INVESTIGATION ON INDICES OF WORKABILITY AND RUTTING RESISTANCE FOR WEARING COURSE MIXTURES

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Abstract. Simple indices easily help to evaluate a performance of hot mix asphalt mixtures. This study aimed to develop a simple workability index and rutting resistance index for wearing course mixtures. Seven aggregate gradations were prepared to investigate dense, coarse, and fine-graded hot mix asphalt mixtures. The study used the Marshall compactor to fabricate specimens. The Superpave Gyratory Compaction was employed to measure the workability of the seven blends, namely the workability energy parameter of asphalt mixtures. The study also conducted Wheel Tracking Test to evaluate rutting resistance of those mixes. The results showed a strong relationship between the workability index and the workability energy of hot mix asphalt mixtures, namely increasing the workability energy of mixtures with increasing the workability index value. The workability energy value of an asphalt mixture may be high when the area of continuous maximum density for a proportion of stone, which illustrates a degree of far away from the Fuller maximum density line, is low. Moreover, the rutting resistance index correlated well with rutting resistance of the hot mix asphalt mixtures.

Keywords: aggregate gradation, continuous maximum density, hot mix asphalt mixtures, rutting, stone content, Superpave Gyratory Compaction, workability.

1. Introduction

Workability of hot mix asphalt (HMA) illustrates characteristics associated with the construction of the HMA layer, namely being placed, worked by hand, and compacted (Gudimetta et al. 2003). An HMA mixture, which has higher workability, can be more easily compacted. Low workability may affect durability and stability of the HMA mixtures in field construction. On the other hand, it is not proper to use an HMA mixture which is very workable, because it may show a poor rutting performance under repeated traffic loads (Haryanto, Takahashi 2007a).

Past researchers pointed out that some compaction equipment such as torque-meter (Gudimetta et al. 2003), Superpave gyratory compactor (SGC) (Dessouky et al. 2013) and modified roller compactor (Oliver, Alderson 2006) enable to measure workability of HMA mixtures. Moreover, Asphalt Pavement Analyzer and Wheel Tracking Test (WTT) are commonly simulative tests to evaluate rutting resistance of HMA mixtures. Dynamic stability (DS) of WTT is a good parameter for assessing rutting potential of HMA mixtures (Haryanto, Takahashi 2007b). However, those devices are expensive and have not been widely available in developing countries.

Marshall Compactor is still a basic equipment to fabricate HMA mixtures specimens. Therefore, development of HMA indices obtained by Marshall Compactions and related to workability and rutting resistance of HMA mixtures is required. Those indices will help asphalt designers in the process of choosing an adequate aggregate structure.

Aggregate gradation has a strong effect on the workability of the HMA mixture. If aggregate gradation of an HMA mixture is close to the maximum density line (MDL), the HMA mixture may be compacted properly (Haryanto, Takahashi 2007a). Aggregate gradation passing below the restricted zone could be more workable than that passing above the restricted area (Gudimetta 2003; Haryanto, Takahashi 2007a). HMA mixtures with a high fraction of stone or sand may show a low workability (Haryanto, Takahashi 2007a). However, none of the studies has clearly introduced the relationship between characteristics of an aggregate gradation and workability of an HMA mixture. There are not unique guidelines for designers who do not have enough experience in design of adequate aggregate gradations, which lead to proper workable HMA mixtures.

This study aimed to develop a simple index and applied it to investigate an effect of an aggregate gradation on the workability of 12.5 mm nominal maximum particle...
size (NMPS) wearing course mixes with different compactors. The study also discussed another simple performance index for assessing rutting resistance of HMA mixtures. SGC was conducted to measure the workability of seven blends, which were following the Vietnamese standard for wearing course HMA mixtures. Moreover, a relationship between the workability and the rutting susceptibility of HMA mixtures was also investigated. The WTT evaluated the rutting resistance of those mixtures.

