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Effect of Crumb Rubber as Fine Aggregate Replacement in Cold Mixture Asphalt

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Abstract: The number of waste tires has been increasing as an impact of rapidly growing number of vehicles and becomes a global environmental concern. The environmental impact can be reduced by converting the waste tires to crumb rubber and reusing it as a replacement of fine aggregates in asphalt mixture. Dense graded cold mixtures asphalt design was developed for rubberized mixtures with up to 100% (by weight) crumb rubber replacement. Series of laboratory testing were performed for evaluating the Marshall stability and volumetric properties of rubberized cold mixture asphalt. The findings of this laboratory study indicated that Marshall stability and volumetric properties of these mixtures were affected by crumb rubber percentage. Although the use of crumb rubber in cold mixture asphalt could decrease the mechanical and volumetric properties of mixtures, but still has a great potential as a partial fine aggregate replacement in cold mixture asphalt. Rubberized cold mixture asphalt could be considered as a flexible pavement subjected to low traffic medium load.

Keywords: Crumb rubber; bitumen emulsion; cold mix; Marshall test.

Introduction

A serious problem that lead to environmental pollution is the increase of waste tires disposal. The environmental impact can be reduced by converting this tire waste to crumb rubber and reusing it to replace fine aggregate in asphalt mixture. Several studies presented the application of crumb rubber in asphalt mixtures as flexible pavement [1-5].

Crumb rubber from waste tires is widely used as a bitumen modifier (in the wet process) or as a substitute of part of a mineral component (aggregate) in asphalt mixtures (in the dry process) for use in asphalt–rubber mixtures for construction of pavement layers.

Cold Mixture Asphalt (CMA) is a pavement mixture using bitumen emulsion without heating the materials and mixed at ambient temperature. The mixtures set when the water evaporates. CMA consists of two types of mixtures, dense graded and open graded emulsion mixture. Dense graded mixtures contain selected aggregate including fines material and filler. Open graded mixture, on the contrary, contain aggregate without fine aggregate.

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The present study has been undertaken in order to develop a CMA incorporating crumb rubber into mixtures. This study investigates the mechanical and volumetric properties of CMA containing crumb rubber. The rubberized CMA was produced by replacing part of fine aggregates with crumb rubber by varying the percentage of crumb rubber. The use of crumb rubber as a fine aggregate replacement in CMA is considered as a sustainable material in pavement construction.

Materials and Experimental Design

This study investigated the effect of crumb rubber as fine aggregate replacement in cold mixture asphalt. Crumb rubber was supplied by a local industry, which was produced from waste tire rubber. In this study, crumb rubber #40 (0.42 mm) was used as the replacement of fine aggregates in CMA. Four percentage; 25%, 50%, 75%, and 100% by weight of fine aggregates are considered in this study. The difference in density of fine aggregates crumb rubber was taken into consideration while replacing. Each design mixture was prepared for three samples. At first stage, 15 samples for unmodified cold mixture asphalts were investigated to determine the optimum bitumen content (OBC). The next stage required a total of 45 samples to investigate the possibility of the crumb rubber utilization as fine aggregate replacement.

Aggregates

In this study, local aggregates were utilized to make the CMA. The use of local aggregates, which has lower quality material, is in order to reduce the energy consumption for the transport of aggregates from quarry to site. It is still acceptable for low volume traffic pavement. The coarse and fine aggregates (Figure 1) used for this study was supplied from Banyuwangi quarry, East Java Province in Indonesia. Aggregates with maximum size of 15 mm were used as coarse aggregates. The physical properties and specifications of aggregates are shown in **Error! Reference source not found.** according to the specification limits of the Department of Public Works of Indonesia [6].

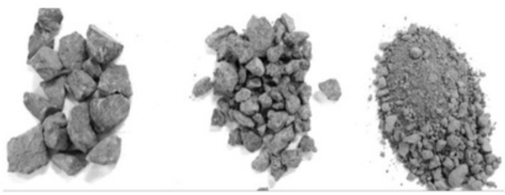


Figure 1. The Coarse and Fine Aggregates

Fly ash type C (Figure 2) was applied in all sample mixtures as a filler material at 2% of total mass of aggregates. The use of fly ash was to accelerate the Marshall stability of CMA. As it is known that CMA has weak early life strength as emulsion bitumen in mixture contains water and need long curing time to evaporate water content. There was a significant enhancement in properties of cold asphalt mixtures incorporating of fly ash [7]. Fly ash Type C as filler material, passed sieve 0.075 mm (No. 200), as a waste material, was taken from Paiton Power Plant in East Java.

