Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1302 - 1312, 2005

WORKABILITY AND RESILIENT MODULUS OF ASPHALT CONCRETE MIXTURES CONTAINING FLAKY AGGREGATES SHAPE

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Abstract : Flaky aggregates is normally avoided in bituminous mixtures, they influence the aggregate gradation, reduce interlocking characteristics, and it should be therefore limited. Indonesian National Standards (SNI) specified a tolerance of flaky aggregate content for a maximum of 25% in Asphalt Concrete mixture for surface course. Gradation was modified into 5 variations of flaky aggregate content, i.e. 5%, 15%, 25%, 35% and 45%. The Marshall test were done with 5 variations of asphalt content such as 5.0%, 5.5%, 6.0%, 6.5% and 7.0%, respectively. Each variation of flaky aggregate content resulted on different optimum asphalt content of 5.85%, 5.90%, 6.0%, 6.05% and 6.15%. Workability Index (WI) measured using gyropac (350 gyrations) at their optimum asphalt content show that the WI decreases with decreasing the flaky aggregate content. The results of Modulus measurement using UMATTA at their optimum asphalt content show that the modulus values decrease when the flaky aggregate content increase.

Key Words : Flaky Aggregates, Workability Index; Asphalt Concrete; Gyropac; Resilient Modulus

1. INTRODUCTION

Road as one of land transportation infrastructure is very important in supporting the economic for both regional and national development. The quality of material for road construction will also influence the road performance. Asphalt concrete as one of road surface material is mainly influenced by the quality of aggregates since aggregate occupies 95% by weight in total mixture. Various shapes of aggregates might be occurred during crushing in the crushing plant starting from rounded to flaky and elongated aggregates (Figure 1). Some tests on aggregates have to be done prior its use in asphalt mixture such as gradation, toughness, durability, shapes, surface texture, specific gravity, micro texture, etc. The engineering properties of aggregates, including aggregate shape are therefore very important in having satisfied performance of asphalt concrete mixture including the workability index and stiffness modulus. One of the aggregate properties is called as ‘flaky’, measured as a Flakiness Index (FI) and it is suspected to influence the performance of asphalt concrete mixture. Marshall analysis indicate that optimum asphalt content slightly decreases when the flaky aggregate content increases (Bachtiar, 2000). This paper therefore reports the investigation of the influence of flaky aggregate content in the asphalt mixture and relates it to some properties of asphalt mixture such as :

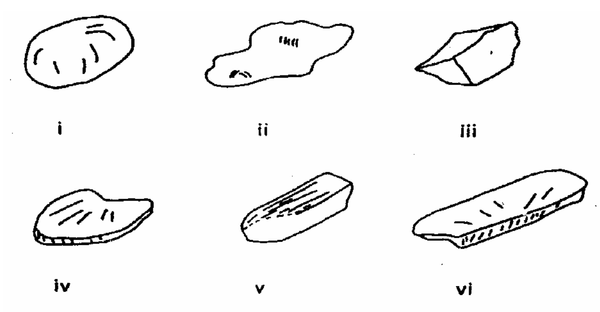
a. optimum asphalt content,
b. workability index and
c. resilient modulus

2. FLAKY AND ELONGATED AGGREGATES

One test related to the shape of aggregates prior to its use in asphalt concrete mixture is a flakiness test measured as flakiness index (FI), normally accompanied by the elongation test measured as elongation index (EI). In this investigation, flakiness index was used as independent variables and other properties such as gradation are kept constant as far as their properties met the specification required for the asphalt mixture. The influence of flaky aggregate content variations were then investigated against the workability index which is simulated to the ease of handling and compacting of the material mixture in the field of construction and their modulus as a value indicated the response of asphalt mixture to traffic loading.

Aggregates from natural stone can have a various shape after crushing in the stone crusher. British Standard Institution (BSI-812, 1975) classifies aggregates into 6 classes that are rounded, irregular, angular, flaky, elongated and flaky and elongated. The rounded, irregular and angular for special purposes are grouped into one category as equidimensional or cuboidal. Meanwhile, the aggregate are flaky, elongated, flaky and elongated or equal dimension are determined by the ratio of the shortest, the longest and the average diameter of the particle. As an illustration, suppose the aggregate shape is a cubical beam, the shortest diameter is its thickness, the longest diameter is its length and the width as an average diameter.

