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*by* Daniel Tjandra

# The Effect of Aggregate Gradations Limit on Dense Graded Cold Mixture Asphalt

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**Abstract.** Cold mixture asphalt has several benefits like environmental friendly, easy to use, and economical. This mixture is suitable for use in remote areas or in difficult climatic areas. The purpose of this study was to analyze the effect of aggregate gradations limit on cold mixture asphalt. There are five aggregate gradation limits used in this study, as lower, lower to middle, middle, middle to upper, and upper limit. The laboratory Marshall tests were conducted to investigate the performance of dense graded cold mixture asphalt with various aggregate gradations. The results of this study showed that middle-upper gradation cold mixture asphalt generated the best results compared to the middle and lower gradation mixtures considering the required porosity of the mixtures. Furthermore, designing gradations of mixtures is an economical effort to obtain the best-required cold mixture asphalt.

## INTRODUCTION

Bitumen emulsion is combined with aggregates to create cold mix asphalt, just like hot mix asphalt. It is made by combining aggregate with bitumen emulsion without heating process. Cold mix asphalt has several benefits like environmental friendly, easy to use, and economical. Unlike hot mix asphalt, it does not required any heating and the mixture can be applied directly from its packaging without using any additional equipment. It is suitable for use in remote areas or in difficult climatic areas. The limitation of cold mixture asphalt is on its low initial strength, a longer time to increase strength, and higher porosity than hot mixture asphalt [1, 2, 3, 4, 5]. Thus, it should be designed properly. Cold mixture asphalt is suitable for low to medium traffics.

There are two primarily types of cold mix asphalt, dense graded and open graded. The influence of gradation on performance of cold mixture asphalt should be considered. In mix design, the aggregate gradation is directly related to the percent bitumen content in mixture and thus influence the performance of asphalt mixture. The finer the aggregate gradation, the greater the amount of bitumen required. Conversely, the coarser asphalt mixture, demand less bitumen. Furthermore, aggregate gradation influences cold mix asphalt volumetric properties. Dense Graded Cold Mixture Asphalt laboratory tests were carried out in this study. The purpose of this study was to analyze the effect of aggregate gradations limit on cold mixture asphalt. The required gradation for a cold mixture asphalt used as wearing course is rely on the environmental condition, traffic design, and material availability.

## MATERIALS AND METHODS

### Materials

This study was using bitumen emulsion CSS-1h, which is one of the most widely used in dense graded cold mixtures asphalt. CSS-1h is is a slow-setting type of cationic bitumen emulsion. The characteristics of bitumen emulsion CSS-1h, based on Indonesia National Standard (SNI), are shown in Table 1.

**TABLE 1.** Characteristics of asphalt emulsion CSS-1h.

| Parameter | Test Results | Specification Limit | Standard Test Method |
|---|---|---|---|
| Viscosity test Saybolt-Furol at 25° C (second) | 53 | 20-100 | SNI 03-6721 |
| Storage stability test 24 hours (%) | 0.34 | < 1 | SNI 03-6828 |
| Particle charge test | Positive | Positive | SNI 03-3644 |
| Sieve test retained on No. 20 (%) | 0.04 | < 0.10 | SNI 03-3643 |
| Distillation: Residue (%) | 60.77 | > 57 | SNI 03-3642 |
| **Residue after distillation test:** | | | |
| Penetration at 25° C, 100g, 5 sec (0.1 mm) | 67.7 | 40-90 | SNI 06-2456 |
| Ductility at 25° C, 5 cm/min (cm) | 70 | > 40 | SNI 06-2432 |
| Solubility in trichloroethylene (%) | 98.01 | > 97.5 | SNI 06-2438 |

### Methods

In this study, coarse and fine aggregates were supplied from the same quarry, which is located in Jember area in Indonesia. Several laboratory tests were performed to determine the characteristics of aggregates. Table 2 shows the characteristics of aggregates used in this study, based on Indonesia National Standard (SNI). The characteristics of aggregates used were met the requirement specification. Each gradation of mixture in this study contained the coarse and fine aggregates designed for dense graded cold mixture asphalt.