Figure 2. Fly ash type C

Bitumen Emulsion

Bitumen emulsion consists of three main ingredients; bitumen, water, and emulsifier agent. The emulsion bitumen used in this study was CSS-1h. This type is a cationic slow setting asphalt emulsion. Bitumen emulsions are classified based on the type of surface charge. The electrical charge of the bitumen is to improve adhesion properties with aggregates being used in mixtures. Slow setting emulsions make the setting process very slow, which give sufficient time for uniform blending of the mixtures. The properties and specifications of bitumen emulsion are shown in Table 2.

Crumb Rubber

Crumb rubber is a term usually applied to recycled rubber from automotive and truck scrap tires. Crumb Rubber is made from selected waste tire which no longer be contaminated by steel wire or nylon. There are two major technologies for producing crumb rubber – ambient mechanical grinding and cryogenic grinding. The cryogenic system is used

Table 1. Physical Properties and Specifications 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 2. Properties and Specifications of Bitumen Emulsion CSS-1h

Properties	Units	Method	Results	Specifications
Test on Emulsions				
Viscosity, Saybolt-Furol at 25° C	second	ASTM D-244	23.275	20-100
Storage stability, 24 hours	%	ASTM D-6930	0.33	1 max.
Particle charge	-	ASTM D-244	Positive	Positive
Sieve test, retained on No. 20	%	ASTM D-6935	0.00	0.1 max.
Distillation				
Residue	%	ASTM D-244	63.46	57 min.
Test on Residue from Distillation test				
Penetration at 25° C, 100g, 5 sec	0.1 mm	ASTM D-5	51.60	40-90
Ductility at 25° C, 5 cm/min	cm	ASTM D-113	107	40 min.
Solubility in trichloroethylene	%	ASTM D-2042	98.992	97.5 min.

to reduce the material in size and then to remove the metals. In this study, crumb rubber (CR) #40 (0.42 mm) was used as the replacement of fine aggregates in dense graded cold mixture asphalt (Figure 3).

Figure 3. Crumb Rubber #40 (0.42 mm)

Cold Asphalt Mixtures

First stage in this study was to determine the Optimum Bitumen Content (OBC) of Cold Mixtures Asphalt (CMA). According to the previous studies [8-10], the OBC is determined by optimizing all Marshall properties, especially soaked stability and porosity or Void in Mixture (VIM). Before producing CMA samples, the percentage of initial residual asphalt content (P), by mass of total mixture, was estimated using the formula as shown in Equation 1 [11].

$$P = (0.005A + 0.1B + 0.5C) \, x \, 0.7 \qquad (1)$$

The values A, B, and C were determined based on the aggregate gradation for dense graded emulsion mixtures (DGEM) Type IV as shown in Table 3. A = percentage of aggregate retained on the sieve 2.36 mm (No. 8) = 14.12%, B = percentage of aggregate passing the sieve 2.36 mm (No. 8) and retained on the sieve 0.075 mm (No. 200) = 37.38%, and C = percentage of aggregate passing the sieve 0.075 mm (No. 200) = 7.26%. It was calculated that P was 5.65%. Then, the percentage of initial emulsion content (IEC), by mass of total mixture, was determined using Equation 2 [11]

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

The value X is residue asphalt in bitumen emulsion = 63.46% as shown in Table 2. The value of initial emulsion content was determined at 9%.

The aggregate gradation for each CMA is shown in Figure 4 based on the specifications in Table 3. Based on the results of initial emulsion content, samples were prepared with variation of bitumen content at two points above and two points below the initial emulsion content 9% in interval of 0.5%. Three cylindrical Marshall samples were prepared at each bitumen emulsion contents, yielding a total of 5 specimens. Each sample was made with 101.6 mm diameter, approximately 70 mm height and 1200 g of mass. The materials were mixed in room temperature. Mixtures were then placed in the Marshall moulds and compacted with 75 blows of the Marshall compactor on each side of the samples. After compaction, all the moulds containing mixture samples were cured for one day at room temperature. After that, samples were taken out and kept one day in an oven at 40°C. Then, the samples were removed from oven and stored one day at room temperature. The samples were then tested for Marshall Stability at room temperature.

