The Effect of Aggregate Gradation on Workability of Asphalt Concrete

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***Abstract*— Aggregate gradation is one important part of the performance of asphalt mixture. Workability is one of the important parameters in asphalt mixture design that can easily be done in the field. Marshall compactor type is the most widely used in Indonesia even in the world. Therefore it is necessary to measure the workability using a type of Marshall compactor. The purposes of this study were: (1) measures the workability of asphalt concrete on five aggregate gradation targets that would be obtained the relationship between gradation index (GI) and workability index (WI), and (2) develop workability measurement asphalt mixture with Marshall compactor. The result showed that Marshall compactor can be used to measure workability of asphalt mixture and the relationship between aggregate gradation or gradation index and workability index is very strong. The model is WI = 0.005 (GI^2)-0.2374 (GI) + 5.9197 with R^2 = 0.9721.**

Keyword- Aggregate gradation, Gradation Index, Workability, Asphalt Concrete

I. Introduction

Aggregate gradation is one important part of the performance of asphalt mixture. Aggregate gradation effect in almost all important characteristics of the asphalt mixture, namely: stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance, and resistance to moisture damage [1], [2].

Workability is one of the important parameters in asphalt mixture design that can easily be done in practice, not just a mixture must be strong and durable. The parameters workability with Workability Index (WI) at 8 types of mixtures Hot Rolled Asphalt (HRA) using a gyratory compactor [3]. The results showed that the mixture with a mixing temperature of 150 °C has the best workability (WI> 6) than on mixing temperature of 120 °C and 75 °C reduction in temperature caused by the transport process, placed and compacting. Reduction temperatures below 120 ° C will result in a mix of hard compacted so that it will have a low density, high air voids, and high permeability.

The workability on a type of mixture of Asphalt Treated Base (ATB), Asphalt Concrete (AC), Hot Rolled Sheet (HRS) using Marshall compactor was evaluated [4]. Asphalt concrete aggregate grading is set at five types of gradation are gradation lower limit, between the lower and the middle, the middle limit, between the middle and the upper limit, and the upper limit. However, workability is measured only at middle limit optimum bitumen content, so it has not demonstrated the workability of the mixture for another aggregate gradation. How the test requires a relatively large specimen. Asphalt mixture is measured workability requires 6 specimens. If the duplo specimen, it takes 12 specimens only to find the one value of workability. Use of the different specimen of the mixture will be very prone to drift results because the position of the aggregate in the mix will be different with another specimen, the temperature will change, and the mixing process is done manually. The results showed the value of the workability of the asphalt concrete for five types of gradation does not have a significant influence. WI values of asphalt concrete are between 2.389 up to 2.396 [4].

Workability of a large stone aggregate gradation, the maximum aggregate size is 37.5 mm was examined [5]. Three types of compactor, namely compactor press play or gyropac, kango hammer vibration compactor, and compactor with impact techniques of free fall (Marshall compactor). Workability is influenced by the level of asphalt and aggregate gradation. Asphalt content, the greater the content of asphalt gives a tendency easier for compacted or treated. Fuller aggregate gradation approach provides better workability. Further [5] make the relationship between the height of the test specimen with the number of gyropac revolutions. Line relationship with the position nearly parallel to the horizontal axis (not forming an angle), then the mixture would be difficult to do, and vice versa.

Workability of the asphalt concrete was examined with providing aggregate flakiness percentage change in the composition of the asphalt mixture [6]. The tool used is gyratory compactor that can record height changes on the test specimen automatically. Workability index calculation formula refers to [3].

Marshall compactor is the most widely used in Indonesia for asphalt mixture design. Therefore it is necessary to measure the workability using a type of Marshall compactor. The purposes of this study were (1) measures the workability of the mixture at five targets aggregate gradation of asphalt concrete that would be obtained the relationship between gradation index (GI) and workability index (WI), and (2) develop workability measurement asphalt mixture with Marshall compactor. Compaction of the specimen using automatic Marshall compactor with a speed of 62 blows per minute. Marshall automatic compactor comes from Engineering Laboratory Equipment (ELE) Limited, Hemel Hempstead, Hertfordshire, England, lab-owned Highway and Transportation Gadjah Mada University in Yogyakarta.