**TABLE 2.** Characteristics of aggregates

| Properties | Test Results | | Specification limit | Standard Test Method |
|---|---|---|---|---|
| | Coarse[(1)] | Fine[(2)] | | |
| Bulk Specific Gravity | 2.51 | 2.69 | - | |
| Bulk SSD Specific Gravity | 2.55 | 2.74 | - | SNI 1969:2008 |
| Apparent Specific Gravity | 2.64 | 2.82 | 2.5 min. | |
| Absorption (%) | 1.99 | 1.64 | 3 max. | |
| Los Angeles Abrasion (%) | 28.85 | - | 40 max. | SNI 2417:2008 |

(1) Coarse aggregate is retained on sieve No. 8 (2.36 mm); (2) Fine aggregate is passing sieve No 8 (2.36 mm)

All specimens made in this study were dense graded cold mixture asphalt. Each specimen were prepared for about 1200 gram of weight. A dense graded cold mixture asphalt contains suitable proportion of coarse and fine aggregates. The gradation limit and the gradation curve are shown in Table 3 and Fig. 1. Selected aggregate gradation used in this study was based on Indonesian Specification for Dense Graded Cold Mixture Asphalt for Type IV [6]. There were five aggregate gradations being investigated in this study, lower, lower-middle, middle, middle-upper, and upper limit.

**TABLE 3.** Aggregate gradations for Dense Graded Cold Mixture Asphalt type IV.

| Sieve size | | Specification | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| No | mm | | Lower Limit | Lower-Middle Limit | Middle Limit | Middle-Upper Limit | Upper Limit |
| 3/4" | 19 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1/2" | 12.5 | 90-100 | 90 | 92.5 | 95 | 97.5 | 100 |
| 4 | 4.75 | 45-70 | 45 | 51.25 | 57.5 | 63.75 | 70 |
| 8 | 2.36 | 25-55 | 25 | 32.5 | 40 | 47.5 | 55 |
| 50 | 0.3 | 5-20 | 5 | 8.75 | 12.5 | 16.25 | 20 |
| 200 | 0.075 | 2-9 | 2 | 3.75 | 5.5 | 7.25 | 9 |

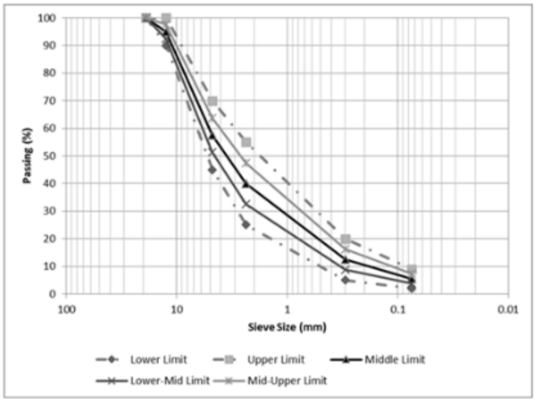


**FIGURE 1.** Aggregate gradation for design mixtures.

There were at least three samples prepared for each emulsion bitumen content according to the Marshall method with standard sample size of 63.5 mm in height by a 101.6 mm diameter. The bitumen content were prepared in five variations, on the basis of 0.5 percent increments of initial emulsion content, with two bitumen contents above the design value and two below this value. The initial emulsion content was determined based on the value of initial residual asphalt content calculated using Equation 1 as recommended by the Asphalt Institute [7]:

$$P = (0.005A+0.1B+0.5C) \times 0.7 \quad (1)$$

where P is the initial residual asphalt content by mass of total mixture (%), A is the percentage of aggregate retained on the 2.36 mm (No. 8) sieve, B is the percentage of aggregate passing the 2.36 mm (No. 8) sieve and retained on the 0.075 mm (No. 200) sieve, and C is the percentage of aggregate passing the 0.075 mm (No. 200) sieve. The values of A, B, C were determined based on each of aggregate gradation in Table 1.

$$IEC = (P/X) \quad (2)$$

where IEC is the initial emulsion content by mass of total mixture (%) and X is the percentage of bitumen content in the emulsion (60.77%). From calculation using Equation 2, the initial bitumen content for each gradations from lower limit to upper limit are as following, 4.9%, 5,7%, 6.5%, 7.2%, 8%, consecutively.

The following procedures were conducted during the sample mixing process. The oven-dried aggregates were prepared according to selected gradation as in Table 3. Then dried aggregates were moistened with 2% of water to achieve the best coating level. The determined emulsion bitumen content was then added to the aggregates. Five different bitumen emulsion contents were determined as bitumen content by mass of total mixture for each type of aggregate gradations. All specimens were mixed thoroughly and then compacted at ambient temperature with heavy compaction level. The compaction energy was generated by applying double of 75 blows to each end of sample using Marshall compactor [1]. High compaction energy was applied to achieve the required porosity of 5-10%. After being compacted, specimens was left in the mold for 24 hours at room temperature, followed by curing process in an oven at 40°C for 24 hours. Samples were then cooled down at room temperature for 24 hours and continued with capillary soaking condition at half the height of sample for 2x24 hours to determine the Marshall soaked stability [1].