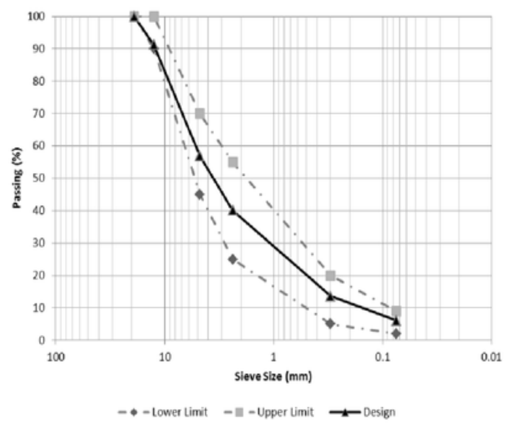


Figure 4. Aggregate Gradation for Design Mixtures

Results and Discussion

The Marshall properties of the DGEMs type IV for a variation in bitumen content are shown in Figures 5 to 9. It is shown that all properties of design mixtures meet the requirement and specifications, as shown in Table 4.

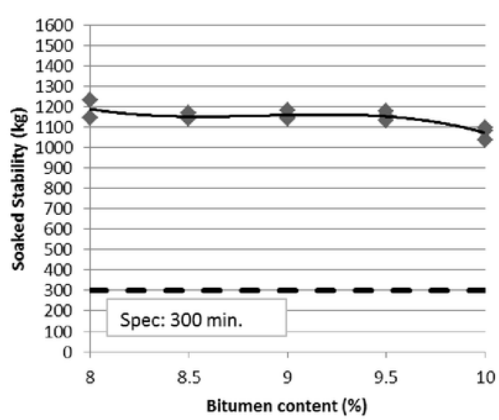


Figure 5. Bitumen Content vs Soaked Stability

Table 3. Aggregate Gradation for DGEM Type IV

Sieve size		Coarse Aggregate (F1)	Medium Aggregate (F2)	Fine Aggregate (F3)	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

Table 4. Determination of OBC by Marshall Method of Mix Design

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.