2. Literature review

SGC gives the vertical pressure and the angle of gyration to an HMA sample during compaction (Asphalt Institute 2001). The computer system automatically measures and records the height of the sample at each gyration. The data is used to evaluate workability of HMA mixtures (Dessouky et al. 2013). The researchers used compaction curves to develop two indices associated with field construction. The first index presented workability of an HMA mixture when a volume of the mixture changes from the beginning to 92% of the theoretical maximum specific gravity ($G_{mm}$). The second index, which was calculated by the change in volume from 92% to 96% of $G_{mm}$, illustrated the shear strength of an HMA mixture due to interlocking between aggregate particles (Dessouky et al. 2013). Based on this idea, two simple indices, namely the workability energy index (WEI) and the compact ability energy index (CEI), were defined as follows (Dessouky et al. 2013):

\[
WEI = \frac{\pi d^2}{4} P \left( \frac{h_0 - h_{92\%}}{N_{92\%}} \right),
\]

\[
CEI = \frac{\pi d^2}{4} P \left( \frac{h_{92\%} - h_{f\%}}{N_{des\%} - N_{92\%}} \right),
\]

where $d$ – a diameter of sample, m; $P$ – a compaction pressure of SGC, kN; $h_0$ – a height of sample before compacting, mm; $h_{92\%}$ – a height of sample as air voids of the mixture reach 8%, mm; $h_{f\%}$ – a height of sample with $N_{des\%}$ mm; $N_{92\%}$ – a number of gyrations as air voids of the mixture reach 8%; $N_{des\%}$ – a number of design gyrations.

Designing an adequate aggregate gradation to obtain a proper void in mineral aggregate (VMA) is one of the necessary steps in a design process of HMA mixtures. The past research pointed out that the $CMD_{area}$ parameter has a good relationship with VMA (Nhan 2015; Nhat et al. 2016). VMA of HMA mixtures increases as the value of the $CMD_{area}$ increases. Therefore, the $CMD_{area}$ parameter is useful in controlling a value of VMA. Based on the concept of the maximum density gradation (Christopher et al. 2011), $CMD_{area}$ parameter is calculated as follows:

\[
P_{CMD}(d_i) = \left( \frac{d_{i+1}}{d_i} \right) P(d_{i+1}),
\]

\[
P_{dev}(d_i) = P_{CMD}(d_i) - P(d_i),
\]

\[
CMD_{area} = \frac{\sum_{i=0.075}^{NMPS} A_i}{0.075}
\]

where $P_{CMD}(d_i)$ – percent passing by mass for sieve size $d_i$ on the continuous maximum density (CMD) line, %; $d_{i+1}$ – one sieve larger than $d_i$, mm; $P(d_{i+1})$ – percent passing by mass for sieve $d_{i+1}$, %; $P_{dev}(d_i)$ – a deviation from the CMD line to $P(d_i)$ for sieve $d_i$, %; $P(d_i)$ – percent passing by mass at sieve $d_i$; $A_i$ – an area between $P_{dev}(d_i)$ and $P_{dev}(d_{i+1})$ as shown in Fig. 1. In Fig. 1, a sieve size of the horizontal axis is represented in a logarithmic scale.

3. Development of WI

Aggregate gradation plays a major role in determining the workability of the HMA mixture. A fraction of sand and stone at 2.36 mm sieve for 12.5 NMPS mixes has a great relationship with the workability of the HMA mixture. Workability of an HMA mixture having a high fraction of sand is low (Haryanto, Takahashi 2007a). The CMD pilot illustrates how much the aggregate gradation is far from the Fuller MDL at each sieve (Christopher et al. 2011). Past researchers reported that it is easy to compact the HMA mixture in which the aggregate gradation fits the MDL (Haryanto, Takahashi 2007a). The authors of the present study assumed that the area of CMD for stone proportion ($CMD_{area-stone}$) has a strong relationship with the workability of HMA mixtures. When the $CMD_{area-stone}$ of an HMA mixture is high, this mixture may not be compacted.
easily. Fig. 2 illustrates the meaning of the CMD\_area-stone for an aggregate gradation.

