CIPUNEGARA RIVER AGGREGATES ENGINEERING PROPERTIES AND ITS USE IN ASPHALT CONCRETE FOR ROAD PAVEMENT MATERIAL

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Abstract : The investigation described in here was concerned with an evaluation of the engineering properties of Cipunegara aggregate and of asphalt concrete binder course made with the aggregate. Tests were conducted of crushed coarse and fine aggregate and on the natural fine aggregate. For purpose of comparison a parallel investigation was conducted using crushed aggregate from Banjaran. The test data indicate that the Cipunegara aggregate satisfied specified and recommended strength, hardness and durability requirements for aggregate used in binder course mix. The Marshall procedure was used to design mixes containing crushed coarse and fine Banjaran aggregate, crushed coarse and fine Cipunegara aggregate and crushed coarse and natural fine Cipunegara aggregate. Mixtures at optimum bitumen content were tested for durability, resilient modulus and resistance to deformation. The results of the investigation indicate that a satisfactory asphalt concrete binder course mix can be made with Cipunegara aggregate.

Key Words : Aggregate, Asphalt Concrete, Marshall, Bitumen Content, Deformation

1. INTRODUCTION

Indonesia comprises more than 13,500 islands covering a land area of about 1,920,000 square kilometres with a population of around 200 million inhabitants. Java covers about 132,000 square kilometres and comprises only 7% of the whole Indonesian territories. The population of Java is around 120 million which is is about 60% of the total Indonesian population. This island is the most densely populated area in Indonesia with metropolitan-type cities such as Jakarta, Bandung, Semarang and Surabaya. Jakarta is the capital city of Indonesia, and Cirebon is a coastal city which is also an important port in the province of west Java and is defined as a Primary Function City and Regional Development Centre of West Java. Both cities have developed extensive economic activities, especially in the field of trade, and have become destinations for industrial centres located along the northern coast of Java.

Rapidly increasing traffic volumes has resulted in insufficient highway capacity. In recognition of the demand for increased highway capacity, the construction of a new expressway between Jakarta and Cirebon (Figure 1) has been considered by the Directorate General of Highway of the Ministry of Public Works as a portion of the Trans Java Highway Network. Construction of part of the Jakarta - Cirebon Toll Road, the section between Jakarta and Cikampek, began in 1984 and was completed in September