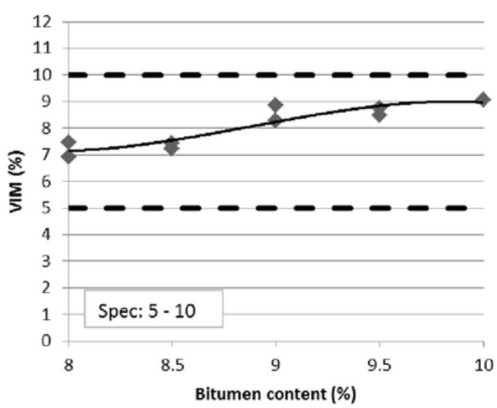


Figure 6. Bitumen Content vs VIM

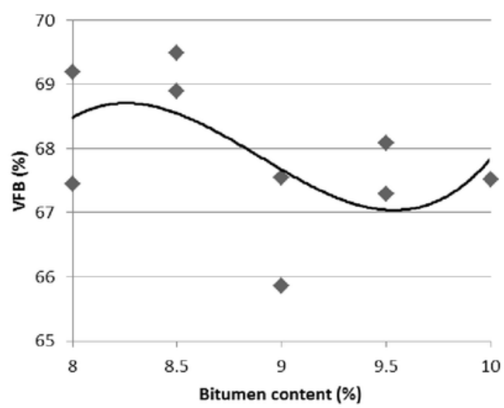


Figure 8. Bitumen Content vs VFB

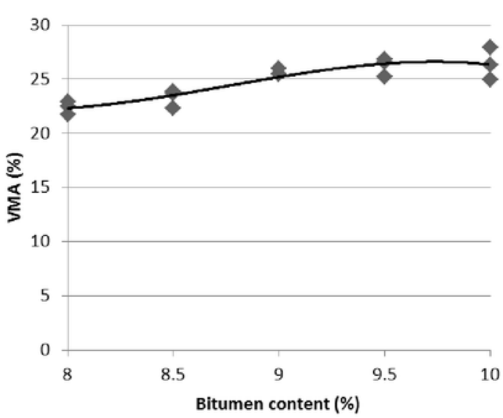


Figure 7. Bitumen Content vs VMA

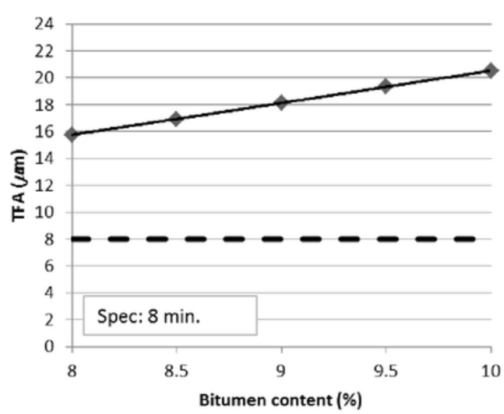
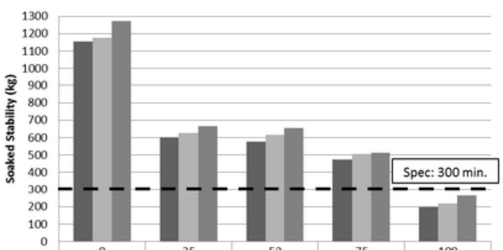


Figure 9. Bitumen Content vs TFA

The main parameters are considered as the soaked stability and porosity or Void in Mixture (VIM) [9]. By optimizing soaked stability and VIM [10], which is maximum soaked stability and minimum VIM, as shown in Figures 5 and 6, the OBC was determined to be at 8%. Meanwhile, other parameters were within standard requirement. VMA and VFB are not specified in dense graded CMA.

This study designed CMA samples at previously determined OBC as the control mixture and four variations of rubberized CMA samples at OBC. Each type of mixtures consisted of three samples. Crumb rubber #40 (0.42 mm) was used as the replacement for four various percentage of fine aggregates in CMA, as 25%, 50%, 75%, and 100% by weight of fine aggregates. In this study, aggregates with maximum size of 2.36 mm were considered as fine aggregates. Considering the different densities of crumb rubber and fine aggregates, the replacement with crumb rubber was conducted with an equal volume of crumb rubber. Finally, the samples were cured for different times, 3 and 7 days respectively, at room temperature prior to Marshall stability test.



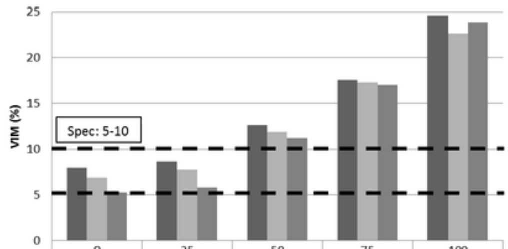
	0	25	50	75	100
0	1156.445	600.558	577.295	473.602	197.317
3 days	1176.919	625.626	617.353	504.583	218.147
7 days	1273.346	664.047	654.568	514.788	264.402

CR Content (%)

■ 0 ■ 3 days ■ 7 days

Figure 10. Effect of Crumb rubber (CR) Content on Soaked Stability

The Marshall stability of samples was measured for without curing time (0), 3 days of curing time, and 7 days. Overall, it is clearly shown in Figure 10 that the Marshall soaked stability of each control and crumb rubber mixtures increase over the curing time of 3 and 7 days. The increase of stability of CMA is greatly affected by the evaporation of water content in the mixtures. It is observed that the Marshall stability reduced significantly as the amount of crumb rubber as replacement of fine aggregates increased. However, crumb rubber content up to 75% showed good result in stability and meet the minimum requirement for design mixtures. When crumb rubber content increases, the asphalt mixture become more flexible. This could cause instability under loading condition, which is shown by high deformation of mixture.