A high workability HMA mixture having a proper apparent film thickness (AFT) can easily be compacted. The AFT is an average thickness of asphalt binder that coats aggregate particles. An HMA mixture with a higher AFT value has higher workability (Christopher \ et \ al. \ 2011). When effective asphalt content (V_{he}) increases, the AFT of the mixture also increases (Christensen, Bonaquist 2006). Therefore, V_{he} parameter may be a positive factor affecting workability of the HMA mixture (Haryanto, Takahashi 2007a). In addition, a proportion of fine aggregate particles has a strong effect on AFT. When a proportion of fine aggregate in a mixture increase, an aggregate specific surface area in the mixture also increases. As a result, the AFT value reduces due to asphalt absorption of the fine aggregate. For this reason, workability of the HMA mixture deteriorates.

Too many interceptor particles may disrupt dense packing of the aggregate structure and create additional voids. Asphalt binder may fill the new voids, and workability of the HMA mixture may improve (Haryanto, Takahashi 2007a). No study has investigated to quantify an effect of interceptors on the aggregate interlocking related to the workability of the HMA mixture. This study employed a disruption factor (DF) of a dominant aggregate size range (DASR) model as a parameter to illustrate an effect of aggregate interlocking on the workability of HMA mixtures. The DASR is an interactive range of particle sizes that develops aggregate interlocking in the HMA mixture. Coarse particles play the main role in forming a backbone aggregate structure. Aggregate particles smaller than the DASR aggregate along with asphalt binder and fine aggregate (interstitial components (IC)) occupy the air voids created by aggregate particles of the DASR. Aggregate particles larger than the DASR solely float in the DASR aggregate matrix and do not play a major role in the aggregate structure. Aggregate particles interact each other and significantly contribute to friction strength in the HMA mixtures when relative proportions between contiguous size particles in the DASR is lower than 70/30 (Chun \ et \ al. \ 2012). The DF determines whether fine aggregate disrupts the DASR structure (Chun \ et \ al. \ 2012). When a DF value is high, fine aggregate reduces the backbone aggregate, and interlocking effect of coarse aggregates is small. As a result, compacted load easily shifts stone particles (Haryanto, Takahashi 2007a). In contrast, if DF has a low value, fine aggregate does not take part in transferring loads in the aggregate structures (Chun \ et \ al. \ 2012).

In the past research, the smallest sieve of DASR model may be 1.18 mm (Chun \ et \ al. \ 2012). In the Bailey method, a secondary control sieve (SCS) splits out coarse sand and fine sand. SCS for 12.5 mm NMPS aggregate gradation is the 0.6 mm sieve (Varik \ et \ al. \ 2002). For a coarse sand fraction of 12.5 mm NMPS aggregate gradation, 0.6 mm was the smallest particle size in the DASR (Haryanto, Takahashi 2007c). Therefore, the present study chose 0.6 mm as the smallest particle size of coarse aggregate to calculate DF of the DASR for all blends.

Based on the above analysis, the following equation and other associated variables show the process of calculating workability index (WI). The present study built a hypothesis that WEI increases with increasing WI. It is possible to obtain the WI value from a stage of mix design procedure.

\[
WI = \left( \frac{1}{CMD_{area-stone}} \right) \left( \frac{V_{he}}{S_{s}} \right) DF, \quad (6)
\]

\[
S_{s} = \frac{P_{0.30} + P_{0.15} + P_{0.075}}{5}, \quad (7)
\]

\[
DF = \frac{\text{Volume of potentially disruptive IC particles}}{\text{Volume of DASR voids}}, \quad (8)
\]

where \( S_{s} \) - the area of aggregate specific surface, m\(^2\)-kg\(^{-1}\); \( P_{0.30} \), \( P_{0.15} \), and \( P_{0.075} \) - an aggregate content passing 0.30 mm sieve, 0.15 mm sieve and 0.075 mm sieve, percent by total mass of aggregates, %, respectively; \( V_{he} \) - effective asphalt content, percent by total volume of a mixture, %. Eq (7) illustrates an effect of fine aggregate on the area of the aggregate specific surface (Christopher \ et \ al. \ 2011).