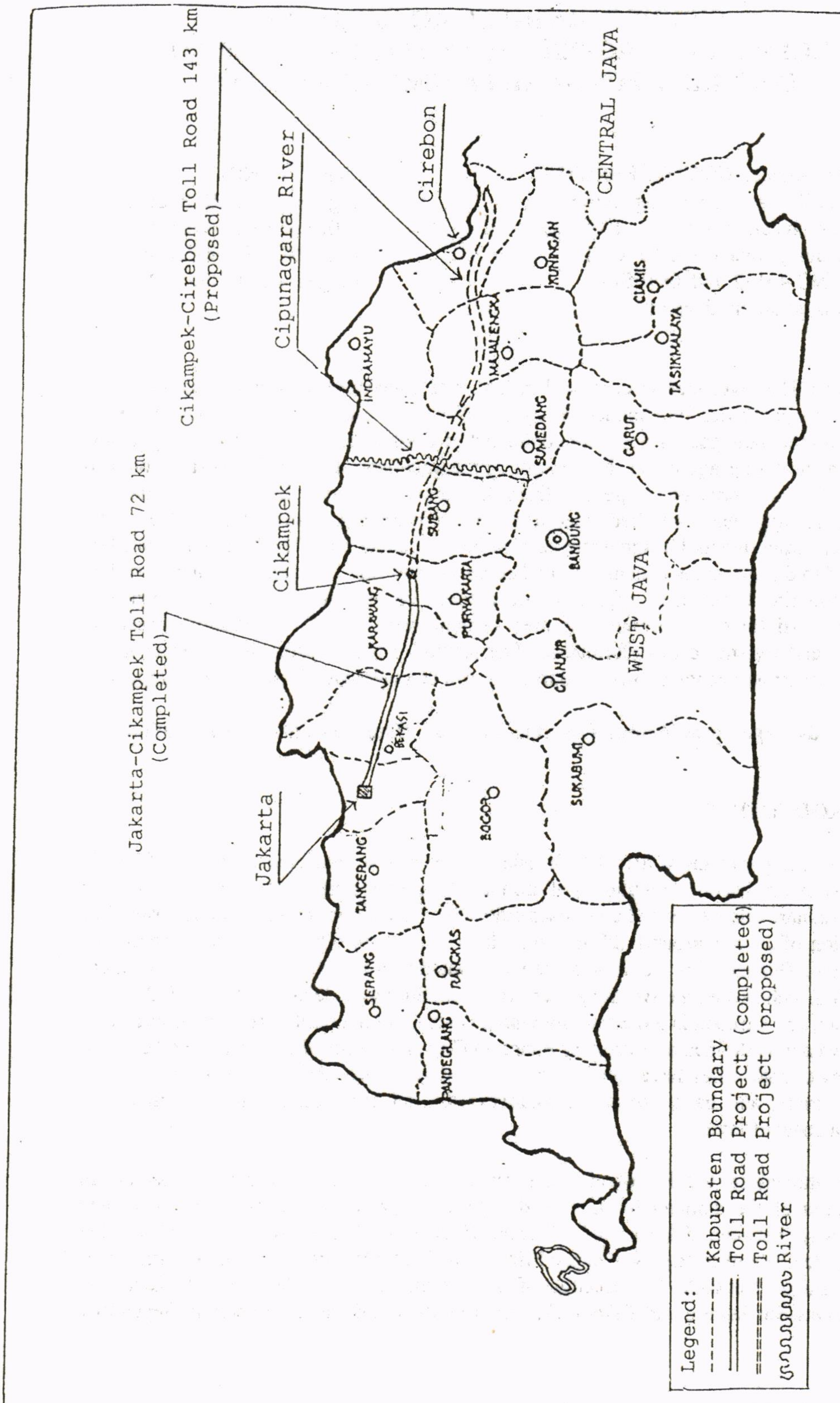


Figure 1 Proposed Toll Road Project of Cikampek - Cirebon

section between Jakarta and Cikampek, began in 1984 and was completed in September 1988. In addition, Bina Marga carried out a feasibility study for the Cikampek - Cirebon section. This feasibility study was completed in December 1989 by the Japan International Cooperation Agency - JICA (The Feasibility Study Cikampek - Cirebon Toll Road Project, 1989). However, from 1989 until present, there has been no progress in the design or construction stages for the implementation of this project. The proposed Cikampek - Cirebon tollway is approximately 143 km in length, starting from the end point of the Jakarta - Cikampek tollway and connecting with East Cirebon.

The Cipunegara river in Subang regency runs from Mount Cimanggu in the south of Subang to the Java sea in the north of Subang and is about 120 km in length. This river is a natural boundary between the Subang regency and the Sumedang and Indramayu regencies. Along this river there are potential aggregate sources which have not yet been investigated in detail. The Institute of Road Engineering (IRE) in a report No. 11-072.PT.89) published in 1989 describes a road materials inventory of the Subang district. The Cipunegara location is not among the 27 locations recorded in the inventory. Processing of Cipunegara aggregate including crushing began in 1994 but 3 years later this effort was stopped because of the financial crisis and at the end of 1998, processing of the material resumed.

Proven material deposits around the Cipunegara bridge and along 1 15 km river length are about 3 million cubic metres; potential material deposits along 1 40 km upstream river length are about 8 million cubic metres. The gravel deposits at Cipunegara may provide an economic source of material for use in the construction of sections of the Cikampek - Cirebon toll road. This research investigated the properties of aggregate from Cipunegara and evaluated the laboratory performance of asphalt concrete binder course mixture containing Cipunegara aggregate and compare the properties and performance of Cipunegara River Aggregate with those of the more widely used crushed aggregate from Banjaran.

2. BITUMINOUS MIXTURES

2.1. Introduction

The amount of mineral aggregate in bituminous mixture is generally 90 to 95 percent by weight of the total mixture and the nature and quality of the aggregate are obviously important. High quality aggregate is required for strong, high quality mixtures in the surfacing layer of a flexible pavement where wheel loads are concentrated and stresses are high. Lower quality aggregates can often be used in bitumen bases because strength requirements are not as high as for the surface course. This often permits use of locally available and lower cost aggregates, and reduces pavement costs.

Mineral aggregate has been defined as any hard, inert mineral material used for mixing in graduated particles or fragments. It includes sand, gravel, crushed stone, slag, rock dust or powder. Larger particles of aggregate, called coarse aggregate and larger than about 2.5mm are normally obtained from crushing rock or slag, or from crushing and screening gravel. Finer particles of aggregate, called fine aggregate and smaller than about 2.5mm are obtained from natural sand or fine screening from rock crushing operations. Normally a mineral filler such as rock dust is added to the fine aggregate (The Asphalt Institute, MS-1, 1969).

2.2. Aggregate for Bituminous Mixtures

Aggregate is a combination of sand, gravel, crushed stone, slag or other mineral composition used in combination with a binding medium to form material such as bituminous and cement concrete, mortar, etc. Mineral aggregate is primarily responsible for the load supporting capacity of the pavement. Selecting an aggregate material for used in an asphalt pavement depends upon the availability, cost, and quality of the material, as well as the types of construction that are intended.

a. Coarse Aggregate
Coarse aggregate is the material which is substantially retained on a 2.36mm sieve, equal to the No.8 ASTM standard sieve. For asphalt concrete, the coarse aggregate has a significant effect on mix performance because the stability of asphalt concrete is derived from the interlocking of aggregate. Coarse aggregate should consist of clean, tough, durable material free from dirty or objectionable matter. ROAD RESEARCH LABORATORY (1962) states that the properties of most importance in a road making aggregate are its resistance to crushing, impact, abrasion and polishing, its specific gravity and water absorption, and its grading and particle shape. The laboratory tests performed to evaluate the coarse aggregate are specific gravity and water absorption, Los Angeles Abrasion, Aggregate Impact, Aggregate Crushing, Ten Percent Fines, Flakiness Index, Soundness, and Affinity for Asphalt.

