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The use of crumb rubber for replacing fine aggregate in cold mixture asphalt

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Abstract. In order to consider the environmental impact, this study investigated the effect of crumb rubber on the mechanical performance of cold mixture asphalt. Crumb rubber was obtained from the process of recycling waste tires, which this waste material becomes a major environmental problem due to the rapid increase in the number of motor vehicles in Indonesia. Cold mixture asphalt is an environmental friendly option on flexible pavement, which reduces energy consumption because it does not need heat during the process as in hot mixture asphalt. In this study, laboratory tests were conducted for Dense Graded Emulsion Mixture Type IV. The first stage in this study was to perform laboratory experiments on compacted mixture to determine the optimum residual bitumen content. In the next stage, a series of tests on crumb rubber mixtures were conducted in the optimum residual bitumen content condition to investigate the effect of crumb rubber as a partial replacement of fine aggregate. Fine aggregate in cold mixture asphalt was replaced with 50% of crumb rubber. Three different sizes of crumb rubber, 20 mesh (0.841 mm), 40 mesh (0.42 mm) and 60 mesh (0.25 mm), were applied in a series of laboratory experiments. Tests were done using Marshall Test equipment to obtain the mechanical performance of cold mixture asphalt. The finding indicated that finer crumb rubber produced higher stability than the larger size of crumb rubber. Even though the use of crumb rubber decreased stability of mixtures, it still met the minimum specified requirement of cold mixture asphalt. The stability of the crumb rubber cold mixtures were also comparable to hot mixture asphalt. Replacement of fine aggregate with crumb rubber on cold mixture asphalt is expected to overcome the environmental problems by reuse the waste materials to preserve the natural aggregates.

1. Introduction

In Indonesia, hot mix asphalt (HMA) is the most commonly used as asphalt pavement on new roads, overlays, and pavement patching. HMA needs high quality of aggregate to produce life-long pavement, such as tough and abrasion resistant aggregates. In some areas in Indonesia, to produce the specified HMA, the aggregates are often supplied from other area, which needs more cost and time. Compared to cold mixture asphalt (CMA), HMA also consumes more energy to heat the mixture. As the car tyres become a major global waste problem, it needs more attention on the use of recycled car tyres in the pavement design. The end product of recycled car tyres which is crumb rubber has various sizes depending on the diameter of the crumbs. Crumb rubber is made from selected waste tire which no longer be contaminated by steel wire or nylon.

For the environmental impact, the use of CMA, local aggregate and alternative waste material beside natural aggregate in asphalt mixture could be considered. The use of crumb rubber as waste

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material tends to increase the strength of asphalt mixture [1]. Volumetric and mechanical properties of asphalt mixtures were affected by rubber gradation and percentage [2]. The objective of this study was to investigate the effect of crumb rubber size on performance of cold asphalt mixtures.

2. Materials description and testing procedures

2.1. Materials

CMA in this study used cationic slow setting asphalt emulsion (CSS1-h) produced by Triasindomix company. Table 1 shows the properties and specifications of asphalt emulsion CSS-1h. The asphalt content of the emulsion was 63.46%. The aggregate used in this study was supplied from Banyuwangi quarry, East Java, Indonesia. 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. Filler material passed through a 0.075 mm sieve (No. 200). This study incorporated crumb rubber produced by Pura Agung Company in three variations of sizes. The higher the mesh size, the smaller the crumb. In this study, crumb rubber with mesh size #20 (0.841 mm), #40 (0.42 mm), #60 (0.25 mm) were incorporated into CMA as a replacement material of fine aggregates.

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	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.

2.2. Sample preparations and mix designs

This study was conducted on two stages. First stage performed the mix design to determine optimum bitumen content. Second stage was to investigate the effect of crumb rubber size on performance of cold asphalt mixtures.

In this study, one type of aggregate was used as coarse and fine aggregate. The aggregate gradation for mix design was selected according to Dense Graded Emulsion Mixtures (DGEM) Type IV Specification. The aggregate gradation is given in table 3 and figure 1 shows that the aggregate gradation is within the limits according to the specification limits of the Department of Public Works of Indonesia [3]. In order to improve CMA at the early ages strength of the mixtures, fly ash as filler material (2% by weight of total aggregates) was used in all mixtures.

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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	36.04	38.66	-	40 max.