4. Development of rutting resistance index

The past research pointed out that mixture resistivity is an effective parameter to evaluate rutting resistance of HMA mixtures. Resistivity presents the resistance of an aggregate structure to oppose binder flow in the mix. Resistivity also illustrates a contrary characteristic of permeability for an HMA mixture (Christensen, Bonaquist 2006). The resistivity of an asphalt combination derived from \( S_{s} \), the bulk specific gravity of aggregates \( (G_{sb}) \) and VMA simultaneously expresses rutting resistance of HMA mixtures (Christensen, Bonaquist 2006). A relationship between mixture resistivity and rutting resistance of HMA mixtures may be explained as follows. The strength of adhesion existing in HMA mixtures increases with increasing \( S_{s} \). As the sequence, the indirect tensile strength of HMA mixtures increases when the force of adhesion in mixtures increases (Chen \ et \ al. \ 2002). The indirect tensile test is a sufficient method to measure cohesion of the mixtures (Christensen \ et \ al. \ 2004). Moreover, cohesion has a good relationship with the rutting resistance of HMA mixtures, because this parameter is one of shear strength properties (Haryanto, Takahashi 2007d). Therefore, rutting resistance of HMA mixtures increases with increasing mixture resistivity (Christensen, Bonaquist 2006).
Characteristics of aggregate gradation significantly effect on VMA of the mix. The results of past researches showed that VMA of the HMA mixture increases as the value of the \( CMD_{area} \) increases (Nhan 2015; Nhat et al. 2016). Therefore, the \( CMD_{area} \) parameter indicates an effect of aggregate gradation on the resistivity of the mixture. When calculating mixture resistivity, the present study used \( CMD_{area} \) parameter instead of VMA. The mixture resistivity increases with decreasing the \( CMD_{area} \) of aggregate gradation.

A volume of effective asphalt is also related to rutting performance of an HMA mixture. Mixes with low \( V_{be} \) show high resistivity values (Christensen, Bonaquist 2006). It means that the \( V_{be} \) parameter presents a negative effect of asphalt binder on the mixture resistivity. Moreover, a mixture having a high \( V_{be} \) value has a high AFT value, which reduces rutting resistance of the HMA mixture (Christopher et al. 2011).

As mentioned above, when an HMA mixture is highly workable, it may show poor rutting performance under repeated traffic loads (Haryanto, Takahashi 2007a). Eq (9) presents rutting resistance index (RRI) formulation. A hypothesis of the present study was that rutting resistance of an HMA mixture increases when RRI increases. Eq (10) was based on the equation to calculate resistivity of an HMA mixture (Christensen, Bonquist 2006). Because Eq (10) was not enough for all the components to calculate mixture resistivity, this equation was only used to determine resistivity index (RI), which presents an effect of aggregate gradation on the mixture resistivity:

\[
RRI = RI \left( \frac{1}{V_{be}} \right) \left( \frac{1}{WT} \right)
\]

\[
RI = \frac{S^2 G_{mm}}{CMD^3_{area}}
\]

5. Experience work

5.1. Preparation of HMA materials

The present study used a straight asphalt of Pen 60/80 and mineral aggregates, which were produced in a local Japanese province, to fabricate HMA samples. Both the materials were satisfied with not only the Japanese requirements but also the Vietnamese criteria. The available aggregates were coarse and medium aggregates, coarse and fine sands.

5.2. Design of aggregate gradation

Seven aggregate gradations were blended to investigate the dense, coarse and fine-graded HMA mixtures. The first group was dense-graded HMA mixtures, namely, from Blends 1 to 3. Blend 3 was a conventional aggregate gradation, and others had a parallel tendency with the mixture 3. The second group was coarse-graded HMA mixtures, namely, Blends 4 and 5. The Blend 4 presented a coarse aggregate gradation near stone matrix asphalt mixture (SMA) for 12.5 mm NMPS (Cooley, Graham 2004). The final group was fine-graded HMA mixtures, namely, Blends 6 and 7. The past research suggested that a percentage of aggregates retaining 2.36 mm sieve or a stone content should be more than 30% (Haryanto, Takahashi 2007d). Therefore, the Blend 7 was prepared to illustrate the fine aggregate gradation, which the stone content in the mixture was slightly over 30%. Fig. 3 shows all gradation curves designed in the study.