b. Fine Aggregate
Fine aggregate is material passing the No.8 sieve and retained on the No.200 sieve. Fine aggregate can be natural sand, i.e. from a river or pit, volcanic ash or crushed rock fines. The main function of the fine aggregate is to provide stability and reduce the permanent deformation of the mix through the interlocking and friction of the particles. In this respect, important external characteristics required are angularity and particle surface roughness. The fine aggregate serves to fill the voids in the coarse aggregate, which will affect the density of mixture. The properties required are such as specific gravity, water absorption and sand equivalent.

c. Filler
Filler is material passing the No.200 sieve and should consist of limestone dust, dolomite dust, Portland Cement Fly Ash or other non-plastic material and it should be dry and free from lumps. PELL (1978) states that filler can be considered as acting in one of two ways. Firstly, it can be thought of as modifying the grading of the fines, thereby giving a denser mix with more points of contact between grains, and at the same time reducing the amount of bitumen that is required to fill the remaining voids. Secondly, a better way of regarding the action of filler, when considering the proportions of fines, filler and bitumen in the mortar, is to say that filler and bitumen in the mortar, is to say that filler and bitumen together form a paste that both lubricates and binds the fines to form a mortar. Clearly the properties of this mortar will depend partly on the nature of the fines and partly on the amount and viscosity of the paste or binder. Various researchers state that increasing the quantity of filler tends to increase the stability and reduce the air voids of the mixture. However there is a limit to the

beneficial effect of increasing the filler content. Too high a filler content tends to produce a mix that is brittle and may crack under traffic load, but on the other hand, a filler content that is too low may produce a mix that becomes unduly soft in hot weather.

2.3. Bitumen

Bitumen is complex material with a complex response to stress. The response of a bitumen to stress is dependent on both temperature and loading time. As defines in many books, bitumen as : "A viscous liquid, or their derivatives, which is soluble in trichlorethylene and is substantially non volatile and softens gradually when heated. It is black or brown in colour and possesses water proofing and adhesive properties. It is obtained by refinery processes from petroleum crude, and is also found as a natural deposit or as a component of naturally occurring asphalt, in which it is associated with mineral matter". Bitumen commonly used in Indonesia are AC-10 (approximately equivalent to 80/100 pen) and AC-20 (approximately equivalent to 60/70 pen).

2.4. Asphalt Concrete Binder Course

The binder course, sometimes called the base course, is the asphalt layer immediately below the wearing course. There are two reasons that a binder course is used in addition to the wearing course. First, the bituminous layer is 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 wearing course, so replacing a part of the surfacing by the binder course results in a more economical design.

The binder course mixture is composed of aggregates and bitumen normally mixed in a central plant. The mixture is spread and compacted on a prepared base in accordance with the specification. The binder course is normally a dense graded asphalt mixture designed according to Bina Marga Standard specification (SNI No. 1737-1989-F) for LASTON.

2.5. The Principles of Mix Design

TAI (1993) states that the design of bituminous mixture is largely a matter of selecting and proportioning matter to obtain the desired properties in the finished construction product. The overall objective for the 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 increases 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.

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

2.6. Marshall Method of Mix Design

Perhaps the most widely used method of bituminous mix design is the Marshall or US Army Corps of Engineers Method. In this procedure, specimens 4 in (102mm) in diameter by 2.5 in (63.5mm) high are prepared by compacting in a mould with a compaction hammer that weighs 10 lb. And has a free fall of 18 in. Depending upon the design traffic, 35, 50 and 75 blows of the hammer are applied to each side of the specimen. After overnight curing, the density and voids are determined and the specimen is heated, usually in a water bath to 140°C for the Marshall stability and flow test. The specimen is placed in a cylindrical shaped split breaking head and is located at a rate of 2 in/min. The maximum load registered during the tests is designated as the Marshall stability of the specimen. The amount of movement, or strain, occurring between no load and the maximum load is the flow value of the specimen.

A common procedure is to take the most desirable asphalt percentages for stability, unit weight, and percent voids and average the. This average value should satisfy all the required criteria and if it does not, it should be adjusted until a value is found that will satisfy all criteria. If no such asphalt percent exists, then a different aggregate gradation must be selected. A pavement made with a mixture having a low flow value would be rather rigid and brittle and would have a tendency to crack early in its life. On the other hand, mixes with high flow values are also to be avoided; usually such high flow values are accompanied by low stability values. Thus, the Marshall mix design takes into account three of the basic properties, i.e. stability, durability (by controlling the percent of air voids), and flexibility (as reflected in values of flow).