## RESULTS AND DISCUSSION

### Results

Based on the results of a series of laboratory testing done with selected aggregate and emulsion bitumen CSS-1h, Marshall Stability, flow, and also volumetric parameter of cold mixture asphalts in various gradation are as shown in Table 4 and explained in these following parts.

**TABLE 4.** Laboratory test results of dense graded cold mixture asphalts in various gradation

| **Properties** | **Lower Limit** | **Lower-Middle Limit** | **Middle Limit** | **Middle-Upper Limit** | **Upper Limit** | **Specification DGEM Type IV** |
|---|---|---|---|---|---|---|
| Optimum Bitumen Content (%) | 5.5 | 6.3 | 7.0 | 7.5 | 8.6 | - |
| Soaked Stability (kg) | 778 | 569 | 420 | 406 | 365 | 300 min. |
| Porosity (%) | 10.4 | 13.0 | 10.7 | 8.9 | 8.2 | 5 – 10 |
| Flow (mm) | 3.8 | 5.1 | 5.2 | 6.8 | 5.8 | - |
| Marshall Quotient (kg/mm) | 123 | 112 | 80 | 60 | 63 | - |
| VMA (%) | 20.0 | 23.9 | 23.4 | 22.7 | 24.3 | - |
| VFB (%) | 48.0 | 45.9 | 54.1 | 60.9 | 66.3 | - |

### Discussion

The optimum bitumen content for each aggregate gradation were determined by optimizing two parameters, Marshall soaked stability and porosity. Since the upper gradation mixture contains more fine aggregates than middle and lower gradation, the upper limit gradation mixture has the largest optimum bitumen content. Finer aggregates has larger surface area. Thus, finer aggregates requires more bitumen to cover surface of aggregates.

This study showed that on dense graded cold mixture asphalt, the highest stability is on lower limit gradation mixture since this mixture has the largest portion of coarse aggregate. The more coarse the aggregate, the higher the stability of the mixture.

The upper gradation limit mixtures showed the lowest porosity values. The allowable percentage of porosity is between 5 and 10 percent for dense graded cold mixture asphalt Type IV. Increasing the proportion of fine aggregate and reducing the amount of coarse aggregate could decrease the porosity of mixtures and increase the bitumen content. Increasing the bitumen content reduces the permeability of mixtures.

Flow values of dense graded cold mixture asphalt were not greatly affected by the difference percentage of coarse aggregates. Middle-Upper Limit gradation mixture has the greatest flow value which also show the highest value of deformation.

Marshall Quotient (MQ) is defined as the ratio of the Marshall Stability to the flow. Lower limit gradation mixture has the largest MQ value. It is shown that lower limit gradation mixture also has the largest stability and the lowest flow. A higher value of MQ indicates a more rigid mixture and more resistant to against permanent deformation.

Void in Mineral Aggregate (VMA) includes the volume of air voids and the effective bitumen of the mixtures. The lower the bitumen content, the lower the VMA, which is shown on lower limit gradation. VMA of cold mixture asphalt is also a control value to provide enough bitumen in voids.

As the bitumen content increases, which is shown on upper limit gradation, the Void Filled with Bitumen (VFB) increases. The VFB increases in line with the increasing content of fine aggregates in mixture which also reduce the void in mixture. The greater VFB also indicated enough interlocks of aggregates.

## CONCLUSIONS

Based on the results of laboratory testing evaluation and analysis, conclusions and recommendations of this study are described as the following: all gradation limit of dense graded cold mixture asphalt yielded the minimum required stability value (min. 300 kg). Regarding the required porosity, middle-upper and upper limit gradation mixtures have values in specified range. The results of this study also indicated that finer gradation mixture could improve the bonding between the emulsion bitumen and aggregates. Designing gradations of mixtures is an economical effort to obtain the best-required cold mixture asphalt. Furthermore, the pavement engineer should consider the selection of aggregate gradation to optimize the use of locally available natural aggregate resources as much as possible. Optimal use of local aggregates could reduce transportation costs and energy.

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