5.3. Mix design procedure

According to on the basis of the Marshall method as described in Vietnamese Standard TCVN 8819–2011 Specification for Construction of Hot Mix Asphalt Concrete Pavement and Acceptance, all the mixtures were designed in the following steps.

1. Prepare and evaluate the resources, namely aggregates, sand, filler, and asphalt binder.
2. Mix two samples for each blend with a tentative asphalt content (AC) to determine the \( G_{mm} \) and the effective specific gravity of aggregate (\( G_{ag} \)).
3. Fabricate Marshall Briquettes with five ACs. Seventy five blows are applied on each side of the specimens.
4. Measure and determine volumetric parameters, stability, and flow of each sample.
5. Analyse the asphalt mixture properties to obtain an acceptable range of AC based on the specified requirements as presented in Table 1.
6. Determine the design AC, namely a median of the acceptable AC range.
7. Make five specimens at the design AC. Compare the properties with the design criteria for three samples. Determine residual stability index for the rest of two samples.

![Fig. 3. Aggregate gradations for all the blends](image)

Table 1. Marshall requirements for 12.5 mm NMPS mixtures

| Properties of an HMA mixture | Required range |
|------------------------------|----------------|
| Voids in mineral aggregates (VMA) | ≥14% |
| Voids in mixture (VIM), after 75-2 blows | 3–6% |
| Stability | ≥8.0 kN |
| Flow | 2–4 mm |
| Residual stability | ≥75% |
Table 2. Results of properties for Marshall, SGC specimen, and slab-shaped specimen at the design AC

| Blend | Design AC, % | VIM, % | VMA, % | Gmb | SGC specimens | Slab-shaped specimens |
|-------|-------------|--------|--------|-----|---------------|----------------------|
|       | Ndes (gyration) | Gmb | WEI, Nm | CEI, Nm | VIM, % | VMA, % | Gmb |
| 1     | 4.75 | 5.3 | 14.0 | 2.364 | 70 | 2.366 | 6.99 | 0.96 | 7.1 | 15.6 | 2.318 |
| 2     | 4.70 | 4.1 | 12.7 | 2.392 | 48 | 2.396 | 11.17 | 1.61 | 4.9 | 13.4 | 2.372 |
| 3     | 4.60 | 4.0 | 12.2 | 2.398 | 48 | 2.394 | 11.56 | 1.61 | 4.5 | 12.7 | 2.385 |
| 4     | 6.00 | 4.0 | 15.6 | 2.347 | 120 | 2.341 | 5.84 | 0.36 | 6.6 | 17.9 | 2.285 |
| 5     | 4.70 | 5.5 | 14.3 | 2.356 | 70 | 2.353 | 6.03 | 0.95 | 7.4 | 16.1 | 2.307 |
| 6     | 6.00 | 4.2 | 15.3 | 2.339 | 45 | 2.335 | 10.68 | 1.62 | 3.6 | 14.8 | 2.355 |
| 7     | 6.35 | 4.3 | 16.1 | 2.324 | 70 | 2.317 | 7.45 | 0.97 | 5.5 | 17.2 | 2.296 |

Note: Design AC for Blends 2 and 3 was determined as air voids of the HMA mixture were equal to 4.0%.

Fig. 4. Effect of stone contents on WEI

5.4. Superpave Gyratory Compactor test

SGC data evaluated workability of HMA mixtures. Two specimens with design AC were fabricated using the SGC to determine Ndes for each blend. The Ndes was regarded as the number of gyrations where the HMA mixture had the same bulk specific gravity of mixtures (Gmb) as that of the Marshall specimen. Other samples were fabricated with the design AC and the Ndes to check the Gmb value of the HMA mixture.