3. LABORATORY RESULTS AND DISCUSSIONS

3.1. Introduction

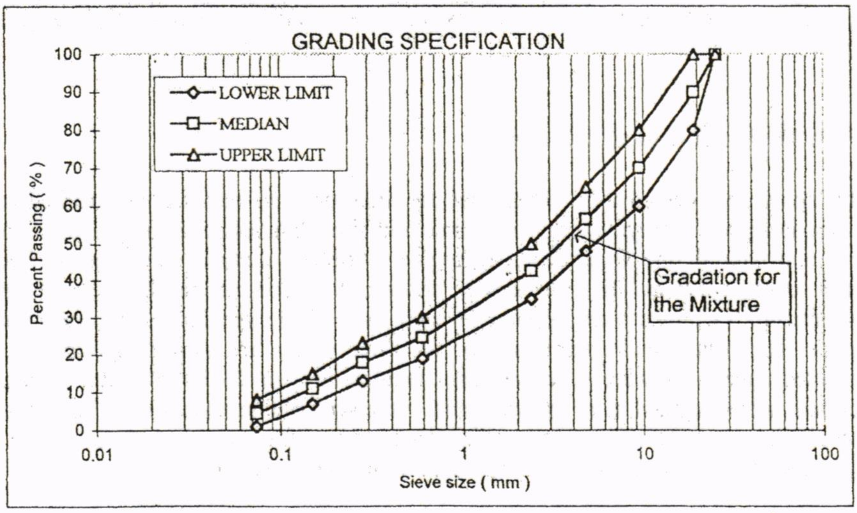
Gravel from the river is stockpiled for processing by the operators of the existing plant and samples were taken from these stockpiles. The Cipunegara river gravel was crushed to meet specification requirements using the small crushing machine at the Institute of Road Engineering, Bandung. Banjaran aggregate was obtained from the stockpile at the Institute of Road Engineering. The aggregate grading used for both aggregates was Type V of Bina Marga specification, details of which are given in Table 1 and Figure 2.

Table 1 Aggregate Grading Specification for Asphalt Concrete

No. of Mix	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Gradation/Tekstur	Coarse	Coarse	Dense	Dense	Dense	Dense	Dense	Dense	Dense	Dense	Dense
Thick of Layer (mm)	20-40	25-50	20-40	25-50	40-65	50-75	40-50	20-40	40-65	40-65	40-50
Sieve size	% Weight of Passing										
1 1/2" (38,1 mm)	-	-	-	-	-	100	-	-	-	-	-
1" (25,4 mm)	-	-	-	-	100	90-100	-	-	100	100	-
3/4" (19,1 mm)	-	100	-	100	80-100	82-100	100	-	85-100	85-100	100
1/2" (12,7 mm)	100	75-100	100	80-100	-	72-90	80-100	100	-	-	-
3/8" (9,52 mm)	75-100	60-85	80-100	70-90	60-80	-	-	-	65-85	56-78	74-92
no.4 (4,76 mm)	35-55	35-55	55-75	50-70	48-65	52-70	54-72	62-80	45-65	38-60	48-70
no.8 (2,38 mm)	20-35	20-35	35-50	35-50	35-50	40-56	42-58	44-60	34-54	27-47	33-53
no.30 (0,59 mm)	10-22	10-22	18-29	18-29	19-30	24-36	26-38	28-40	20-35	13-28	15-30
no.50 (0,279 mm)	6-16	6-16	13-23	13-23	13-23	16-26	18-28	20-30	16-26	9-20	10-20
no.100 (0,149 mm)	4-12	4-12	8-16	8-16	7-15	10-18	12-20	12-20	10-18	-	-
no.200 (0,074 mm)	2-8	2-8	4-10	4-10	1-8	6-12	6-12	6-12	5-10	4-8	4-9

Source : SNI, 1989

Note :
Number of Mix : I, III, IV, VI, VII, VIII, IX, X and XI used for surface course
Number of Mix: II used for surface course, leveling and binder course
Number of Mix: V used for surface course and binder course



Source : SNI, 1989

Figure 2 Specification Limits of Asphalt Concrete Binder Course, Mix Type V

3.2. Tests for Aggregate Properties.

Tests were conducted on the coarse and fine aggregates and on the filler. All of the tests were conducted according to standard laboratory procedures specified by Bina Marga, British Standard Institution, AASHTO or other recognised organisations.

a. Coarse Aggregate
Coarse aggregate is required in general to consist of clean, tough and durable material. The results of laboratory tests are listed in Table 2. Cipunegara and Banjaran crushed aggregates have bulk specific gravity values, respectively, of 2.618 and 2.657. Indonesian National Standard (SNI) states that the specific gravity of coarse aggregate for asphalt concrete should not be less than 2.5 and both aggregates satisfy this requirement. The results of the water absorption test are 2.041%

b. Fine Aggregate
Crushed fine aggregate, defined as material passing sieve size No.8 (2.38mm) and retained on sieve No.200 (0.075mm), was obtained from the small crushing machine operation; natural fine Cipunegara aggregate was obtained by sieving. The laboratory results of fine aggregate are listed in Table 3.

c. Mineral Aggregate
The filler is defined as material which substantially passes the No.200 or 0.075mm sieve. The laboratory test carried out on the filler is the specific gravity test as specified in SNI-1970-1990-F. The filler material was obtained from the crushing operation and the specific gravity values are listed in Table 4.

3.3. Tests on Bitumen Properties

The bitumen used for the asphalt concrete mixtures was 60/70 pen grade. This grade is suitable for the Indonesian climate in order to avoid excessive softening during dry season temperatures. The laboratory tests results and specification requirements, are given in Table 4.5.

3.4. Mix Design of Asphalt Concrete

In this study, mix design were determined for three types of mixture, i.e. crushed coarse and fine Banjaran aggregate, crushed coarse and fine Cipunegara aggregate and crushed coarse and natural fine Cipunegara aggregate. Marshall analysis was used to find the bitumen content that satisfies mix design criteria. As recommended by Bina Marga for heavy traffic, 75 blows were applied to each face of the specimen with the Marshall hammer. The results and comparison of the three mixes are shown in Figure 3. The compacted specimens were cured at room temperature for 24 hours. After curing, the specimens were weighed in air, in water and in the saturated surface dray (SSD) condition to obtain the bulk specific gravity. They were then immersed in a water bath at a temperature of 60°C for about 30 minutes and immediately tested.