Table 3. Aggregate gradations for DGEM type 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%	100%	DGEM Type IV
3/4"	19	23.00	32.00	43.00	2.00	100.00	100
1/2"	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

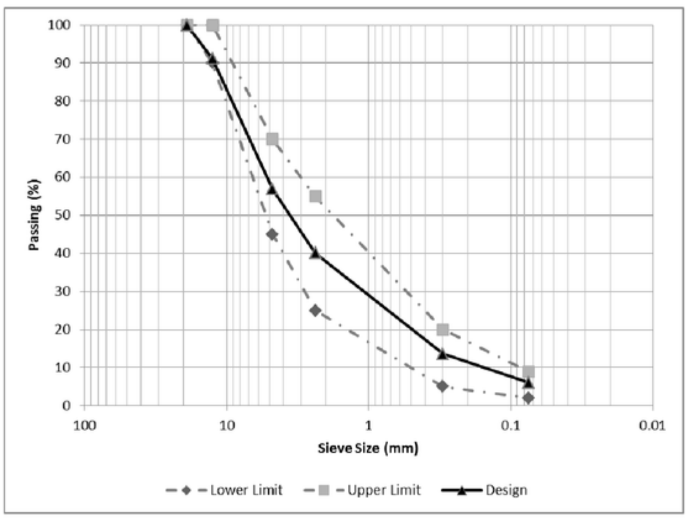


Figure 1. Aggregate gradation for design mixtures.

In order to determine the optimum bitumen content (OBC), mix designs were done in various emulsion content based on calculation as in equation (1) and equation (2) from the Asphalt Institute [4]. The initial emulsion content was determined as 9% by mass of total mixture.

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

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

$$IEC = (P/X) \tag{2}$$

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

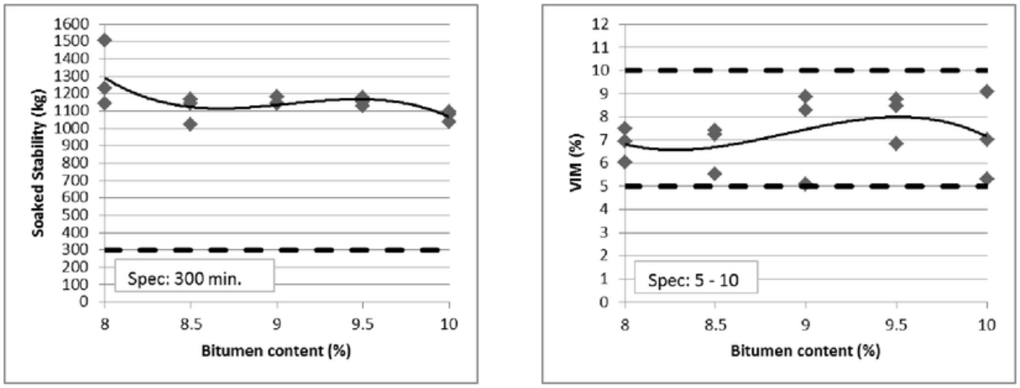
The mixing process was conducted as following procedures. Prepare the oven-dried proportioned aggregate as in table 3. The dried aggregate then was pre-wetted with 2% water at the beginning of the mixing process. Five different bitumen emulsion content were determined as 8%, 8.5%, 9%, 9.5%, and 10% by mass of total mixture. The determined emulsion content was then added to the aggregates. Compactions of the DGEMs were done by applying 75 blows to each end using Marshall Compactor. The DGEMs then cured in oven at 40°C for 24 hours. Then, Marshall Test was conducted to determine the optimum bitumen content and Marshall properties.

3. Results and discussion

Table 4 shows the Marshall, stability and flow test results of fifteen specimens, three specimens were prepared at each bitumen content. The OBC was chosen as the percentage of bitumen content at which the CMA properties meet the specifications of DGEM Type IV as shown in table 4. The OBC was determined considering the maximum soaked stability mixture which was at 8% by mass of total mixture [5], as shown in figure 2. The values of VMA and VFB in all mixtures also meet the general requirements as in specification of HMA, although VMA and VFB are not specified in CMA.

Table 4. Properties of the DGEM Type IV.