5.5. Wheel tracking test

WTT evaluated rutting resistance for the HMA mixtures investigated in the present study. Slab specimens of the mixtures with the dimension of 300×300×50 mm were prepared for WTT. This study used a laboratory steel roller compactor to fabricate the slab specimen. The process of steel roller compactor in the present study was commonly applied in Japan. The compaction procedure included two stages. The first stage was a passing number of 5 times, without a shield tire. The second stage had a passing number of 20 times by using the shield tire.

The present study conducted the WTT at a temperature of 60 °C. A wheel speed was 42 passes/ min, and a load was 686 N (Haryanto, Takahashi 2007d). A DS value illustrates passage times of wheel load per 1 mm rut depth. The DS is an evaluation parameter in the Japanese WTT standard for a rutting susceptibility (Haryanto, Takahashi 2007d). The following equation was used to calculate a value of DS:

\[ DS = 1.5 \times \frac{d_{60} - d_{45}}{d_{45}} \]

where \( d_{60} \) and \( d_{45} \) – a rut depth at 60 min and 45 min, mm, respectively.

6. Results and discussions

6.1. Result of mix design

Table 2 shows design ACs and volumetric properties of the seven HMA mixtures fabricated by the Marshall compaction. Each value of the properties was an average value from three specimens. In the process of design, Blends 2 and 3 could not meet the requirement of VMA even though AC was changed five times (Nhat, Takahashi 2016).

According to Vietnamese Standard TCVN 8820–2011, for dense-graded HMA mixtures, it is possible to determine design AC when air voids of the HMA mixture are equal to 4.0%. Therefore, the authors assumed that design AC for Blends 2 and 3 was established as the AC that gave 4.0% air voids in the mixtures. Each value of the properties illustrated in Table 2 for Marshall specimens was also an average value from three samples.

6.2. Effect of aggregate gradations on workability

Table 2 also shows HMA properties of SGC specimens and results of workability and compactibility for the seven blends. WEI and CEI were calculated from SGC measured data. Among all the blends, Blend 4 following the SMA aggregate gradation has the smallest WEI value. It means that Blend 4 is hard to be compacted. The past research reported that an HMA mixture aggregate gradation of which is close to the MDL is easily compacted because individual aggregate particles easily interlock to fit together and create the densest packing of backbone aggregates (Haryanto, Takahashi 2007a). Fig. 4 illustrates the effect of stone contents or aggregates retaining at 2.36 mm sieve size on the workability of the HMA mixtures. A high correlation...
coefficient, namely $R^2 = 0.84$, is obtained between stone contents and WEI. The trend line points out that the workability of the HMA mixtures is high if the aggregate gradation is close to the MDL. This result agrees with Haryanto finding (Haryanto, Takahashi 2007a).

Table 3 presents results of parameters to calculate the WI of HMA mixtures. The WI value of each Marshall specimen is equal to that of the SGC specimen. The WI values of the Marshall and SGC samples are also different from that of the slab-shaped samples because of the difference of $V_{be}$. The Marshall and SGC specimens have the same $V_{be}$, even though all Marshall specimens have the same compaction energy but SGC specimens individually have the different compaction energy. The $V_{be}$ values of the Marshall and SGC samples are also different to that of the slab-shaped samples. The $V_{be}$ indicates a ratio between the volume of effective asphalt and the total mixture volume. In the period of compaction, with the help of compaction energy, a porosity of an HMA mixture gradually reduces. This process leads to decrease the total mixture volume and to increase the $V_{be}$ and the $G_{mb}$ of the HMA mixture. Therefore, when a mix was fabricated by various devices, the mixture with high $G_{mb}$ has high $V_{be}$. Table 3 shows that $V_{be}$ changed slightly, so that WI values from Marshall, SGC specimens, and slab-shaped specimen are almost same.