Three specimens were prepared at each of six bitumen contents, expressed as percentage by weight of total mix. The data were presented on graphs as follows :

Table 2 Properties of Coarse Aggregates

PROPERTY	TEST METHOD	UNITS	Cipunagara Crushed	Banjaran Crushed	Specification	
					Min.	Max.
Bulk Specific Gravity	SNI-03-1969-1990	-	2.618	2.657	2.5	-
SSD Specific Gravity	SNI-03-1969-1990	-	2.672	2.748	-	-
Apparent Specific Gravity	SNI-03-1969-1990	-	2.766	2.861	-	-
Effective Specific Gravity	SNI-03-1969-1990	-	2.692	2.759	-	-
Absorption of Water	SNI-03-1969-1990	%	2.041	2.261	-	3
Los Angeles Abrasion Value	SNI-06-2417-1991	%	19.20	13.68	-	40
Aggregate Impact Value	BS-812	%	14.63	10.25	-	30[1)]
Aggregate Crushing Value	BS-812	%	19.48	11.43	-	30[1)]
Flakiness Index	SNI-M-25-1993-03	%	21.50	19.90	-	25
Elongation Index	SNI-M-25-1993-03	%	18.75	17.50	-	25
Soundness	ASTM:C88-76	%	0.45	0.17	-	12
Affinity for Asphalt	SNI-2439-1991	%	95+	95+	95	-
Ten Percent Fines Value	BS-812	Tons	18	25	-	-

Note: 1) Suggestion Values

Table 3 Properties of Fine Aggregates

PROPERTY	TEST METHOD	Cipunagara Natural	Cipunagara Crushed	Banjaran Crushed	Specification	
					Min.	Max.
Specific Gravity :	SNI-03-1970-1990					
- Bulk		2.592	2.620	2.684	2.5	-
- SSD		2.697	2.667	2.718	-	-
- Apparent		2.894	2.745	2.777	-	-
- Effective		2.743	2.682	2.731	-	-
- Water absorption (%)	SNI-03-1970-1990	4.026	1.688	1.245	-	3
- Sand Equivalent (%)	AASHTO T-176	76.8	61.47	66.3	50	-

Table 4 Properties of Fillers

PROPERTY	TEST METHOD	Cipunagara Natural	Cipunagara Crushed	Banjaran Crushed	Specification	
					Min.	Max.
Specific Gravity :	SNI-03-1970-1990	2.815	2.775	2.743	-	-

a. Stability vs Bitumen Content
b. Flow vs Bitumen Content
c. Unit Weight vs Bitumen Content
d. Voids Filled with Bitumen Content
e. Voids Filled with Bitumen (VFB) vs Bitumen Content
f. Voids in Mineral Aggregate (VMA) vs Bitumen Content
g. Voids in Mix (VIM) vs Bitumen Content

Based on these graphs, the Optimum Bitumen Contents (OBC) of the mixes were determined. The Asphalt Institute (MS-2) (1993) states that the final selected mix design is usually the most economical one that will satisfactorily meet all of the established criteria. However, the mix may be designed to optimise one particular property. Mixes with abnormally high values of stability are often less durable and may crack prematurely under heavy volumes of traffic. This situation is especially critical where the base and subgrade material beneath the pavement are weak and permit moderate to relatively high deflections under the actual traffic. The design of bitumen content should normally be a compromise selected to balance all of the mix properties. Normally, the mix design criteria will produce a narrow range of acceptable bitumen contents selection can be adjusted within this narrow range to achieve a mix property that will satisfy a requirement of a specific project. Different properties are more critical for different circumstances, depending on traffic, structure, climate, construction equipment and other factors.