II. EXPERIMENTAL DESIGN

A. Material Selection

Unmodified asphalt cement (AC) 60/70 ex. Pertamina is used as a binder. Asphalt AC 60/70 is recommended by the Indonesian Directorate General of Highways [7] according to the tropical climate in Indonesia. Asphalt test results meet 2010 Indonesian Highway Specification 3rd Revision.

Aggregate derived from the Tinalah River, Kulon Progo, Yogyakarta is one of the quarries to the construction of roads and buildings in Yogyakarta and surrounding areas. Aggregate test results and target aggregate gradation meet 2010 Indonesian Highway Specification 3rd Revision [7]. Five types of aggregate gradation have been selected. Five aggregate gradations are (1) upper limit (UL); (2) The middle of the lower limit and the mid-range (UM); (3) mid-range (MR); (4) middle of mid-range and upper limit (ML); and (5) lower limit (LL) as can be seen in Fig. 1.

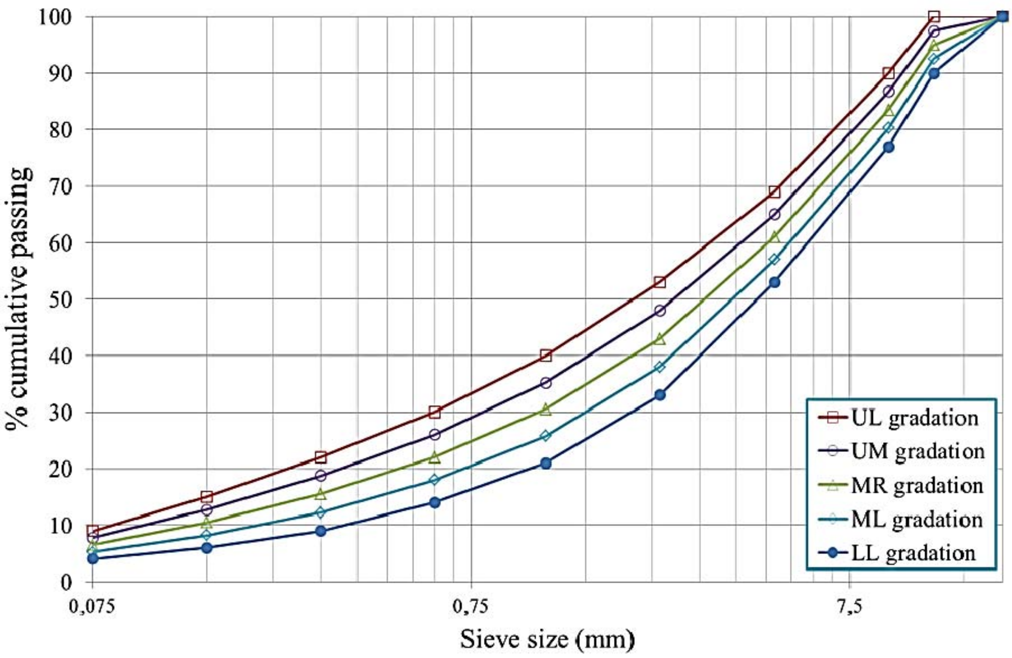


Fig. 1. Types of aggregate gradation

B. Mix Design

Marshall method used to design mix and determine the optimum bitumen content of each type of gradation. Criteria for selection of the optimum bitumen content (OBC) based on stability, flow, voids in the mix (VITM), voids filled with asphalt (VFWA), and voids in mineral aggregate (VMA) based on the specifications of the Directorate General of Highways [7]. Fifteen specimens prepared for each gradation with asphalt content variation of 4.5% to 6.5% of the mix, interval 0.5% to UM, MR, and ML gradation; UL gradation using bitumen content variation 5% to 7% at intervals of 0.5%; and gradation LL variation asphalt content of 6% to 8% with intervals of 0.5%. Mixing and compaction temperatures measured on the viscosity of 0.2 Pa.s and 0.4 Pa.s, respectively. The test results show the viscosity of the mixing temperature 157 °C and the compaction temperature of 143 °C. Optimum bitumen content for the aggregate gradation UL, UM, MR, ML, and LL are 5.97%; 5.84%; 5.56%; 5.65%; and 7.09% of the mix, respectively.