British Standard Institution (BSI-812, 1975) stated that aggregate with a ratio of average diameter and the longest diameter is less than 0.55, said as elongated aggregate; meanwhile, when the ratio of the shortest diameter and the average diameter is less than 0.60, the aggregate is therefore grouped into flaky. In general, the aggregate shape and its division are shown in the following Figure 1:



i.*Rounded*; ii. *Irregular*; iii. *Angular*; iv. *Flaky*; v. *Elongated*; vi. *Flaky & Elongated*

Source : BSI 812 : 1975

Figure 1. Aggregate Shapes

3. MIXTURE DESIGN

Mixture design includes the determination of proportion on the component of material in the mixture in order to meet the specification required as shown in the Table 1. The aggregates used were collected from near Bandung area and the asphalt used was penetration grade of 60/70 obtained from national oil company of Indonesia (Pertamina). Aggregates with special shape (flaky shape) from the same source of stone crusher plant as other aggregates were intently collected and sufficiently accumulated to replace the normal shape of aggregate in the mixture. The aggregates with flaky shape used were in the content of 5%, 15%, 25%, 35% and 45% consisting of 33.33% portion of aggregate passing on sieve size of ¾" and retained on sieve size of ½" and 66.66% portion of aggregate passing on sieve size of ½" and retained on sieve size of 3/8".

Table 1. Aggregate Gradation for the Asphalt Mixture

Gradation Type V (SNI)		
Sieve Sizes		% - Passing
1"	25.4 mm	100
¾"	19.1 mm	80 – 100
½"	12.7 mm	-
3/8"	9.52 mm	60 – 80
No. 4	4.76 mm	48 – 65
No. 8	2.38 mm	35 – 50
No. 30	0.59 mm	19 – 30
No. 50	0.279 mm	13 – 23
No. 100	0.149 mm	7 – 15
No. 200	0.074 mm	1 - 8

Hot mix asphalt concrete is a mix of aggregates and asphalt in hot condition. The gradation used was gradation type V according to the Standard National Indonesia (SNI) and various asphalt content in percentage of total mixture were applied for the mixtures (Table 1). Marshall design and criteria was used to assess the Marshall properties of the asphalt mixture and finally obtain the optimum asphalt content for each asphalt mixture (Table 2).

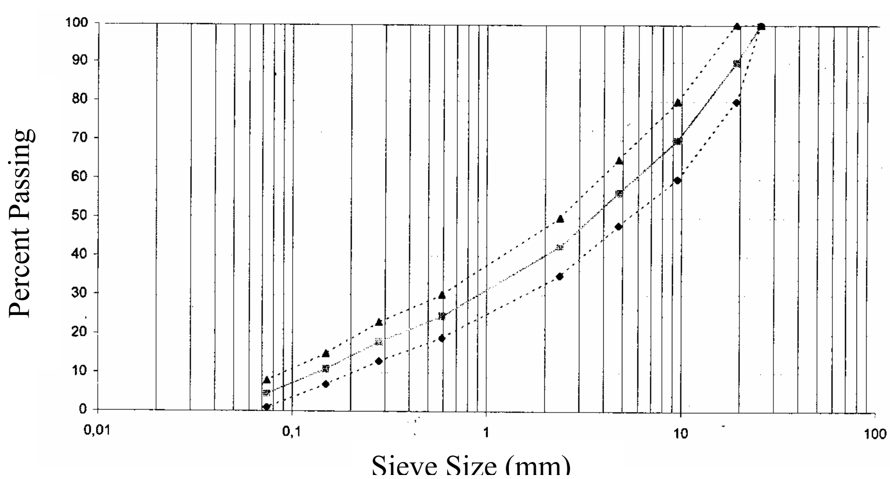


Figure 2. The Gradation of Type-V from SNI

Parameters such as stability, flow, VMA, VIM are calculated for any asphalt content used in the asphalt mixture; meanwhile some data were obtained during compaction process of the specimens for the calculation of the workability index. The compaction used was gyropac which was able to monitor the height changes during compaction process. Bachtiar (2000) in his research stated that optimum asphalt content increases with increasing flaky aggregate content. The influence of flaky aggregate content was also marked in wheel tracking test inline with increasing flaky aggregate content.