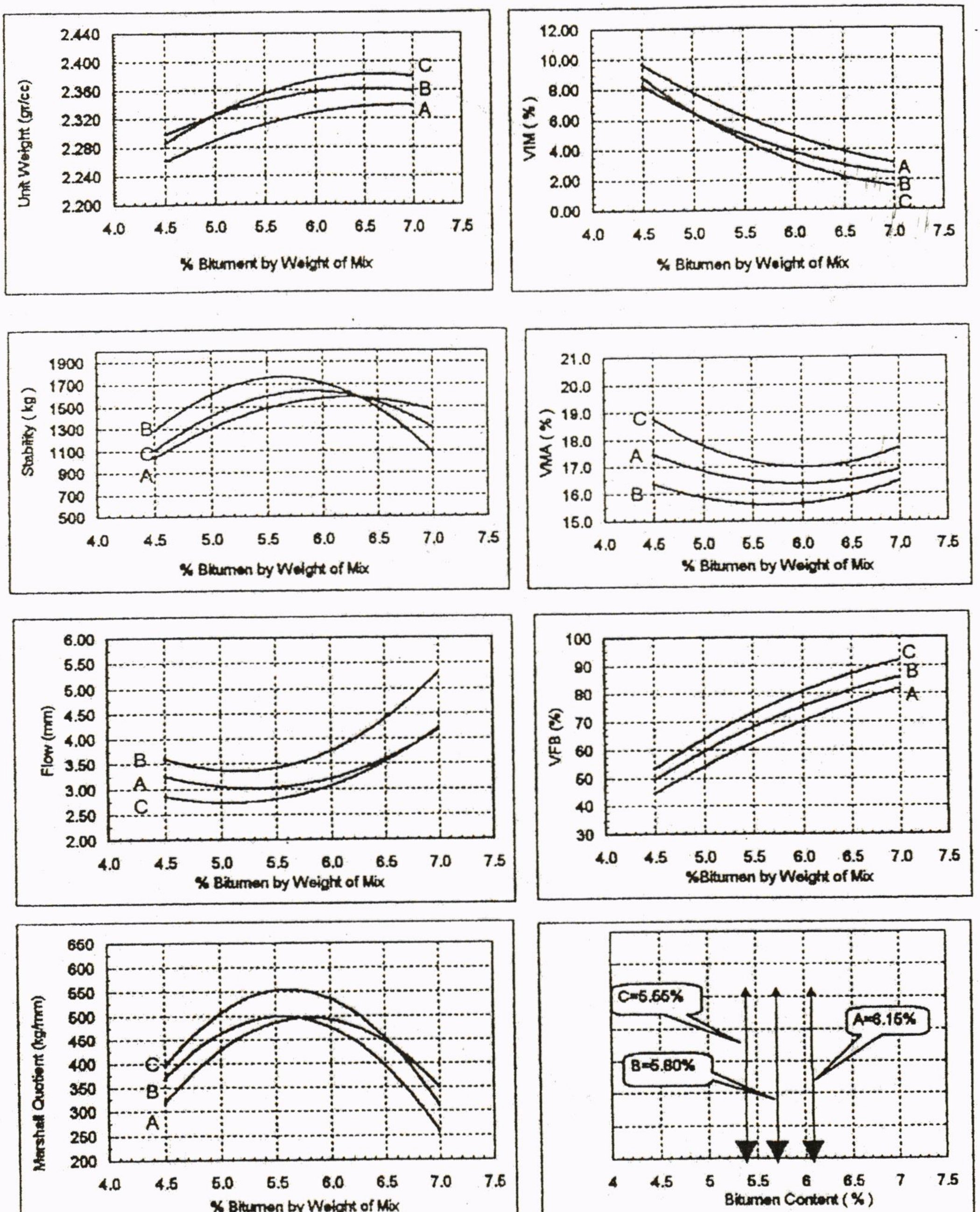
The Marshall test procedure and analysis were used to find the ranges in bitumen contents for the three types of mixture that satisfy Bina Marga mix design criteria for heavy traffic. Three specimens of each mixture were prepared at bitument content ranging from 4.5% to 7.0% in 0.5% increments. The results are compared in Figure 3 where the optimum bitumen content determined for each mixture is indicated.

3.5. Laboratory Performance Tests

Laboratory performance tests are normally conducted on bituminous mixture at optimum bitumen content and under conditions which are representative of field conditions.

a. Susceptibility to Water Damage
   Susceptibility to water damage normally involves measurement of a change in a mechanical property of a compacted bituminous mixture after immersion for a prescribed period in water at a specified temperature. The ratio of Marshall stability after and before immersion, expressed as a percentage, is known as the Marshall Index of Retained Strength (IRS) and this parameter was used in the investigation as the indicator of mix durability. Six specimens of each mixture were prepared at optimum bitumen content; three specimens were tested under standard Marshall conditions and the remaining three specimens following immersion for 24 hours at 60°C.

b. Susceptibility to Permanent Deformation
   Resistance to permanent deformation is frequently evaluated in the Wheel tracking Test. The test was carried out at 30°C, 45°C and 60°C, the wheel applying a load of 525 N to the surface of the specimen. The performance of the material was assessed by measuring the rut depth after a given number of passes or period of time, the rate at which deformation accumulates and the number of passes per millimetre of



A=Crushed Coarse and Natural Fine Cipunagara
B=Crushed Coarse and Fine Cipunagara
C=Crushed Coarse and Fine Banjaran

Figure 3 Comparison Between the Three Mixtures

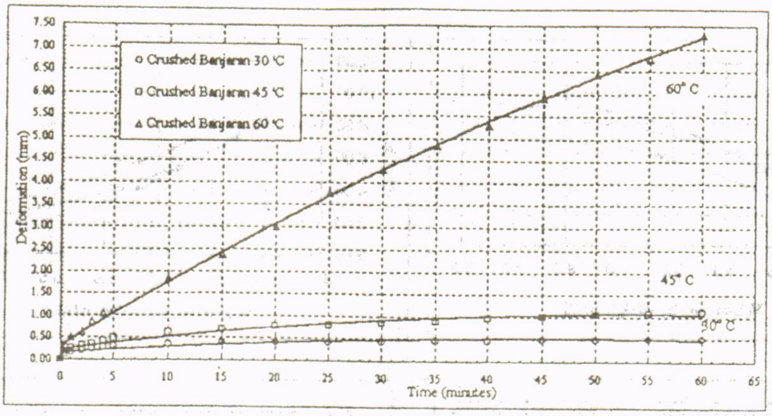


Figure 4 Wheel Tracking Test Results for Crushed Coarse and Fine Banjaran Aggregate at 30°C, 45°C, 60°C