C. Workability

1) Previous Research: Some researchers define and formulate the workability as shown in Table I. The workability index of energy is the energy required for compacting asphalt mixture reaches 92% Gmm [8]. Asphalt mixture with a low WEI is a mix of hard compacted the loose condition up to 92% Gmm conditions that require more revolution gyratory compactor. The workability index is the area under the curve intercept data from density to 92% Gmm [9]. Determination of the energy index is done by measuring the compaction pressure, the cross section area of the specimen, and the calculation of the height change of the specimen.

TABLE I
Several Formulas of Workability Indices

Index	Definition	Formula	Abbreviation	Reference
Workabi-lity Indices	Porosity index	100/A	PI	[3]
	Volumetrix energy index (EI) from intercept to 92% Gmm	$P(\frac{\pi d^2}{4})\sum_{N=1}^{N=92}\Delta h$	$EI_{(92\%)}$	[9]
	Workability energy index (WEI) from intercept to 92% Gmm	$EI_{(92\%)} / N_{92}$	WEI	
	Workability energy index from loose to 92% Gmm	$\left(\frac{\pi d^2}{4}P(h_0 - h_{92\%})\right)/(N_0 - N_{92\%})$	WEI	[8]

The workability is defined as the inverse intercept the porosity index of the mixture at 0 revolutions [3]. Compaction is done by means of gyropac the vertical pressure of 0.7 Mpa, rotation angle of 1 °, and the number of revolution 30. The revolution number of 30 is equivalent to the number blow of Marshall as much as 50 per side impact specimens.

The workability of asphalt concrete is measured by using a gyratory compactor [6]. Gyratory compactor compaction is done by axial pressure is 240 kPa, gyration angle is 20 °, speed of gyration is 60 rpm and design gyration N_{design} is 120 gyratory revolutions. Height change of the test specimen is measured automatically by means of gyratory then calculated porosity. How to measure workability in [6] is the same as [3].

2) How to Measure Workability: Workability calculation process performed in the following manner:

a. The video takes to determine the position changes and calculate the height of the specimen after compaction (Fig. 2). The position change was taken from a fragment of the video that has been taken snapshots at 1 up to 75 blows. Changing the height of the test specimen can be measured from the image snapshot using distance measuring software that has a measurement accuracy of up to 0.001 mm;

b. The volume of the specimen calculates using the height specimen data at 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, and 75 blows. The specimen volume (Vi) is calculated by equation 1. Density (Di) is calculated by equation 2. Porosity (Pi) is calculated by equation 3. Specific gravity (SG) is calculated by equation 4. The relationship between porosity and number of blows is formulated by equation 5. Workability Index (WI) is determined by equation 6.

$$V_i = \frac{10.16^2}{4}\pi h_i \quad (1)$$

Where Vi is volume of specimen at i blow (cm^3) and hi is height of specimen at i blow (cm).

$$D_i = \frac{W_a}{V_i} \quad (2)$$

Where Di is density at i blow (g/cm^3), and Wa is weight of the specimen in air (g).

$$P_i = \left(1 - \frac{D_i}{SG}\right)100 \quad (3)$$

Where, Pi is total porosity total at i blow (%), and SG is specific gravity of specimen (g/cm^3).

$$SG = \frac{100}{\frac{P_{wa}}{SG_a} + \frac{P_{ws}}{SG_s} + \frac{P_{wf}}{SG_f} + \frac{P_{wb}}{SG_b}} \quad (4)$$

