# The effect of crumb rubber in dense graded and open graded cold mixture asphalt

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# The effect of crumb rubber in dense graded and open graded cold mixture asphalt

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**Abstract.** Recycling tires is one of the eco-friendly way for reducing environmental problems. Incorporating crumb rubber in asphalt mixtures is an alternative way for reusing the end-of-life tires in road construction. The main purpose of this study is to evaluate the cold mix asphalt incorporating crumb rubber as a substitute for a part of fine aggregates. In this study, the aggregate gradations for mix design were selected according to the specification, Dense Graded Emulsion Mixtures (DGEM) Type IV and Open Graded Emulsion Mixtures (OGEM) Type E/20. The design bitumen content in this study was optimized for stability, void in mixture (porosity), and density. Crumb Rubber (CR) emulsion mixtures were made with optimum bitumen content at 8% by mass of total mixture for DGEM and OGEM. In order to incorporate crumb rubber into the cold emulsion mixtures, laboratory testing were performed for 25% and 50% of fine aggregates replaced with an equal volume of crumb rubber. In general, CR emulsion mixtures showed good results in all parameters. The CR emulsion mixtures also had a good comparison to hot mix asphalt specification for medium volume traffic loads with porosity less than 10%. From this study, crumb rubber can be recommended as a substitution material of fine aggregates in cold mix asphalt.

## 1. Introduction

Cold mix asphalt (CMA) is a combination of aggregates and bitumen emulsion. CMA are produced by mixing unheated aggregates with bitumen emulsion at ambient temperatures. Bitumen emulsion is a liquid product, which also does not need to heat before the mixing process of CMA. Since this mixing process does not require heating, CMA are good for environment and has great energy savings during mixing process. CMA may be suitable for use in local roads where hot mix asphalt installation are unavailable. Many researches have been done on CMA with promising results to be applied as flexible pavement [1,2,3,4].

Generally, crumb rubber (CR) is produced from waste tires. Recycling tires is one of the eco-friendly way for reducing environmental problems. Incorporating crumb rubber in asphalt mixtures are an alternative way for reusing the end of life tires in road construction. Crumb rubber asphalt mixtures have been widely studied and have numbers of prospective results [1,2,5,6,7,8]. The main purpose of this study is to evaluate the cold mix asphalt incorporating crumb rubber as a substitute for a part of fine aggregate.

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## 2. Materials description and testing procedures

### *2.1. Materials*

The aggregate used in this study was supplied from Banyuwangi quarry, East Java, Indonesia. CMA in this study used cationic slow setting bitumen emulsion (CSS1-h) produced by Triasindomix company. Table 1 shows the properties and specifications of a bitumen emulsion CSS-1h. The residue content of the emulsion was 63.46%. Several laboratory tests were conducted to determine the properties of aggregate. Table 2 shows the physical properties and specifications of aggregates and meet the specifications. Fly ash Type C as filler material was taken from PLTU Paiton, passed through a 0.075 mm sieve (No. 200). In this study, crumb rubber produced by Pura Agung with mesh size #20 (0.841 mm), was incorporated into CMA to substitute 25% and 50% of fine aggregates in the mixtures.

**Table 1.** Properties and specifications of bitumen emulsion CSS-1h.

| Properties | Units | Method | Results | Specifications |
|---|---|---|---|---|
| | | **Test on Emulsions** | | |
| Viscosity, Saybolt-Furol at 25° C | second | SNI 03-6721 | 23.275 | 20-100 |
| Storage stability, 24 hours | % | SNI 03-6828 | 0.33 | 1 max. |
| Particle charge | - | SNI 03-3644 | Positive | Positive |
| Sieve test, retained on No. 20 | % | SNI 03-3643 | 0.00 | 0.10 max. |
| **Distillation** | | | | |
| Residue | % | SNI 03-3642 | 63.46 | 57 min. |
| **Test on Residue from Distillation test** | | | | |
| Penetration at 25° C, 100g, 5 sec | 0.1 mm | SNI 06-2456 | 51.60 | 40-90 |
| Ductility at 25° C, 5 cm/min | cm | SNI 06-2432 | 107 | 40 min. |
| Solubility in trichloroethylene | % | SNI 06-2438 | 98.992 | 97.5 min. |