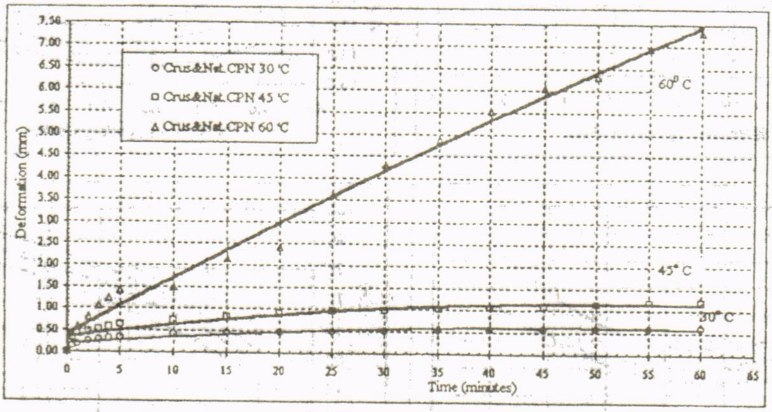


Figure 5 Wheel Tracking Test Results for Crushed Coarse and Natural Fine Cipunagara Aggregate at 30°C, 45°C, 60°C

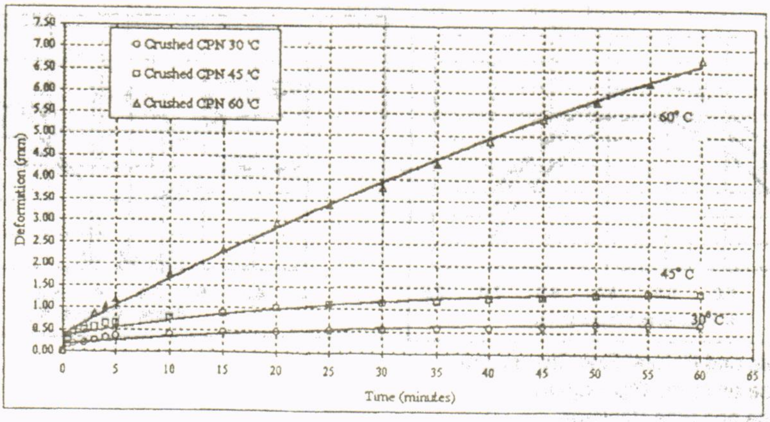


Figure 6 Wheel Tracking Test Results for Crushed Coarse and Fine Cipunagara Aggregate at 30°C, 45°C, 60°C

Table 5 Summary of Mix Characteristics at Optimum Bitumen Content

Properties at Optimum Bit. Cont.	MIX I	MIX II	MIX III
Optimum Bitumen Content (%)	5.55	5.80	6.15
Effective Bitumen Content (%)	5.319	4.971	5.237
Bitumen Film Thickness (micron)	8.266	7.746	8.191
MARSHALL TEST			
Density (gr/cc)	2.355	2.353	2.330
Stability (kg)	1600	1775	1580
F l o w (mm)	2.80	3.60	3.25
Stability/Flow (kg/mm)	550	490	480
Voids in Mixtures (%)	4.50	4.20	4.60
Voids in Mineral Aggregate (%)	17	16	16
Voids Filled with Bitumen (%)	73	72	72
IMMERSION TEST			
Immersion Index (%)	94.29	89.08	77.28
INDIRECT TENSILE TEST			
Indirect Tensile Strength (psi) at 35^0C	62.06	54.04	46.83
Indirect Tensile Strength (psi) at 45^0C	48.47	44.15	41.25
UMATTA TEST			
Resilient Modulus (Mpa) at 35^0C	1570.50	1272.50	1450.50
Resilient Modulus (Mpa) at 45^0C	788.75	750.45	762.65
WHEEL TRACKING TEST			
PD (mm) at 30^0C	0.51	0.70	0.61
PD (mm) at 45^0C	1.12	1.41	1.21
PD (mm) at 60^0C	7.31	6.76	7.32
RD (mm/min) at 30^0C	0.001	0.004	0.002
RD (mm/min) at 45^0C	0.007	0.009	0.008
RD (mm/min) at 60^0C	0.093	0.091	0.084
DS (passes/mm) at 30^0C	33000	11000	22000
DS (passes/mm) at 45^0C	6000	5077	5500
DS (passes/mm) at 60^0C	471	482	524

PD:Permanent Deformation
RD:Rate of Deformation
DS:Dynamic Stability

MIX I:Crushed Coarse and Fine Banjaran
MIX II:Crushed Coarse and Fine Cipunagara
MIX III:Crushed Coarse and Natural Fine Cipunagar

deformation. The results of the wheel tracking test show consistently increases with increasing temperature. At 30°C and 45°C, permanent deformation is relatively low and there is a tendency for the curve to level off (Figure 4, 5 and 6). At 60°C, there is a significant increase in the permanent deformation which accumulates consistently with the number of passes of the loading wheel.