Table 2. Mix Design Criteria

No	Marshall Parameters	Compaction (2 x 75) blows	
		minimum	maximum
1	Stability (kg)	550	-
2	Flow (mm)	2	4
3	Stability/Flow (kg/mm)	200	350
4	Retained Stability (%)	75	-
5	Voids in Mix (%)	3	5
6	Voids in Mineral Aggregates (%)	See Table 3	

Source : SNI-1737-1989-F

Table 3. Voids in Mineral Aggregates (VMA)

Nominal Aggregate Size (mm)	Minimum VMA value (%)
1.18	23.5
2.36	21.0
4.75	18.0
9.50	16.0
12.50	15.0
19.00	14.0
25.00	13.0
37.50	12.0
50.00	11.5
63.00	11.0

Source : SNI-1737-1989-F

4. TESTS ON ASPHALT MIXTURES AND RESULTS

4.1. Marshall Test

Marshall design was used to make an assessment on some Marshall parameters and analyze the optimum asphalt content for each type of mixture. Five types flaky aggregate content namely 5%, 15%, 25%, 35% and 45% were used to modify and adjust the content of aggregate shape in the mixture gradation, meanwhile the gradation itself was still expected to follow gradation type-V of the SNI. The properties of Marshall were then calculated and using the Marshall standard design criteria, five values of optimum asphalt content were then obtained for each mixture containing percentage of flaky aggregate as seen in Table 4. Five Marshall parameters were used to obtained the optimum asphalt content and the optimum asphalt content values would be used later on for the making of specimens for other test purposes. The optimum of asphalt content can be seen in Table 4 as follow.

Table 4. Optimum Asphalt Content Values

Mix Type	Flaky Aggregate Content	Stability (kg)	Flow (mm)	MQ (kg/mm)	VMA (%)	VIM (%)	Optimum Asphalt Content
A	5%	1540	2.85	535	15.15	3.80	5.85
B	15%	1510	3.05	520	15.70	3.85	5.90
C	25%	1400	3.10	450	15.90	4.00	6.00
D	35%	1380	3.20	430	16.30	4.10	6.05
E	45%	1250	3.30	370	15.30	4.30	6.15

4.2. Marshall Immersion Tests

The Marshall Immersion test was done to evaluate the resistance of mixtures against water. Specimens were made at their optimum asphalt content and immersed in the water bath for 24 hours at 60^{o}C and some other specimens were immersed in the water bath for 30 minutes at 60^{o}C too. The Index of Retained Strength (IRS) was then calculated using equation :

$$IRS = \frac{S_1}{S_0} x100\% \quad \ldots\ldots \ldots\ldots \ldots\ldots \ldots\ldots \ldots\ldots \ldots\ldots \ldots\ldots \ldots\ldots \quad (1)$$

where :

S_1 = Marshall Stability for specimens immersed in water bath for 24 hours
S_0 = Marshall Stability for specimens immersed in water bath for 30 minutes

The results of Index of Retained Strength at their optimum asphalt content were shown in Table 5.

Table 5. The Values of Index of Retained Strength

Mix Type	Flaky Aggregate Content	Stability (kg) (60^{o}C, 30 min.)	Stability (kg) (60^{o}C, 24 hrs)	IRS (%)
A	5%	1544	1416	91.70
B	15%	1495	1290	86.30
C	25%	1418	1181	83.30
D	35%	1362	1094	80.30
E	45%	1177	938	79.70

All values of IRS satisfy the minimum requirements of 75% with a note that the values decrease with increasing of flaky aggregate content. It is indeed that the flaky aggregates content in the asphalt mixture influence the stability after immersion inline with the increasing values of VMA and VIM.