**Table 2.** Physical properties of aggregates.

| Properties | Units | Method | Results | | | Specifications |
|---|---|---|---|---|---|---|
| | | | F1 | F2 | F3 | |
| Specific gravity, bulk | - | | 2.534 | 2.772 | 2.523 | - |
| Specific gravity, SSD | - | | 2.580 | 2.820 | 2.548 | - |
| Specific gravity, apparent | - | | 2.644 | 2.908 | 2.587 | - |
| Water absorption | % | | 1.650 | 1.680 | 0.977 | 3 max. |
| Los Angeles Abrasion | % | SNI 2417 | 36 | 39 | - | 40 max. |

### *2.2. Sample preparations and mix designs*

In this study, the aggregate gradations for mix design were selected according to the specification, Dense Graded Emulsion Mixtures (DGEM) Type IV and Open Graded Emulsion Mixtures (OGEM) Type E/20. The aggregate gradation for DGEM and OGEM are given in Table 3 and Table 4. Figure 1 shows that the aggregate gradation are within the limits according to the specification limits of the Department of Public Works of Indonesia [7]. Fly ash as filler material (2% by weight of total aggregates) were incorporated into emulsion mixtures to improve the early age strength of the mixtures. Crumb rubber was incorporated directly in the mixture based on dry process by volumetric replacement of fine aggregates in the designed emulsion mixtures. Different percentages of Crumb rubber, 25% and 50%, were then analyzed.

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**Table 3.** Aggregate gradations for DGEM (IV).

| Sieve size | | Coarse Aggregate (F1) 10-15 mm | Medium Aggregate (F2) 5-10 mm | Fine Aggregate (F3) 0-5 mm | Filler (Fly Ash Type C) | Combined Aggregate | Specifications |
|---|---|---|---|---|---|---|---|
| No | mm | 23% | 32% | 43% | 2% | | DGEM (IV) |
| ¾ inch | 19 | 23.00 | 32.00 | 43.00 | 2.00 | 100.00 | 100 |
| ½ inch | 12.5 | 14.16 | 32.00 | 43.00 | 2.00 | 91.16 | 90-100 |
| 4 | 4.75 | 0.39 | 11.73 | 42.75 | 2.00 | 56.88 | 45-70 |
| 8 | 2.36 | 0.35 | 2.68 | 35.39 | 2.00 | 40.43 | 25-55 |
| 50 | 0.3 | 0.00 | 1.56 | 11.53 | 2.00 | 15.09 | 5-20 |
| 200 | 0.075 | 0.00 | 1.09 | 4.81 | 2.00 | 7.90 | 2-9 |

