 mm. The VMA value is much dependent on the particle shape and surface texture, the maximum size of aggregate particle, the grading of the total aggregate and the method of compaction utilised. The VMA values for all aggregate gradings exceed the minimum values of the TAI and Bina Marga criteria. At OBC, the VMA of Specimen Type-B is highest and that of specimen Type-A is lowest. Over the range in bitumen contents investigated, the VMA of Specimen Type-A is consistently lowest.

e. Voids Filled with Bitumen (VFB)
The VFB is the percentage of the VMA that is filled with bitumen and does not include the absorbed bitumen. The VFB is included as a criterion by TA which requires it to lie in the range 65% to 75% but is not specified as a Bina Marga criterion. The VFB values at OBC are given in Table 9. The VFB at OBC of Specimen Type-A (70.15%) is lowest; over the range in bitumen contents investigated VFB of all mixes at OBC satisfies the TAI criterion..

f. Stability
The Marshall Stability values at OBC of Specimen Type-B (1,087 kg) is lowest and that of Specimen Type-A (1,157 kg) is highest. Nevertheless, the stability of all mixes at Optimum Bitumen Content satisfies The Asphalt Institute (minimum of 1,800 lb or 810 kg) and Bina Marga (minimum of 500 kg) criteria.

g. Flow

A mixture that was a low flow value at OBC is likely to have good ability to resist deformation. However a flow value that is too low, particularly when combined with high stability indicates a mix that is susceptible to cracking. The Marshall flow values at OBC of Specimen Type-A (2.83mm) is lowest and that of Specimen Type-B (3.27mm) is highest. The flow of all mixes at OBC satisfies The Asphalt Institute (2.0 to 3.5 mm) and the Bina Marga (2.0 to 4.0 mm) criteria.

h. Marshall Quotient
The Marshall quotient calculated as the ratio of stability to flow, can be used as an indicator of mixture flexibility. Marshall Quotient is included as a criterion in the Bina Marga specification which requires it to be in the range of 250 to 350 kg/mm but is not specified as a criterion by The Asphalt Institute. The Marshall Quotient at OBC of Specimen Type-B (331 kg/mm) is lowest and that of Specimen Type-A (410 kg/mm) is highest. Only Specimen Type-B (334 kg/mm) and Specimen Type-E (347 kg/mm) at OBC satisfy the Bina Marga criterion.

From the results shown above, it concludes that aggregate gradation and compaction method do apparently influence the mixes properties since fine content will of course affect the Marshall properties of the mixes. The relationship between energy on Marshall compactor and features in gyratory compactors given to the specimens lead to the different properties owned by individual specimen of bituminous mixes.

4.3. Marshall Immersion Test

After the optimum bitumen content of the mixes was obtained, six samples of each mix type were prepared at the bitumen content for the immersion test. Three of the samples from each batch were tested under standard Marshall conditions, the remaining three samples were immersed in a water bath at 60°C for 24 hours prior to testing for stability and flow. The Marshall immersion test in concerned with the ability of asphalt paving mixtures to resist disintegration induced by water. The susceptibility to water damage is assessed by immersion of sample in a water bath for 24 hours at a temperature of 60°C prior to testing under standard Marshall conditions and determining the consequent loss in stability. The index of retained Marshall stability of each of the mixes tested was calculated from the average of tests conducted on three samples following immersion. Data on the Marshall retained stability of the samples after immersion in water at 60°C for 24 hours is summarised in Table 10. The index of retained Marshall stability of Specimen Type-A (83.15%) is lowest and that of Specimen Type-B (89.97) is highest, but all mixes have retained stability values greater than 75%, the minimum criterion set by Bina Marga.

4.4. Results on The Wheel Tracking Test

Two samples of each grading were prepared at optimum bitumen content and were tested in the wheel-tracking machine at 45°C and 60°C. The results of the wheel tracking tests are shown that at 45°C Specimen Type-A exhibits the highest dynamic stability of 6,496 passes/mm and at 60°C the Dynamic Stability of Specimen Type-A is again highest, 1,925 passes/mm, indicating Specimen Type-A to have the highest resistance to permanent deformation.