4.3. Workability

Workability is a term to simulate that level of ease for pavement material construction in the field. In the laboratory, workability is measured during compaction by monitoring the height changes of specimens being compacted at compaction temperature of around 125^{o}C – 135^{o}C. Gyropac similar to Gyratory Testing Machine (GTM) produced by Industrial Process

Controls Ltd (1977), is one of the apparatus that can be used for the purpose of workability measurement. A combination of static and dynamic loads are applied together by which the static load is applied axially and the dynamic load is horizontally as a kneading action to the specimens by setting the angle of gyration. In this investigation, specimens at their optimum bitumen content were studied and the process of compaction used the former investigation done by Alkas (2000). The axial pressure = 240 kPa, gyration angle = 20, speed of gyration = 60 rpm and design gyration N_{design} = 120 gyratory revolutions. This kind of compaction is expected to simulate the compaction in the field in comparison with the impact compactor like Marshall compaction. Height changes and the amount of its revolutions can be automatically recorded. Cabrera and Dixon (1994) proposed that the calculation of workability in term of Workability Index (WI) is the inverse of mixture's porosity value on revolutions equal zero. He also stated that from the experience in the field that mixtures having workability index less than 6, indicated difficulties during compaction in the field.

Workability Calculation Process

a. Volume of specimens for every gyrations
   The volumes of specimens for 0, 25, 50, 75, 100, 125 and 150, 175, 200, 225, 250, 275, 00, 325 and 350 gyrations are calculated using the formula of :

$$Vi = (0.25 \times \pi \times d^2) \times hi \quad \ldots\ldots (2)$$

where :

Vi = specimens volume at the- i - gyrations (cm^3)
hi = specimens height at the - i - gyrations (cm)
d = specimens diameter size (cm)

b. Density and porosity for every gyrations

$$Di = Wa / Vi \quad \ldots\ldots (3)$$
$$Pi = 100 (1 - Di/SG) \quad \ldots\ldots (4)$$

where :

Di = Density at the -i- gyrations
Wa= Specimens weight
Pi = Porosity at the -i- gyrations
SG = Specific Gravity of specimens

c. Plotting the Porosity values against the gyrations
   The results of porosities were then plotted against the revolutions in the form of :

$$Pi = A - B \log i \quad \ldots\ldots (5)$$

where :

A = the intercept of the line and y - axis
B = the angle between the line x - axis
i = the amount of gyrations

d. Workability Index (WI) is determined by

$$WI = 100/A \quad \ldots\ldots (6)$$

where :