Among all the parameters, CMD$_{area-stone}$ has the best relationship with the WEI of HMA mixtures. Fig. 5 shows the effects of CMD$_{area-stone}$ on WEI values for the seven aggregate blends. The correlation coefficient is relatively high, namely $R^2 = 0.89$. The trend line presents that the WEI value of HMA mixtures decreases as the CMD$_{area-stone}$ of the aggregate gradations increases. When an aggregate gradation falls close to the MDL, this aggregate gradation has a low CMD$_{area-stone}$ and the mixture can be more workable. The shape of trend line between CMD$_{area-stone}$ and WEI values is simpler than that of between the stone content of aggregate gradations and WEI values. Those results pointed out that CMD$_{area-stone}$ is a more suitable parameter than the stone content of aggregate gradations to indicate a degree of the distance between aggregate gradation and the MDL, which strongly affects the workability of HMA mixtures.

Figure 6 illustrates relationships between WI values of specimens using various devices and WEI values of the SGC specimens for the seven blends. The high correlation coefficient, namely $R^2 = 0.96$, is obtained. The relationship shows the expected tendency, namely increasing the workability of an HMA mixture with increasing the WI values. It seems that the index applies to assess workability of HMA mixtures even though the samples are fabricated with the different compaction energy.

6.3. Evaluation of relationship between rutting resistance index and dynamic stability

Table 4 illustrates RRI values of the specimens using various compactors and DS values for the seven blends. Because the WI values change slightly with different compactions, the RRI values of samples compacted with three
kinds of compactors are almost same. Fig. 7 shows a relationship between the RRI values and the DS values. The relationship among the RRI values of Marshall, SGC or slab-shaped specimens and the DS values shows a reasonable correlation coefficient, namely $R^2 = 0.91$. The trend lines present that rutting resistance of the HMA mixtures increases when RRI increases. The results also illustrate that three RRI values of the samples fabricated from Marshall, SGC and steel roller compactor may be employed for the same objective, namely assessment of rutting resistance for 12.5 mm NMPS wearing course mixtures. A suitable DS value for 12.5 mm NMPS mixtures should be more than 800 cycles/mm (Haryanto, Takahashi 2007d). Based on the Fig. 7, the RRI value should be more than 40 ($\cdot 10^{-2}$) for specimens compacted with any kinds of compactors.

6.4. Relationship between workability energy index, compact ability energy index and dynamic stability

Figures 8 and 9 show relationships between the WEI, the CEI and rutting resistance of the HMA mixtures for the seven aggregate blends. Correlation coefficients between the WEI, the CEI, and the DS are not high. The WEI and the CEI are not associated with rutting resistance of an HMA mixture. The past research pointed out that the gyration angle, namely 1.25 degree, in SGC is not adequate to evaluate the shear stress that causes rutting in HMA mixtures. This angle should increase to assess rutting potential of HMA mixtures (Anderson et al. 2002).

7. Conclusion

The findings of the present study are summarized as follows.

1. This study has developed the workability index for assessing the workability of hot mix asphalt mixtures. The workability index, which consists of aggregate gradation parameters and a mix parameter, can be obtained without any mechanical tests. The workability parameter shows a strong relationship with the workability of mixtures. It means that the index is sufficient to evaluate workability of hot mix asphalt mixtures.

2. The results show that the area of continuous maximum density for a proportion of stone has a high correlation coefficient with workability of mixtures. When this aggregate gradation parameter is low, the mixture shows a proper workability.

3. The relationship between the rutting resistance index values and the dynamic stability values is high. When the rutting resistance index values increase, rutting resistance of hot mix asphalt mixtures also has a tendency to increase. On the Marshall conventional mixture design method, it is easy to calculate this parameter without any mechanical tests. Therefore, the rutting resistance index of Marshall cylindrical specimens sufficiently indicates rutting resistance of wearing course mixtures. Experimental results show that an adequate value of the rutting resistance index for 12.5 mm nominal maximum particle size mixtures is more than 40 ($\cdot 10^{-2}$) for Marshall, Superpave gyratory compactor specimens or slab-shaped specimens.

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