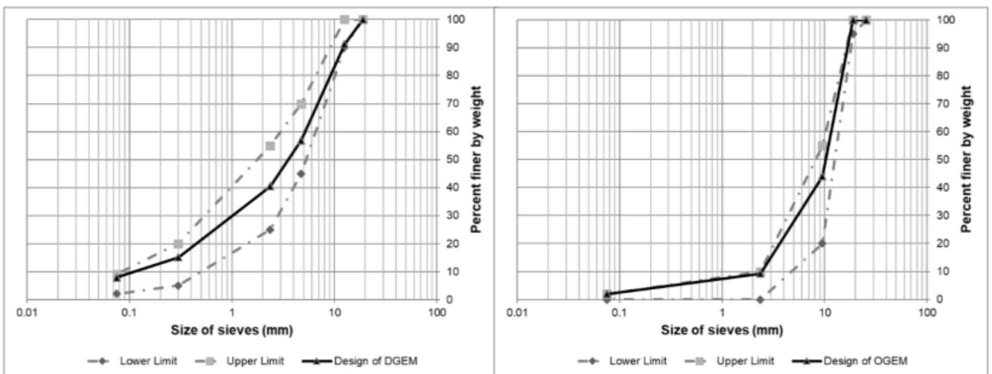


**Figure 1.** Aggregate gradation for dense (DGEM) and open (OGEM) graded design mixtures.

**Table 4.** Aggregate gradations for OGEM (E/20).

| Sieve size | | Coarse Aggregate (F1) 10-15 mm | Medium Aggregate (F2) 5-10 mm | Fine Aggregate (F3) 0-5 mm | Filler (Fly Ash Type C) | Combined Aggregate | Specifications |
|---|---|---|---|---|---|---|---|
| No | mm | 68% | 24% | 6% | 2% | | OGEM (E/20) |
| 1 inch | 25.4 | 68.00 | 24.00 | 6.00 | 2.00 | 100.00 | 100 |
| 3/4 inch | 19 | 68.00 | 24.00 | 6.00 | 2.00 | 100.00 | 95-100 |
| 3/8 inch | 9.5 | 12.10 | 24.00 | 6.00 | 2.00 | 44.10 | 20-55 |
| 8 | 2.36 | 0.68 | 1.68 | 4.91 | 2.00 | 9.26 | 0-10 |
| 200 | 0.075 | 0.00 | 0.00 | 0.00 | 2.00 | 2.00 | 0-2 |

## 3. Results and discussion

### *3.1. Determination of optimum bitumen content for emulsion mixtures*

Table 5 and Table 6 shows the cold mix design results for DGEM and OGEM, three specimens were prepared at five variations of bitumen content for DGEM and OGEM. All the specimens were prepared for Marshall testing in standard molds with 75 blows Marshall hammer on each side of the specimen in room temperature.

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**Table 5.** Results of mix design for DGEM (IV).

| Properties | Units | Bitumen content (%) | | | | | Specifications |
|---|---|---|---|---|---|---|---|
| | | **8** | 8.5 | 9 | 9.5 | 10 | |
| Soaked Stability | kg | **1145** | 1142 | 1141 | 1130 | 1036 | 300 min. |
| Void in Mixture (VIM) | % | **6.9** | 7.4 | 8.3 | 8.5 | 5.3 | 5 – 10 |
| Density | gram/cm$^3$ | **2.192** | 2.165 | 2.131 | 2.111 | 2.169 | |
| Void in Mineral Aggregate (VMA) | % | **23** | 24 | 26 | 27 | 25 | - |
| Void Filled with Bitumen (VFB) | % | **69** | 69 | 68 | 68 | 79 | - |
| Asphalt Film Thickness (AFT) | µm | **16** | 17 | 18 | 19 | 21 | 8 min. |

**Table 6.** Results of mix design for OGEM (E/20).

| Properties | Units | Bitumen content (%) | | | | | Specifications |
|---|---|---|---|---|---|---|---|
| | | **8** | 8.5 | 9 | 9.5 | 10 | |
| Soaked Stability | kg | **812** | 659 | 663 | 580 | 662 | 300 min. |
| Void in Mixture (VIM) | % | **4.6** | 4.3 | 3.5 | 3.0 | 2.2 | - |
| Density | gram/cm$^3$ | **2.244** | 2.235 | 2.237 | 2.234 | 2.237 | - |
| Void in Mineral Aggregate (VMA) | % | **20** | 21 | 21 | 22 | 22 | - |
| Void Filled with Bitumen (VFB) | % | **77** | 80 | 83 | 86 | 90 | - |
| Asphalt Film Thickness (AFT) | µm | **44** | 48 | 51 | 54 | 58 | 8 min. |