Where P_w is percentage weight in mix, a is coarse aggregate, s is sand or fine aggregate, f is filler, and b is bitumen.

$$P_i = A - B\log_{10}(i) \quad (5)$$

Where A is intercept with the y axis, B is slope of the line, and *i* is number of blows.

$$WI = \left(\frac{1}{A}\right)100 \quad (6)$$

Equipment used to measure the change in height of the specimen are an automatic Marshall compactor and the Nikon D 7000 camera. The frame rate of the video is 23 frames per second (fps). The frame rate of at least 23 fps video capture is useful for capturing the height position changes of the specimen accurately.

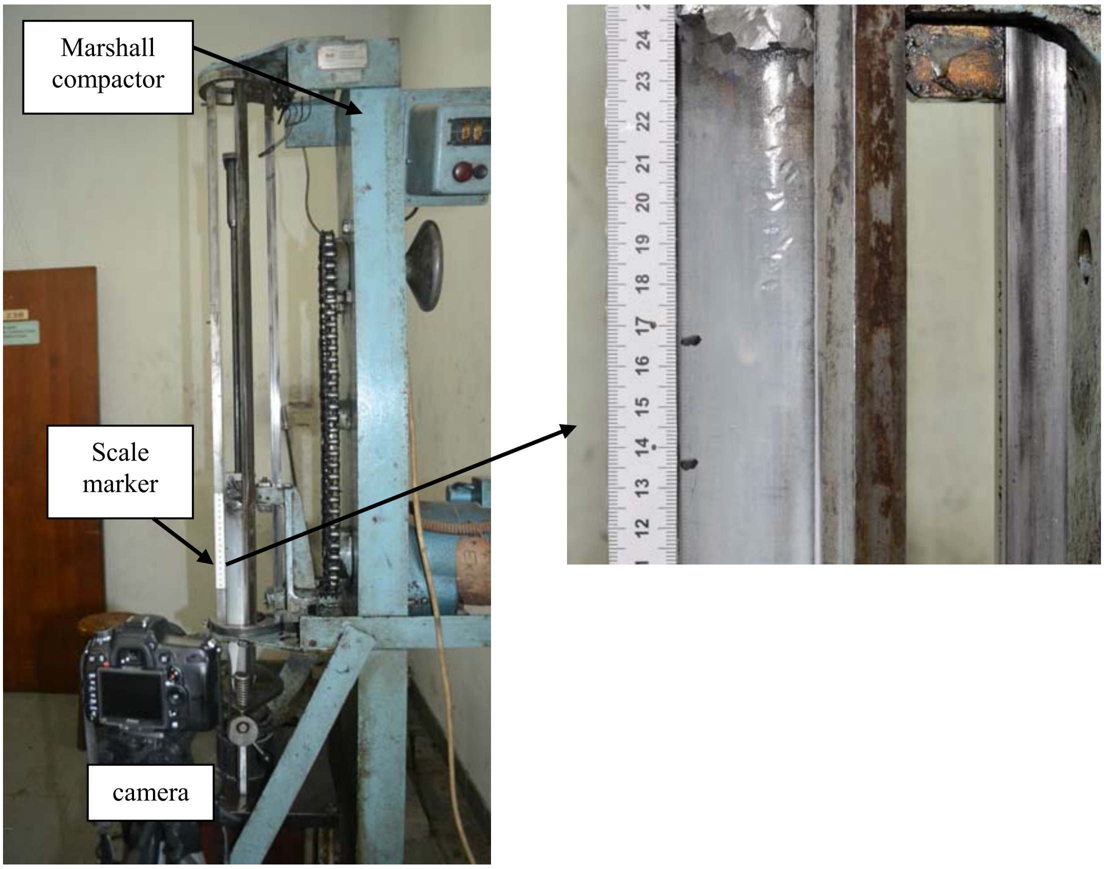


Fig. 2. Automatic Marshall compactor, camera Nikon D7000, and scale marker

D. Gradation Index

Gradation index (GI) was proposed in this study in order to know the continued relationship to determine the effect of a treatment on aggregate gradation and can determine a gradation coarser or finer. Gradation index is defined as the ratio of the area of the retained area curve and the total area of an aggregate grading curve (equation 7 and equation 8). Illustration about Gradation Index is shown in Fig. 3.