WI = Workability Index
A = the intercept of the line and y – axis

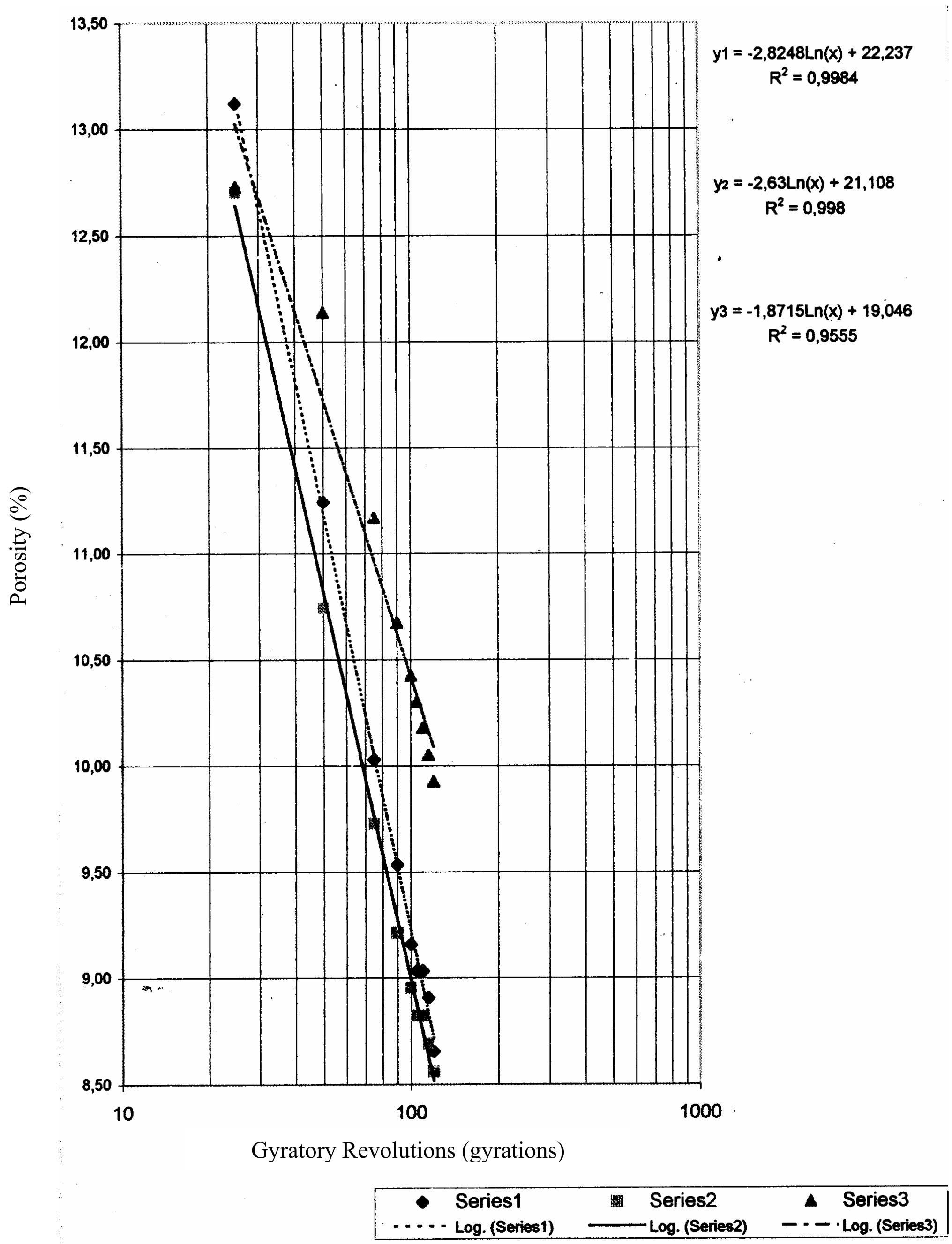


Figure 3. Porosity and Gyratory Revolutions
(KAO = 5.85% and Flaky Aggregate Content of 5%)

4.4. Resilient Modulus Test

Resilient Modulus is an important parameter to determine the performance of pavement, to analysis the pavement response to traffic loading. The test was done by measuring the indirect tensile strength in repeated loading using Universal Material Testing Apparatus (UMATTA).

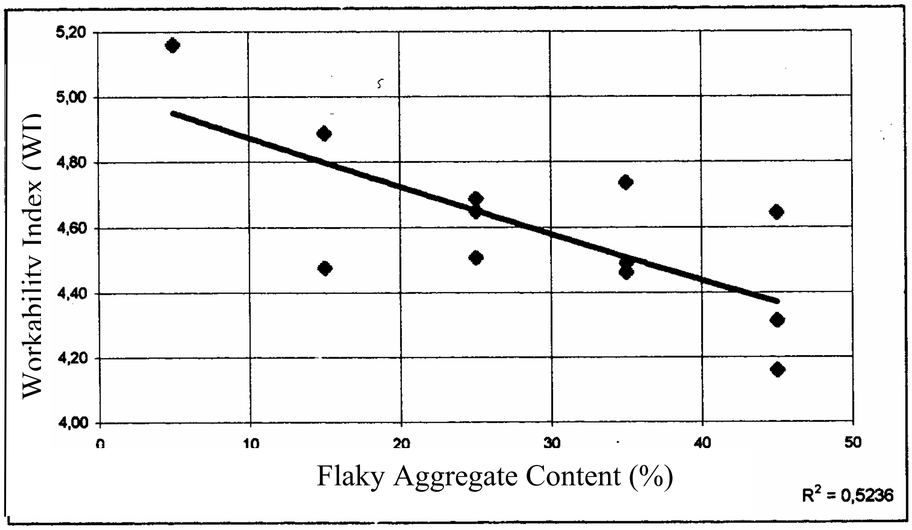


Figure 4. The Relationship between Workability Index and Flaky Aggregate Content (350 gyratory revolutions)

Specimens at their optimum bitumen content were made and loaded by diametrical force in pulse loading. This apparatus consists of Control and Data Acquisition System (CDAS), personal computer and related integrated software. The test follows the ASTM Designation D 4123-82. Data inputted were condition pulse count = 5, condition pulse period = 3000 ms, test pulse period = 2000 ms, rise time = 50 ms, peak loading force = 1000 N and estimated poisons ratio = 0.35 (Ginting, 2001).