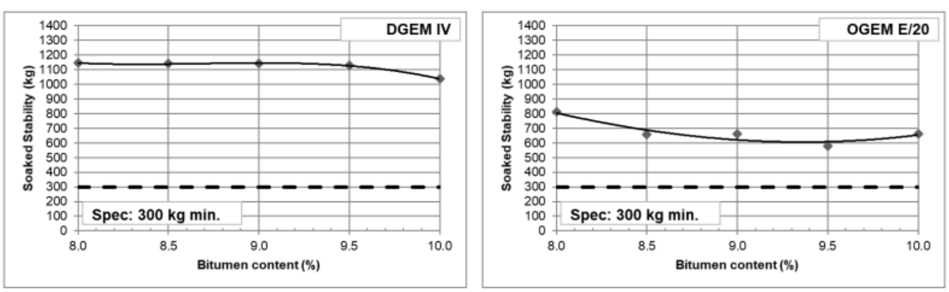


**Figure 2.** Stability of mix design for DGEM and OGEM.

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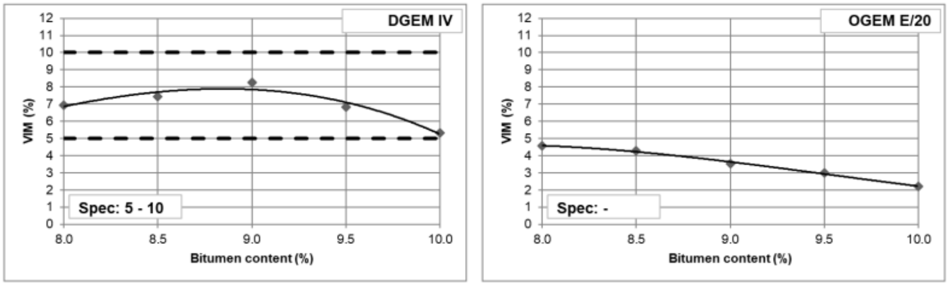


**Figure 3.** Void in Mixture (VIM) of mix design for DGEM and OGEM.

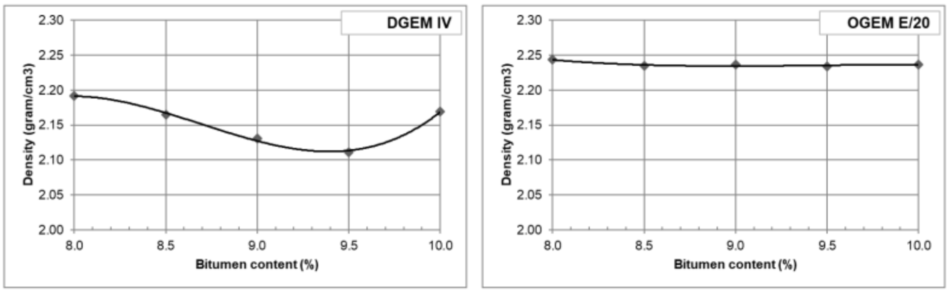


**Figure 4.** Density of mix design for DGEM and OGEM.

The design bitumen content in this study was optimized for stability, void in mixture (VIM), and density. According to the result shown in Figure 2, the maximum stability was reached at mix design for bitumen content of 8% for DGEM and OGEM. The porosity (VIM) of DGEM were also met the requirement in specification, and the porosity for OGEM is not specified in specification (Figure 3). Density of DGEM and OGEM were reached the maximum value for bitumen content of 8%, as shown in Figure 4. Considering these results, it was determined that the optimum bitumen content was at 8% by mass of total mixture for DGEM and OGEM.

### *3.2. Performances of Crumb Rubber emulsion mixtures*

Crumb Rubber (CR) emulsion mixtures were made with optimum bitumen content at 8% by mass of total mixture for DGEM and OGEM. In order to investigate the performance of crumb rubber emulsion mixtures, laboratory testing were performed for 25% and 50% of fine aggregates replaced with an equal volume of crumb rubber. All factors in mixtures were keeping constant. The performances of CR emulsion mixtures were also observed at 7 days of curing time in room temperature due to emulsion mixtures has low early age strength.

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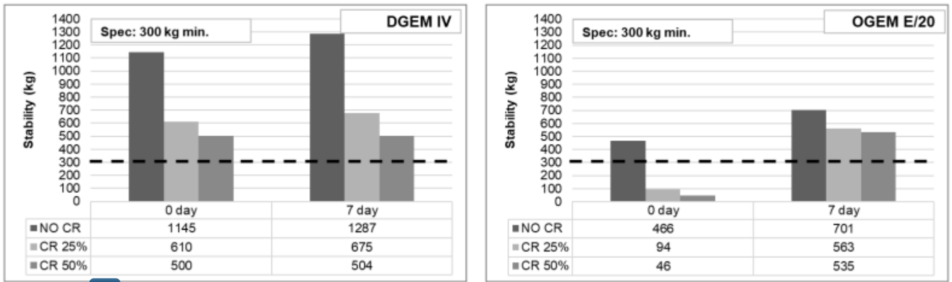


**Figure 5.** The effect of crumb rubber content on stability of emulsion mixtures.

Stability tends to increase with an increase in curing time, as shown in Figure 5 because CMA required longer curing times. Although the use of recycled crumb rubber reduced the stability of CMA about 50%, but still met the minimum requirement as in standard specification for 7 days curing time. The dense graded CMA produced the higher stability than OGEM. However, using of crumb rubber significantly improved the stability of open graded crumb rubber CMA after 7 days of curing time.