At 30°C and 45°C, permanent deformation of Mix-I is greatest, but is lowest at 60°C. Mixture-II has the highest rate of deformation at 30°C and 45°C; at 60°C, it is lower than Mix-I (crushed coarse and fine aggregate from Banjaran) but highest than Mix-III (crushed coarse and natural fine from Cipunegara). This indicates that the performance of Mix-II (crushed coarse and fine aggregate from Cipunegara) is susceptible to deformation at low temperature and ore resistant deformation at high temperature. In addition, at 30°C and 45°C, and in terms of dynamic stability, Mix-II shows the least number of passes per millimeter; at 60°C the dynamic stability of Mixture II is lower than that of Mixture -III but greater than that of Mix-I. As indicated above, the three parameters evaluated in wheel tracking test show a consistent trend for the three mixtures at 30°C and 45°C but not for the 60°C temperature condition.

c. Static Loading Indirect Tensile Strength Test
The Indirect Tensile Test was conducted on Marshall size specimens by applying a load along the vertical diametrical plane, thereby generating indirect horizontal tensile stresses. The indirect tensile strength test was carried out on specimens at two temperature of 35°C and 45°C. The test showed ITS values of 62.06 psi, 54.04 psi and 46.83 psi for Mix-I, Mix-II and Mix-III at 35°C; and at 45°C, the ITS values were 48.47 psi, 44.15 psi and 41.25 psi respectively. The ITS value decreses with incresing temperature and the ITS of Mix-I is more susceptible to temperature change than the mixture made with Cipunegara aggregate.

d. Repeated Load Indirect Tensile Test
The Repeated Load Indirect Tensile Test was conducted using the Universal Material Testing Apparatus (UMATTA). The test was used to measure the indirect tensile resilient modulus at temperatures of 35°C and 45°C, at loads of 500 Newton and 1000 Newton respectively and the poisson's ratio was assumed to be 0.35. The results of the test gave values of 1570.50 Mpa, 1272.50 Mpa and 1450.50 Mpa for Mixture I, II and III at 35°C; and at 45°C, resilient modulus values of 788.75 Mpa, 750.45 Mpa and 762.65 Mpa were obtained for Mix-I, II and III. The trend is for resilient modulus values to decrease with incresing temperature.

The summary of mixture characteristics at their Optimum Bitumen Content are summarised in Table 5.

4. CONCLUSIONS

Based on the results of this investigation and data analysis, the following conclusions are drawn :

a. The Cipunegara river aggregate investigated satisfies specified and suggested requirements for strength, toughness and hardness.. The Cipunegara river aggregate is weaker than the aggregate from Banjaran. The water absorption of crushed coarse banjaran aggregate is higher than that of crushed coarse Cipunegara aggregate but is lower for the crushed fine aggregate but is lower for the crushed fine aggregate; the water absorption of natural fine Cipunegara aggregate is significaantly higher than that of crushed Cipunegara and Banjaran fine aggregate.

b. Analysis of mix design by the Marshall method shows that Mix-I (crushed and fine banjaran aggregate), Mix-II (crushed coarse and fine Cipunegara aggregate) and Mix-III (crushed coarse and natural fine aggregate) have optimum bitumen content of 5.55%, 5.80% and 6.15%, respectively. Mix-III has a highest OBC and the high absorption of the Cipunegara natural fine aggregate is the most likely explanation for the high bitumen demand of mixture made with this aggregate.

c. All of the mixtures satisfy the Bina Marga criterion for resistance to water damage as indicated by Index of Retained Stability (IRS) not less than 75%. Mix-I, II and III have retained stability values, respectively, of 94.3%, 89.1% and 77.3%. Mix-I has the highest IRS while that of Mix-III is close to the minimum acceptable. This may be due to relatively poor adhesion between the bitumen and the natural fine aggregate particles which are likely to have a relatively smooth surface texture.

d. The results of the indirect tensile test at different temperatures shows that Mix-I has consistently the highest values. The indirect tensile strength of Mix-III is consistently lower than that of Mix-II. The effective bitumen content of Mix-II is less than that of Mix-III. The lower tensile strength of Mix-III may again be due to poorer adhesion between the bitumen and the natural fine aggregate particles and reduced interlock of the fine aggregate particles may also be a factor.

e. In the wheel tracking test at 30°C and 45°C, the permanent deformation observed for all three mixtures is relatively low and there is a tendency for the curves to level off. However, at 60°C, there is a significant increase in permanent deformation which accumulates almost linearly with the number of passes of the loading wheel. Mix-II shows the highest permanent deformation and rate of deformation and rate of deformation at 30°C and 45°C but not at 60°C. The dynamic stability of Mix-I is higher than that of the other mixtures at 30°C and 45°C but is lowest at 60°C. As indicated above, this test shows a consistent trend for the three mixtures at 30°C and 45°C but not at 60°C. At none of the temperatures investigated is there a significant difference in the performance of the three mixtures.

f. The resilient modulus values of the mixtures made with Banjaran aggregate are higher than those of the other mixtures at 30°C and 45°C. For mixtures made with Cipunegara river aggregate, the resilient modulus values of the mixture containing natural fine aggregate (Mix-III) are higher than those of the mixture containing crushed fine aggregate (Mix-II).

g. Based on the results of this laboratory investigation, the three mixtures comply with the Bina Marga specification and can be used for asphalt concrete binder course. Considering the Cipunegara river aggregate only, the mixture containing crushed coarse and fine aggregate (Mix-II) is generally superior to the mixture containing crushed coarse and natural fine aggregate (Mix-III) with the exception of the resilient modulus data.

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