$$GI = \left(\frac{a}{A}\right)100 \quad (7)$$

$$a = \sum_{i=0}^{n}\left(\frac{Sr_i + Sr_{i+1}}{2}\right)\left(T_i - T_{i+1}\right) \quad (8)$$

Where *a* is area retained of the curve (mm^2); *A* is total area (mm^2) obtained from the calculation formula $T_0.Sr_0$ (mm^2); Sr is sieve size (mm); and T is cumulative retained aggregate (10%=10 mm).

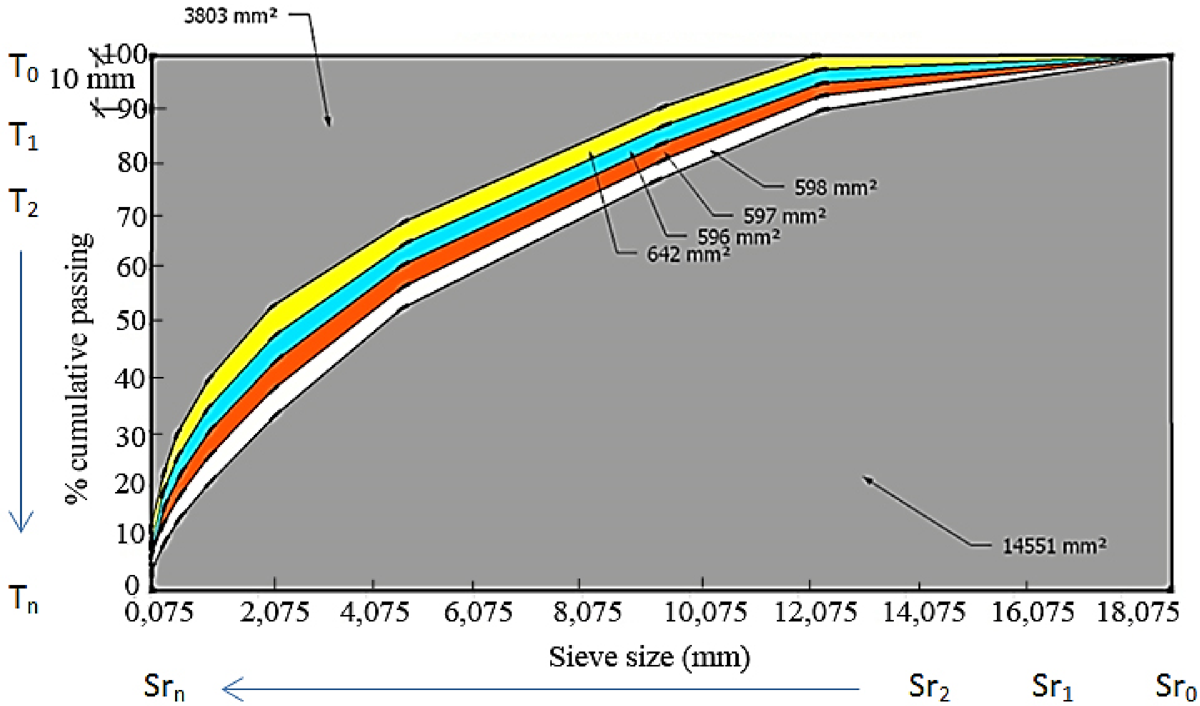


Fig. 3. Retained area for each type of aggregate gradation

III. Results and Discussion

A. Porosity using Marshall Compactor

The specimen is made of the optimum bitumen content is then selected void of asphalt mixture that is void in the mix (VIM), voids filled with asphalt (VFA) and voids in mineral aggregate (VMA) that meet the optimum bitumen content, or so-called optimum void. The specimen is measured specimen height changes that have an optimum void (Table II). Controlling variable void aims for optimum workability index measurement results represent the workability characteristics of each type of gradation.