The CR emulsion mixture also produced the required value of porosity (VIM) as in standard specification. Results indicated that porosity (VIM) of the emulsion mixtures increased as the amount of crumb rubber increased. This condition occurred due to the CR emulsion mixtures had become stiffer made mixture hard to compact. The results (Figure 7) showed that at 7 day of curing time the more crumb rubber content in open graded emulsion mixtures produced better void in mixtures, which reached the requirement in specification.

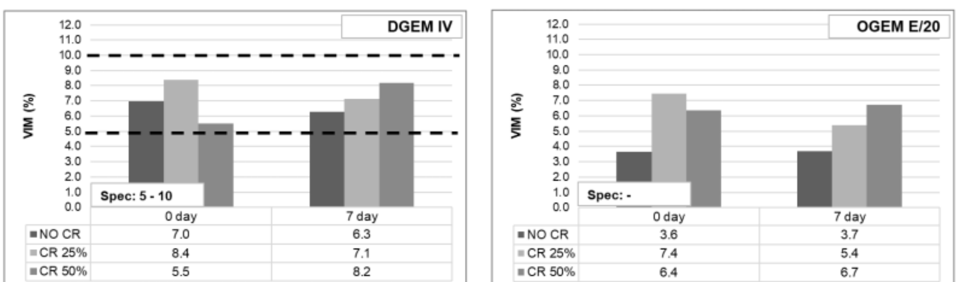


**Figure 6.** The effect of crumb rubber content on porosity (VIM) of emulsion mixtures

The CR emulsion mixtures tend to decrease the mixture density at 7 days of curing time as shown in Figure 7. Along with the porosity (VIM) increases, the density of CR emulsion mixtures decreases. When the porosity of the emulsion mixture increases, it was found that the water absorption also increases (Figure 8). Porous mixtures allow water to pass through the pores.

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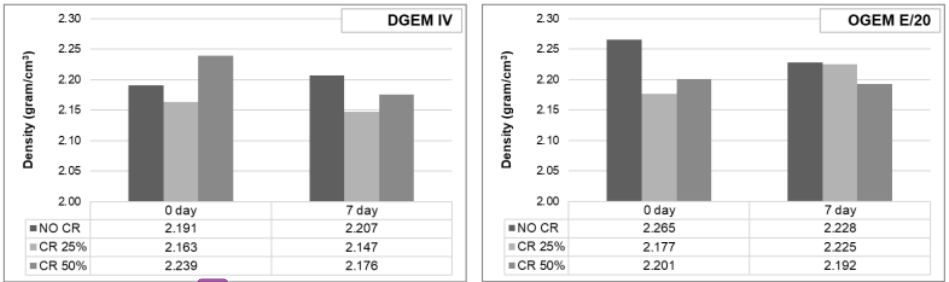


**Figure 7.** The effect of crumb rubber content on density of emulsion mixtures

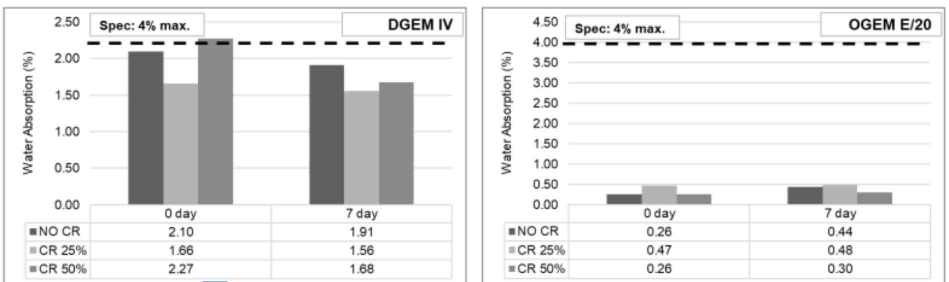


**Figure 8.** The effect of crumb rubber content on water absorption of emulsion mixtures

In general, CR emulsion mixtures showed good results in all parameters. The emulsion mixtures at 7 days of curing time also had a good comparison to HMA specification with porosity less than 10%, as SS, HRS-A and AC-WC, as shown in Table 7 (for dense graded mixtures) and table 8 (for open graded mixtures). Therefore, CR emulsion mixtures could be considered as an alternative mixture to be applied as flexible pavement for medium volume traffic loads. The benefit of CR emulsion mixtures are that this mixture does not need heat during the mixing process and the use of recycling of waste tires, also give contribution to the environment concern.

