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# 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. This laboratory study was aimed to investigate the effect of aggregate gradations limit on cold mixture asphalt. There are five aggregate gradation limits used in this study, as lower, lower-middle, middle, middle-upper, and upper limit. The Marshall test was 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 on cold mix asphalt generated the best results compared to the middle and lower gradations 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

Cold mix asphalt is a combination of aggregates and bitumen emulsion, just like hot mix asphalt. It is produced by mixing unheated aggregate with emulsion bitumen. 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 mix asphalt is on its low strength and durability compare to hot mix 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. In this study, laboratory tests were conducted for Dense Graded Emulsion Mixture Type IV. This study was aimed to investigate 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.

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## MATERIALS DESCRIPTION AND TESTING PROCEDURES

### Materials

This study was using emulsion bitumen CSS-1h, which is one of the most widely used in dense graded cold mixtures. CSS-1h is a cationic slow setting bitumen emulsion. Table 1 shows the properties and specifications of asphalt emulsion CSS-1h.

**TABLE 1.** Properties and specifications of asphalt emulsion CSS-1h.

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

### Sample preparations and mix designs

In this study, aggregates were supplied from local quarry located in Jember, East Java in Indonesia. Several laboratory tests were conducted to determine the properties of aggregate. Table 2 shows the physical properties and specifications of aggregates. The properties of aggregate were met the requirement in specifications. Each gradation of mixture in this study contained the coarse and fine aggregates designed for dense graded cold mixture asphalt.

**TABLE 2.** Properties and specifications of coarse and fine aggregates

| Properties | Units | Method | Results | | Specifications |
|---|---|---|---|---|---|
| | | | Coarse(1) | Fine(2) | |
| Specific gravity, bulk | - | SNI 1969:2008 | 2.51 | 2.69 | - |
| Specific gravity, SSD | - | | 2.55 | 2.74 | - |
| Specific gravity, apparent | - | | 2.64 | 2.82 | 2.5 min. |
| Water absorption | % | | 1.99 | 1.64 | 3 max. |
| Los Angeles Abrasion | % | SNI 2417:2008 | 28.85 | - | 40 max. |

(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. In this study, aggregates from the same quarry was used as coarse and fine aggregate. A dense graded emulsion mixture uses a continuously graded of coarse and fine aggregates. The aggregate gradation is shown in Table 3 and Fig. 1. Aggregate gradation used in this study was based on a specification limit of Department of Public Works of Indonesia for Dense Graded Emulsion Mixture (DGEM) 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 DGEM 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 |

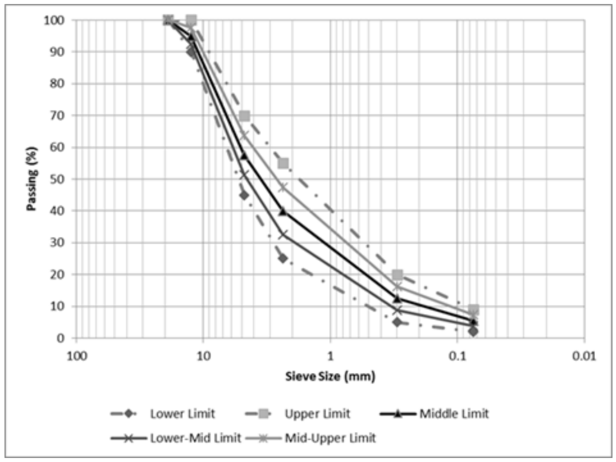


**FIGURE 1.** Aggregate gradation for design mixtures.

There were at least three samples prepared for each emulsion bitumen content. Each sample has an average diameter of 101.6 mm and a height of 63.5 mm. The bitumen content for each gradation were prepared in five variations at two points above and below the initial bitumen content in interval of 0.5%. The initial bitumen content was calculated using formula in Equation 1 and Equation 2 from the Asphalt Institute [7].

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

where:
P = initial residual asphalt content by mass of total mixture (%)
A = percentage of aggregate retained on the 2.36 mm (No. 8) sieve
B = percentage of aggregate passing the 2.36 mm (No. 8) sieve and retained on the 0.075 mm (No. 200) sieve
C = 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. From calculation using Equation 1, 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.

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

where:
IEC = initial emulsion content by mass of total mixture (%)
X = percentage of bitumen content in the emulsion

The mixing process was conducted as following procedures. Prepare the oven-dried proportioned aggregate as in Table 3. The dried aggregate then was pre-wetted with 2% water at the beginning of the mixing process. Five different bitumen emulsion contents were determined as bitumen content by mass of total mixture for each type of aggregate gradations. The determined emulsion bitumen content was then added to the aggregates. All specimens were mixed and compacted at ambient temperature with compaction energy as double of 75 blows at each end. The mixtures then cured in oven at 40°C for 24 hours. Then, prior to Marshall Test, samples were stored at room temperature for 24 hours and continued with capillary soaking condition at half the height of sample for 24 hours for top and bottom side. Marshall Test were conducted to determine soaked Marshall Stability, flow, and also volumetric parameter.

# 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 contains more fine aggregates than middle and lower gradation, the upper limit gradation 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 since this gradation 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 even lower than the requirement in specification. By applying the heavy compaction effort using a Marshall hammer (double of 2x75 blows), the porosity was reduced. To reach the porosity or air voids content as requirements in specification, it need to consider the suitable compaction efforts and adjust as needed according to the aggregate gradation, especially for the finer aggregate gradations. The allowable percentage of porosity is between 5 and 10 percent for dense graded cold mixture asphalt Type IV. The porosity is related to the durability of an asphalt pavement. High porosity in the mixture provides passageways for the entrance of damaging air and water. On the other hand, low porosity in the mixture leads to flushing, which excess bitumen is squeezed out of the mixture to the surface.

Flow values of dense graded cold mixture asphalt were not greatly affected by the difference percentage of coarse aggregates. Middle-Upper Limit gradation 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 has larger MQ value. 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 had values in specified range. The results of this study also indicated that finer gradation 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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