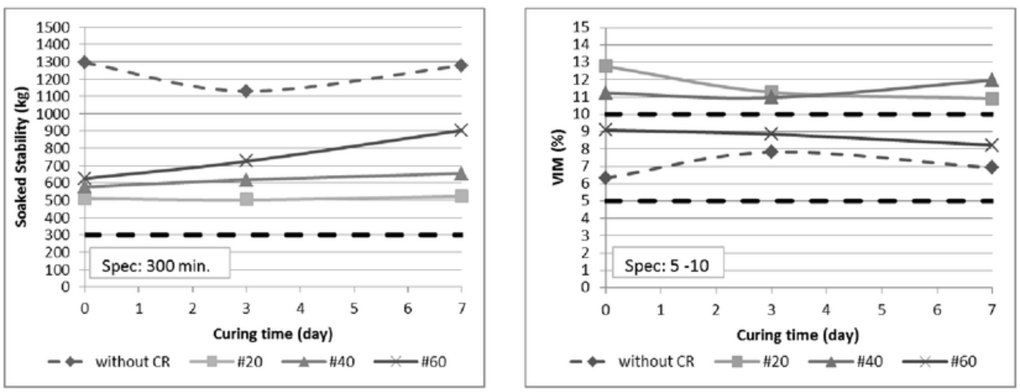
Properties	Units	Bitumen content (%)					Specifications
		8	8.5	9	9.5	10	
Soaked Stability	kg	**1294.045**	1109.841	1155.202	1153.555	1070.673	300 min.
Void in Mixture (VIM)	%	**6.810**	6.724	7.411	8.022	7.141	5 – 10
Void in Mineral Aggregate (VMA)	%	**22.402**	23.286	24.786	26.199	26.406	-
Void Filled with Bitumen (VFB)	%	**69.646**	71.213	70.387	69.448	73.165	-
Asphalt Film Thickness (AFT)	μm	**15.757**	16.931	18.118	19.318	20.532	8 min.



(a) (b)

Figure 2. Relationships of stability (a) and VIM (b) with variation of bitumen content.

Crumb rubber asphalt mixtures were prepared at optimum bitumen content. In order to incorporate crumb rubber into the CMA, a 50% by weight of fine aggregate was replaced with an equal volume of each size of crumb rubber. All factors in mixtures were keeping constant.



(a) (b)

Figure 3. Effect of curing time on soaked stability (a) and VIM (b) of crumb rubber asphalt mixtures.

The stability increased with an increase in curing time, as shown in figure 3 because CMA required longer curing times. Although the use of recycled crumb rubber reduced the stability of CMA, but still met the minimum requirement as in standard specification. The finer crumb rubber in the CMA mixtures produced the higher stability. The finer crumb rubber (#60) in CMA also produced the required value of Void in Mixture (VIM) as in standard specification. In this study showed that the finer crumb rubber produced less void in mixtures, which is closely related to durability of mixtures.

In general, the finer crumb rubber as fine aggregate replacement in CMA had better properties than the larger sized crumb rubber. Also, the mixtures had a good comparison to HMA specification, as HRS-A and AC-WC, as shown in table 5. Therefore, crumb rubber modified CMA can be used as flexible pavement, which does not need heat during the process and the use of recycling of waste tires, also give contribution to the protection of environment.

Table 5. Comparison of mixtures to HMA specifications.

Properties	7 days of curing				Specifications		
	NO CR	#20	#40	#60	DGEM Type IV	HRS-A[1]	AC-WC[2]
Soaked Stability (kg)	1277.211	522.832	654.568	903.820	300 min.	450 min.	800 min.
VIM (%)	6.917	10.906	11.957	8.220	5 - 10	4 - 6	3 - 5
VMA (%)	22.484	25.806	26.681	23.569	-	18 min.	15 min.
VFB (%)	69.282	57.785	55.219	65.124	-	68 min.	65 min.
Flow (mm)	4.572	8.213	7.281	8.043	-	3 min.	2 - 4
Retained Stability (%)	90.347	91.439	79.874	89.189	50 min.	75 min.	75 min.

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

4. Conclusions

From this study, it can be recommended that crumb rubber can be incorporated into CMA as a replacement material of fine aggregates. It has been shown that at 50% crumb rubber replacement, the CMA with crumb rubber had stability that meet the standard specification. The finer crumb rubber in the CMA mixtures produced the higher stability. The finer crumb rubber (#60) in CMA also produced the required Void in Mixture (VIM) as in standard specification. Replacement of fine aggregate with crumb rubber on CMA is expected to overcome the environmental problems by reuse the waste materials to preserve the natural aggregates.

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