	0	25	50	75	100
0	7.976	8.640	12.606	17.599	24.604
3 days	6.838	7.755	11.837	17.285	22.624
7 days	5.253	5.775	11.180	17.039	23.868

CR Content (%)

■ 0 ■ 3 days ■ 7 days

Figure 11. Effect of Crumb Rubber (CR) Content on Porosity/Void in Mixture (VIM)

In Figure 11, it is shown that the increase in crumb rubber content in the mixture was followed by an increase the porosity or VIM. The allowable percentage of porosity is between 5 and 10 percent for dense grades cold mixture asphalt (DGEM 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. As shown in Figure 12, thin film asphalt (TFA) was increasing as the crumb rubber content increased. TFA increased as the surface area of the aggregate is decreased, as the amount of crumb rubber as replacement of fine aggregates increased.

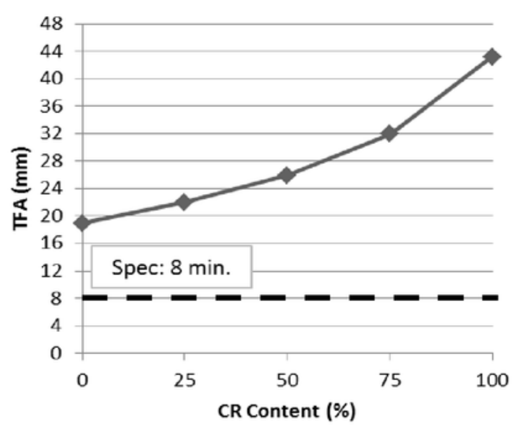


Figure 12. Effect of Crumb Rubber (CR) Content on Thin Film Asphalt (TFA)

It was observed that the optimum result of crumb rubber (CR) as fine aggregates replacement in CMA was at 25%. At optimum CR content, the Marshall soaked stability of dense graded CMA decreased about 50% and VIM increase about 10%. TFA

Table 5. Comparison of Rubberized Cold Mixtures to Conventional Hot Mixture Asphalt (HMA) Specifications [12]

Properties	7 days of curing					Specifications		
	0	**CR 25%**	CR 50%	CR 75%	CR 100%	DGEM Type IV	HRS-A[1]	AC-WC[2]
Soaked Stability (kg)	1273.346	**664.047**	654.568	514.788	264.402	300 min.	450 min.	800 min.
VIM (%)	5.253	**5.775**	11.957	17.039	23.868	5 - 10	4 - 6	3 - 5
VMA (%)	21.105	**22.875**	26.681	30.913	36.592	-	18 min.	15 min.
VFB (%)	70.302	**66.983**	55.219	43.366	32.541	-	68 min.	65 min.
Flow (mm)	3.556	**7.366**	7.281	8.382	8.636	-	3 min.	2 - 4
Retained Stability (%)	90.178	**66.667**	79.874	82.403	83.907	50 min.	75 min.	75 min.

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

increased about 15% at optimum CR content. At the 25% CR content for 7 days of curing time, the Marshall soaked stability increased about 10% and VIM decreased about 30%. Overall, the 25% of CR content produced mixture meets the mix design specification in stability and volumetric properties.

Table 5 shows the variation of Marshall properties of sample mixtures for 7 days of curing time when crumb rubber was used to replace the fine aggregates. Table 5 also shows that the rubberized mixtures have a good comparison to hot mixture asphalt (HMA) specification. At 25% of CR replacement, all properties of mixture are within the specified limit of dense graded mixture (DGEM type IV). In addition, CMA with 25% of CR as fine aggregates replacement is comparable to HRS-A specification [12]. Crumb rubber was proved to have effects on the dense graded cold mixture asphalt and has a great potential to be applied for pavements subjected to low traffic volume loads.

Conclusions

Based on the findings of the series of laboratory testing, the conclusions of this study are described as follows,

1. Crumb rubber has a great potential as partial fine aggregates replacement in cold mixture asphalt. At 25% of crumb rubber replacement, all properties of mixture are within the specified limit of dense graded cold mixture.
2. The higher amount of crumb rubber tends to decrease the strength of asphalt mixture which is followed by the increase of mixture porosity.
3. At 25% of crumb rubber replacement, properties of mixture is also comparable to hot mixture asphalt (Hot Rolled Sheet Wearing Course) specification. Therefore, rubberized cold mixture asphalt has a great potential to be applied for pavements subjected to low traffic volume loads.

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