Changes porosity specimen to any types of gradation or gradation index on any blows can be seen in Table III. The Snapshot showed in Fig. 4.

TABLE II
Optimum bitumen content and void of asphalt mixture

Gradation type	Gradation Index	OBC (% of mix)	VIM (%)	VFA (%)	VMA (%)	Specific Gravity (SG)	weight of the specimen in air (g)
UL	18.65	5.97	3.29	78.79	15.52	2.430	1247.85
UM	21.53	5.84	4.48	71.79	15.89	2.432	1248.85
MR	24.41	5.56	3.51	76.66	15.03	2.433	1244.10
ML	27.29	5.65	4.72	71.60	16.60	2.425	1242.14
LL	30.17	7.09	3.75	78.51	17.46	2.375	1258.48

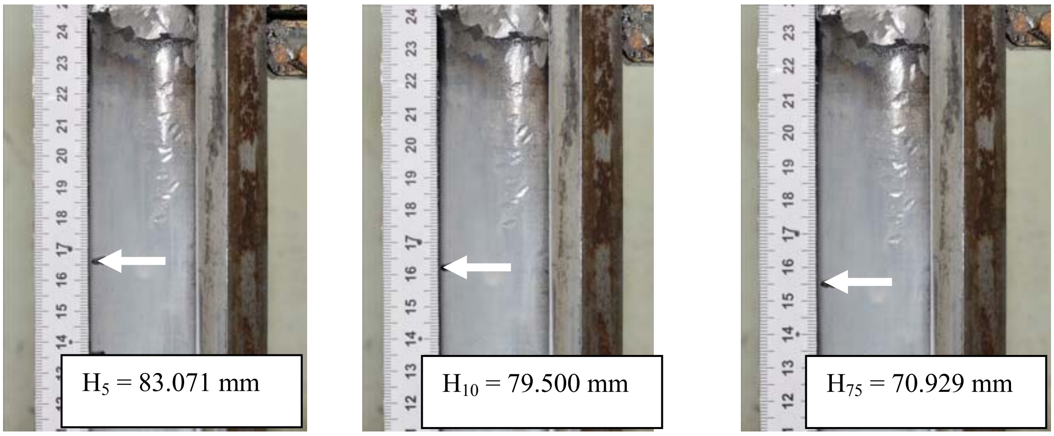
Table III and Fig. 5 show that the porosity changes on any types of aggregate gradation can be measured by using Marshall compactor and video recording at a speed of 23 fps. Height changes of the specimen can be measured to the accuracy of 0.001 mm (Fig. 4).

B. Gradation Index and Workability Index

Workability index calculated by the equation 6. The Intercept of a logarithmic equation is the porosity at 0 blows. The relationship between the number of blows and porosity is very strong. The coefficient of determination or R2 for any types of grading is more than 0.99.

The result of the calculation workability index and gradation index can be seen in Table IV. The porosity at i blows (Pi) is obtained from the formula A-B log i. The value of a slope of the line is minus means that a slash to the left. Aggregate gradation effect on the workability index with the greatest workability on GI = 30.71 and the lowest GI = 24.41. Difference workability index value is also influenced by the optimum bitumen content of each type of gradation. LL aggregate gradation with GI = 30.71 has OBC = 7.09% so that the asphalt is used to cover the void also reduces the resistance of aggregate in the compaction process. In GI = 18.65 (OBC = 5.97%)

more than in Asphalt GI = 24.41 (OBC = 5.56%) to cover the fine aggregate in the aggregate resistance while reducing compaction, so that the WI of GI = 18.65 has a value greater than the WI of GI = 24.41. In general, it can be said that the value generated WI did not differ significantly which is about 3 because on any type of gradation using the optimum bitumen content.