**Table 7.** Comparison of dense graded emulsion mixtures (DGEM) to HMA specifications.

| Properties | 7 days of curing | | | Specifications | | | |
|---|---|---|---|---|---|---|---|
| | No CR | CR 25% | CR 50% | DGEM Type IV | SS-A[1] | HRS-A[2] | AC-WC[3] |
| Soaked Stability (kg) | 1287 | 675 | 504 | 200 min. | 200 min. | 450 min. | 800 min. |
| Retained Stability (%) | 92 | 85 | 77 | 50 min. | 75 min. | 75 min. | 75 min. |
| VIM (%) | 6.3 | 7.1 | 8.2 | 5 - 10 | 3 - 9 | 4 - 6 | 3 - 5 |
| Density (gram/cm3) | 2.21 | 2.15 | 2.18 | - | - | - | - |
| Water Absorption (%) | 1.91 | 1.56 | 1.68 | 4 min. | - | - | - |
| VMA (%) | 22 | 23 | 24 | - | 20 min. | 18 min. | 15 min. |
| VFB (%) | 71 | 69 | 65 | - | 75 min. | 68 min. | 65 min. |
| MQ (kg/mm) | 267 | 95 | 83 | - | 80 min. | 250 min. | 250 min. |
| BFT (mm) | 19 | 23 | 28 | 8 min. | 8 min. | 8 min. | 8 min. |

Note: [1]Sand Sheet (SS-A); [2]Hot Rolled Sheet Wearing Course (HRS-A); [3]Asphalt Concrete Wearing Course (AC-WC)

**Table 8.** Comparison of open graded emulsion mixtures (OGEM) to HMA specifications.

| Properties | 7 days of curing | | | Specifications | | | |
|---|---|---|---|---|---|---|---|
| | **No CR** | **CR 25%** | **CR 50%** | **OGEM E-20** | **SS-A[1]** | **HRS-A[2]** | **AC-WC[3]** |
| Soaked Stability (kg) | 701 | 563 | 535 | 200 min. | 200 min. | 450 min. | 800 min. |
| Retained Stability (%) | 61 | 84 | 77 | 50 min. | 75 min. | 75 min. | 75 min. |
| VIM (%) | 3.7 | 5.4 | 6.7 | - | 3 - 9 | 4 - 6 | 3 - 5 |
| Density (gram/cm3) | 2.228 | 2.225 | 2.192 | - | - | - | - |
| Water Absorption (%) | 0.443 | 0.477 | 0.299 | - | - | - | - |
| VMA (%) | 19 | 21 | 22 | - | 20 min. | 18 min. | 15 min. |
| VFB (%) | 74 | 74 | 69 | - | 75 min. | 68 min. | 65 min. |
| MQ (kg/mm) | 106 | 50 | 60 | - | 80 min. | 250 min. | 250 min. |
| BFT (mm) | 25 | 25 | 26 | 20 min. | 8 min. | 8 min. | 8 min. |

Note: [1]Sand Sheet (SS-A); [2]Hot Rolled Sheet Wearing Course (HRS-A); [3]Asphalt Concrete Wearing Course (AC-WC)

## 4. Conclusions

From this study, crumb rubber can be recommended as a substitution material of fine aggregates in cold mixture asphalt, for dense and open graded emulsion mixtures. After 7 days of curing time, crumb rubber emulsion mixtures for dense and open graded emulsion mixtures have the promising results and comparable to conventional hot mixture asphalt. It has been shown that at 50% crumb rubber substitution for both type of emulsion mixtures, the CR emulsion mixtures still reached the stability values that meet the standard specification for medium volume traffic loads with porosity less than 10%. Substitution of fine aggregate with crumb rubber on CMA is expected to overcome the environmental problems by using the recycles material from used tires to preserve the natural aggregates. Besides the CMA itself is also eco-friendly mixtures as the mixing process done at ambient temperature.

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