Table 9 Summary of Marshall Properties at Optimum Bitumen Content

MIX PROPERTIES	SPECIMEN TYPE					SPECIFI - CATION *)
	A	B	C	D	E	
Optimum Bitumen Content, %	5.5	5.9	5.7	5.7	5.8	-
Unit Weight, g/cc	2.360	2.342	2.357	2.354	2.350	-
VIM, %	4.40	4.73	4.32	4.44	4.49	3 - 5
VMA, %	14.72	15.99	15.18	15.29	15.52	> 14
VFB, %	70.15	70.41	71.56	70.96	71.10	65 - 75
Stability, kg	1157	1087	1146	1133	1108	> 810
Flow, mm	2.83	3.27	3.00	3.10	3.20	2 - 3.5
Marshall Quotient, kg/mm	410	331	383	367	347	-
Effective Bitumen Content, %	4.50	4.95	4.74	4.74	4.84	-

*) Source : The Asphalt Institute, 1993

Table 10 Summary of Marshall Immersion Data at Optimum Bitumen Content

MIX PROPERTIES	SPECIMENS TYPE				
	A	B	C	D	E
Optimum Bitumen Content, %	5.5	5.9	5.7	5.7	5.8
Standard Stability, kg	1157	1087	1146	1133	1108
Stability after Immersion, kg	962	978	970	964	972
Retained Stability, %	83.15	89.97	84.64	85.08	87.73

4.5. Results on Indirect Tensile Strength Test

The relationship between indirect tensile strength and temperature is plotted on Figure 2. At 45°C the indirect tensile strength of specimen Type-B (27.702 psi) is lowest and that of specimen type-A (33.163 psi) is highest. AT 60°C the indirect tensile strength of specimen type-B (15.038 psi) is again lowest and that specimen type-A (16.845 psi) is again highest.

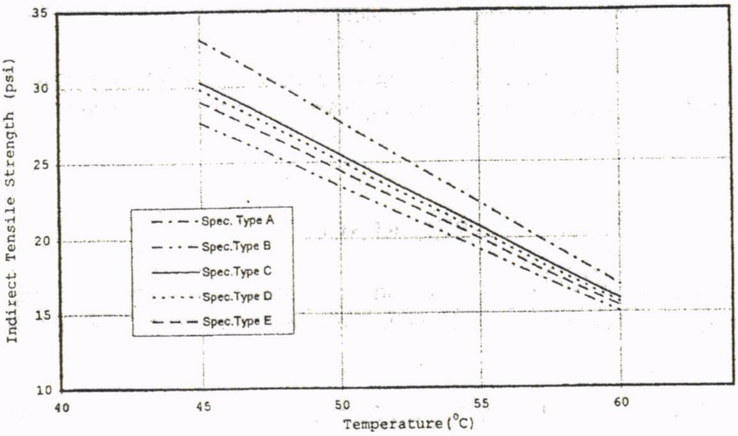

Figure 1 Relationship between Indirect Tensile Strength and Temperature

5. CONCLUSIONS

This investigation was concerned with the performance of an asphalt binder course mix made with aggregate gradations conforming to selected Superpave gradations for a 19 mm nominal maximum size aggregate and to the median of the Bina Marga Type-V gradation. It is emphasized that the mixes were prepared, compacted and analysed according to the Marshall procedure. In the Superpave procedure samples are prepared by gyratory compaction and the analysis is based on parameters related to the compaction procedure. The conclusions given below should be interpreted on the understanding that they may be significantly influenced by the particular compaction procedure used.

The following conclusions are drawn from this investigation :

a. Specimen Type-A which has the lowest percentage of material retained on the 2,38 mm sieve (i.e. 57.50%) has the lowest voids in the mineral aggregate (14.27%), the highest unit weight (2.36 gr/cc). This mix has the highest Marshall stability (1,157 kg) and requires the least bitumen (5.5%) to satisfy design criteria.
b. Specimen Type-B which contains the highest amount of material retained on the 2.38 mm sieve (i.e. 77.0%) has properties at the other end of the scale from Specimen Type-A. Bitumen demand (5.9%) for this mix type is highest and it consequently exhibits high durability. However, it has inferior strength characteristics as indicated by Marshall stability (1,087 kg), has the highest VMA (15.99%), the lowest unit weight (2.34 gr/cc).
c. Specimen Types C, D and E generally exhibit Marshall properties that tend to cluster around the middle of the extremes represented by specimens Type A and Type B. The similarity in composition and performance of these mixes is possibly attributable to the fact that in each case the amount of material retained on the 2.38 mm sieve is 65.40%.

The aggregate grading of these specimens passes through the median (Type C) and the upper (Type D) and lower limits (Type E) of the restricted zone.

d. Specimen Type A has the highest Indirect Tensile Strength at 45°C (33.163 psi) and 60°C (16.845 psi). Mix prepared to this gradation also had the highest Dynamic Stability at 45°C (6,496 passes/mm) and 60°C (1,925 passes/mm) and the least total deformation at the conclusion of the wheel tracking test.
e. The performance of Type B mix was again at the other end of the scale from the Type A mix; the result of wheel tracking tests conducted on mixes with this gradation indicate to have the lowest Dynamic Stability at 45°C (4,331 passes/mm) and 60°C (1,209 passes/mm). Specimen Type C, D and E again generally exhibited properties that tend to cluster around the middle of the extremes represented by specimen Type A and specimen Type B.

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