(a) (b) (c)

Fig. 4. Snapshot from video recording of height of specimens (H) at (a) 5 blows, (b) 10 blows, and (c) 75 blows for MR aggregate gradation

TABLE III
Porosity changes based on type of gradation

Number of blows	Porosity (%) at gradation type [gradation index]				
	UL [18.65]	UM [21.53]	MR [24.41]	ML [27.29]	LL [30.71]
5	23.130	23.806	24.108	23.427	23.233
10	19.983	20.623	20.700	20.655	20.715
15	18.070	18.494	18.503	18.849	18.953
20	16.228	17.086	17.359	17.375	18.185
25	15.159	16.094	15.681	16.388	16.585
30	14.201	15.000	14.868	15.455	16.068
35	13.503	14.038	13.933	14.742	15.149
40	13.079	13.385	13.406	14.016	14.622
45	12.714	12.722	12.656	13.526	14.087
50	11.671	12.387	12.112	12.863	13.409
55	11.488	11.665	11.709	12.528	13.135
60	11.276	11.149	11.117	11.935	12.720
65	10.610	10.887	10.892	11.592	12.442
70	10.500	10.757	10.666	11.075	12.859
75	10.347	10.230	11.117	10.462	11.738

TABLE IV
Workability index and gradation index

Parameter	Gradation types [gradation index]				
	UL [18.65]	UM [21.53]	MR [24.41]	ML [27.29]	LL [30.71]
Intercept (A)	30.933	32.256	32.343	31.585	30.474
Slope of Line (B)	-4.845	-5.102	-5.118	-4.783	-4.289
Determination coefficient (R^2)	0.997	0.999	0.995	0.997	0.993
Workability index (WI)	3.233	3.100	3.092	3.166	3.281