Some parameters were obtained directly by the automatic computer calculation, e.g. resilient modulus, rise time peak, time of loading, tensile stress, peak force and total recoverable strain. The temperature of test was selected as room temperature of 25^{o}C.

The formula of resilient modulus were calculated by :

$$E = Fx\frac{(\mu + 0.27)}{(LxH)} \quad \text{..... ....} \quad (7)$$

where :

E = resilient modulus (MPa)
F = maximum applied load (N)
μ = poisson's ratio
L = length of specimen
H = total horizontal deformation (mm)

The values of Resilient Modulus of the mixture at their optimum asphalt content in relation with their Workability Index (WI) are shown in Table 6.

Table 6. The Values of Workability Index and Resilient Modulus

Mix Type	Flaky Aggregate Content	Optimum Asphalt Content (%)	Workability Index (WI)	Modulus of Resilient (MPa)
A	5%	5.85	5.06	4750.67
B	15%	5.90	4.69	4619.33
C	25%	6.00	4.61	4332.33
D	35%	6.05	4.57	4104.33
E	45%	6.15	4.37	3853.00

The values of Resilient Modulus and Workability Index (WI) decrease with increasing the flaky aggregate content and this might caused by the lowering stability due to high values of Voids in Mineral Aggregates (VMA) and Voids In Mixtures (VIM) (Figure 5).