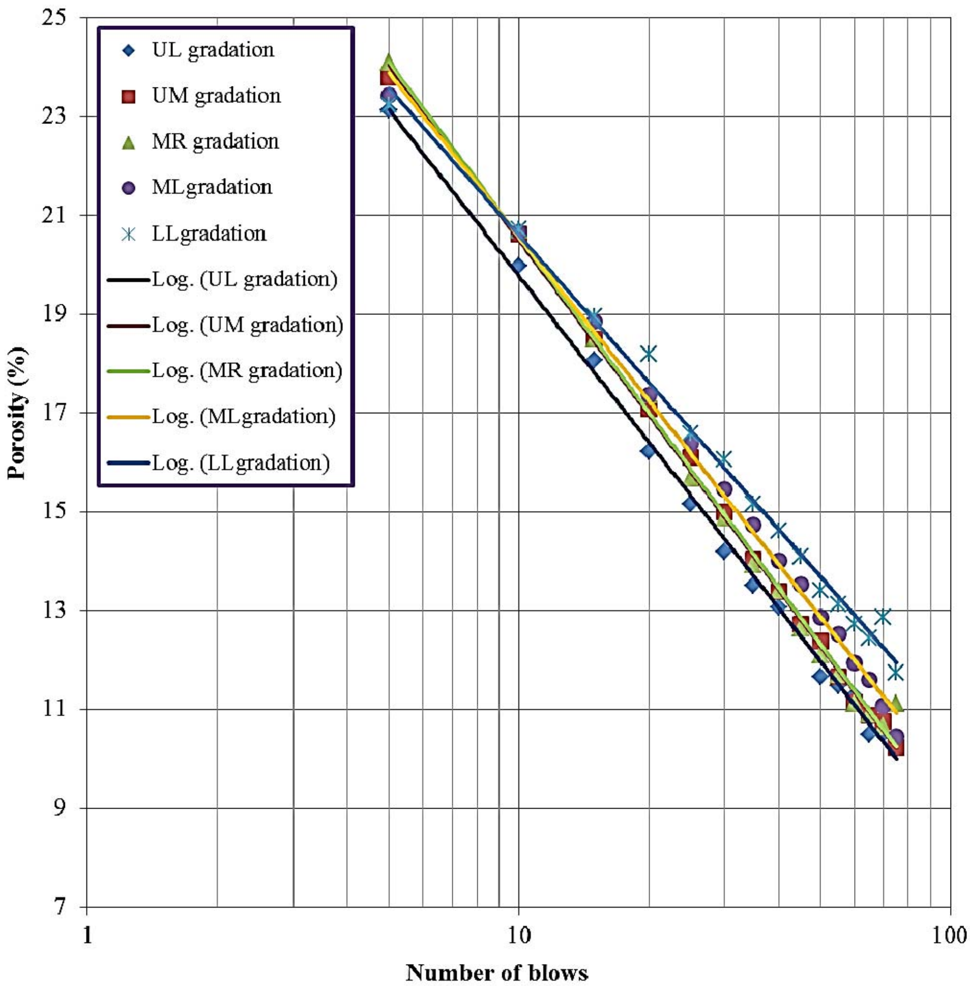
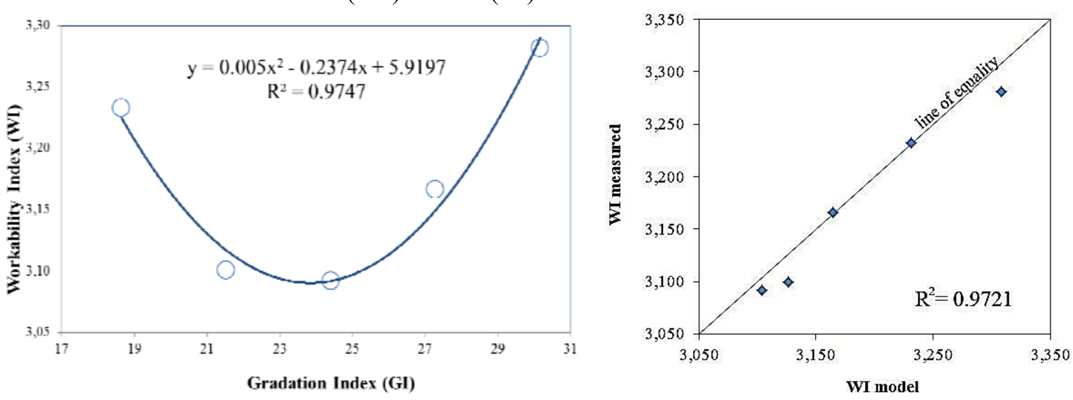


Fig. 5. Porosity and number of blows Marshall compactor

The relationship between gradation index and workability index is very strong. This influence is indicated by the model quadratic polynomial relationship between GI and WI have a coefficient of determination $R^2 = 0.9747$ (a very strong relationship). This model (equation 9) can be used to predict the value of the index on the workability of other GI value (Fig. 6 a). WI measured and WI model have very strong relationship with $R^2 = 0.9721$ (Fig. 6 b). UL (fine aggregate gradation) and LL (coarse aggregate gradation) are more workable than the MR (middle of fine and coarse aggregate gradation). UL has finer aggregate that fills the gap in coarse aggregate so more easily compacted, whereas LL has more asphalt, thereby reducing the resistance of aggregate in the compaction process.

$$WI = 0.005\,(GI^2) - 0.2374\,(GI) + 5.9197 \quad (9)$$



(a) (b)

Fig. 6. (a) Relationship between GI and WI, and (b) Correlation of WI between experimental result and model

IV. CONCLUSIONS

The aim of this study was to evaluate the effect of aggregate gradation on workability asphalt concrete using Marshall compactor. Based on the limited test results obtained in this research study, the following conclusions are drawn:

a. Aggregate gradation at optimum bitumen content has no significant effect on the workability index,
b. Marshall compactor with video recording can be used to measure workability index so it could be used as a solution for measuring the workability of asphalt mixture that is accurate, easy, and cheap, and
c. Gradation index can be used to predict workability index. The relationship between gradation index and workability index is the quadratic polynomial with very strong relationship (R^2 = 0.9747).

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