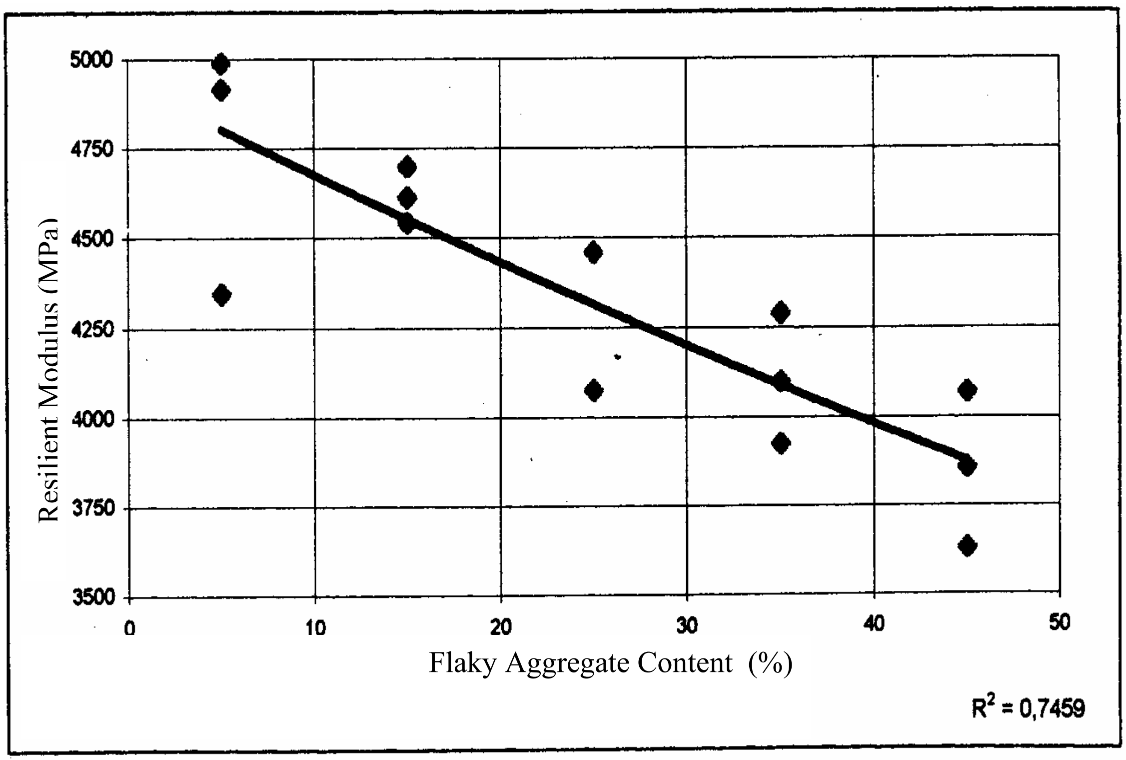


Figure 5. The Relationship between Resilient Modulus and Flaky Aggregate Content

The values differences for every addition of 10% flaky aggregate content for optimum bitumen content are varied from 0.855% up to 1.695%, for Workability Index are varied from 0.868% up to 7.312% and for Resilient Modulus are varied from 2.765% up to 6.213%. In total, the differences between mixture properties containing 5% and 45% flaky aggregates are 5.036% for Optimum Bitumen Content, 14.262% for Workability Index and 20.365% for Resilient Modulus values respectively (Table 7). Depending on the difference limitation applied and with the assumption that the differences allowed is only 10% from the starting mixture containing 5% of flaky aggregate, the maximum allowable flaky aggregate content in the mixtures would be then limited to only 25%, and this value of 25% is so far used as the maximum allowable flaky aggregate content in the bituminous mixtures.

Table 7. The Differences of Optimum Asphalt Content, Workability Index and Resilient Modulus for Every Flaky Aggregate Content

Mix Type	Flaky Aggregate Content (%)		Optimum Asphalt Content (%)	Workability Index (WI)	Modulus of Resilient (MPa)
		DIFFERENCES			
A	5%				
		+ 10	+ 0.05 (+0.855%)	- 0.37 (-7.312%)	- 131.34 (-2.765%)
B	15%				
		+ 10	+ 0.10 (+1.695%)	- 0.08 (-1.706%)	- 287.00 (-6.213%)
C	25%				
		+ 10	+ 0.05 (+0.833%)	- 0.04 (-0.868%)	- 228.00 (-5.263%)
D	35%				
		+ 10	+ 0.10 (+1.653%)	- 0.20 (-4.376%)	- 251.33 (-6.124%)
E	45%				
Total differences			(+5 .036%)	(-14.262%)	(-20.365%)

5. CONCLUSSIONS

a. The flaky aggregate content influence the Marshall properties of asphalt mixture including the optimum asphalt content. The stability decrease, the flow increase, the VMA increase, the VIM increase and the asphalt content increase with increasing the flaky aggregate content.
b. The values of Workability Index are influenced by the flaky aggregate content, the values of workability decrease with increasing the flaky aggregate content.
c. The values of resilient modulus are also influenced by the flaky aggregate content, the values of resilient modulus decrease with increasing the flaky aggregate content.
d. In general, flaky aggregate does influence the properties of asphalt mixture and its use should therefore be limited to avoid the unexpected mixture properties that might be occurred during construction.

REFERENCES

Alkas, M.J. (2000) Pengukuran Kinerja Campuran Hot Rolled Asphalt Menggunakan Alat Pemadat Gyropac, Proceeding on the 3rd Symposium of FSTPT, University of Gadjah Mada, Yogyakarta.

Bachtiar, Z. (2000) Kajian Batasan Jumlah Agregat Pipih untuk Campuran Beton Aspal, Thesis, Magister Program on Highway and Development, Bandung Institute of Technology (unpublished).

British Standard Institution, BS:812 (1975) Method for Sampling and Testing of Mineral Aggregate, Sand and Filler, London, UK

Cabrera, J.G. and Dixon, J.R. (1994) Performance and Durability of Bituminous Material, Proceeding of Symposium, University of Leeds, March 1994.

Ginting, K. (2001) Pengaruh Kadar Agregat Pipih dalam Workabilitas dan Modulus Campuran Beton Aspal, Thesis, Program on Highway and Development, Bandung Institute of Technology (unpublished).

Industrial Process Controls Ltd. (1997) Servopac (Servo-Controlled Gyratory Compactor), Asphalt Compaction Machine, Reference Manual, Boronia, Australia

Standar Nasional Indonesia, SNI-1737-1989-F (1989), Perencanaan Campuran Laston