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Laboratory Study of the Use of Additional Reacted and Activated Rubber (RAR) Materials on Asphalt Concrete-Wearing Course (AC-WC) Mix

Bayu Tirta Leksana Purnomo[1], Latif Budi Suparman[2], Agus Taufik Mulyono[3]
University of Gadjah Mada, Yogyakarta
Leksanabayu@gmail.com[1], lbsuparman@mstt.ugm.ac.id[2], agus@tsipil.ugm.ac.id[3]

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ABSTRACT
The development of infrastructure in Indonesia was increasing. The government focuses on boosting infrastructure development to create long-term economic growth. Therefore, a qualified infrastructure was a standard of an advanced rapidly economy. One of them is under construction was road and toll road infrastructure. As a result of the development was the occurrence of the increasing volume of vehicles on the road. Due to this resulting in an increased load reposition and also increased vehicle load on the road, it was then combined with a wet tropical climate or humid warm areas in Indonesia that have high rainfall and temperatures that can reach 38°C, resulting in structural damage such as cracks, rutting, stripping, and pothole. Performance from pavement also declined faster than the estimated plan. Roads in Indonesia mostly use the type of concrete asphalt mixture. Characteristics for concrete asphalt prioritize stability. In fact, the most important thing was the stability and durability of the road. Various ways can be done to overcome the road damage and acquire the ideal characteristics such as the use of added materials to Hot Mix Asphalt. To improve the performance of pavement characteristics, the use of added materials was expected to overcome problems that are affected by temperature, weather, increased vehicle volume, and increased traffic load. The added materials are to enhance Reacted and Activated Rubber (RAR) which was a developed crumb rubber to increase durability and keep the level of road pavement stability.

INTRODUCTION

The development of infrastructure in Indonesia was increasing. The government focuses on boosting infrastructure development to create long-term economic growth. Therefore, a qualified infrastructure was a standard of an advanced rapidly economy. One of them is under construction was road and toll road infrastructure. As a result of the development was the occurrence of the increasing volume of vehicles on the road. Due to this resulting in an increased load reposition and also increased vehicle load on the road, it was then combined with a wet tropical climate or humid warm areas in Indonesia that have high rainfall and temperatures that can reach 38°C, resulting in structural damage such as cracks, rutting, stripping, and pothole. Performance from pavement also declined faster than the estimated plan. Roads in Indonesia mostly use the type of concrete asphalt mixture. Characteristics for

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concrete asphalt prioritize stability. In fact, the most important thing was the stability and durability of the road. Various ways can be done to overcome the road damage and acquire the ideal characteristics such as the use of added materials to Hot Mix Asphalt. To improve the performance of pavement characteristics, the use of added materials was expected to overcome problems that are affected by temperature, weather, increased vehicle volume, and increased traffic load. The added materials are to enhance Reacted and Activated Rubber (RAR) which was a developed crumb rubber to increase durability and keep the level of road pavement stability.

Problems of the research on the use of Reacted and Activated Rubber (RAR) on pavement mixture of asphalt concrete-wearing course (AC-WC), namely:

1. How does the laboratory design of the Asphalt Concrete-Wearing Course (AC-WC) mix use Reacted and Activated Rubber (RAR)?
2. How was the Marshall Immersion Test of Asphalt Concrete-Wearing Course (AC-WC) mixture use Reacted and Activated Rubber (RAR)?
3. How was the Retained Marshall Stability (RMS) on a mixture of Asphalt Concrete-Wearing Course (AC-WC) use Reacted and Activated Rubber (RAR)?

LITERATURE REVIEW

Asphalt Concrete

According to Kim (2009), asphalt concrete was a complex pavement system with different pavement layers of different materials, combinations of improper traffic load and various environmental conditions. Performance of asphalt concrete related to various processes of asphalt mixture design, pavement design, construction, and rehabilitation. Some factors cause deformation of asphalt concrete such as time (number, length, and duration of load), temperature, age, and moisture.

According to Saragi et al. (2017), asphalt concrete was a combination of aggregate which has a continuous gradation, in which the filter and asphalt forming an interlocking structure. Asphalt concrete was made by adding 275^{o}F/135^{o}C hot asphalt with the combination of 300°F (149°C) hot aggregate which was mixed and compacted on 225°F (107°C) temperature.

According to Directorate General of Bina Marga (2014), the type of asphalt concrete layer was divided into 3 (three) mixed types:

a. Asphalt Concrete-Wearing Course (AC-WC) or asphalt concrete layer, was a surface layer that serves as an impermeable layer, so water from the top does not penetrate into which can cause damage to the pavement. The maximum aggregate size used for AC-WC was 19 mm and the minimum nominal thickness of the pavement was 4.0 cm.
b. Asphalt Concrete-Binder Course (AC-BC) or binder asphalt concrete, was an intermediate layer or binder layer of the surface layer and base layer. The maximum aggregate size used for AC-BC was 25.4 mm and the minimum nominal thickness of the pavement was 6.0 cm.
c. Asphalt Concrete-Base (AC-Base) or asphalt concrete layer was the foundation of the bonding layer and surface. The maximum aggregate size used for AC-base was 37.5 mm and the minimum nominal thickness of the pavement was 7.5 cm.

Asphalt

According to Wignall (2003), asphalt can be divided into 2 (two), namely:

a. Natural asphalt
   Natural asphalt can come from rock asphalt (lake asphalt) and lake (lake asphalt).
b. Homemade asphalt
   Artificial asphalt was derived from the petroleum distillation process, by heating under atmospheric pressure to separate mild fractions, such as gasoline (kerosene), kerosene (kerosene), and gas oil.

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According to Suryadharma (2008), the result of the crude oil distillation/distillation process produces 3 (three) kinds of asphalt, namely:

1) Hard asphalt/heat (asphalt cement, AC)
2) Asphalt cold/liquid (cut back asphalt)
3) Asphalt emulsion (emulsion asphalt)

The most common use was the hard bitumen type (AC). This type of asphalt was solid at temperatures between 25oC - 35oC. In Indonesia AC consists of several types, namely:

1) AC pen 40/50
2) AC pen 60/70
3) AC pen 80/100
4) AC pen 120/150
5) AC pen 200/300

In Indonesia generally used 60/70 AC pen or 80/100 AC pen. The general standard AC was derived from a petroleum filter, shall have the same properties, the content of the paraffin content was not more than 2% and does not contain water/foam at a temperature.

Aggregate

According to Kerbs and Walker, (1971), the aggregate was a combination of a material in the form of sand, gravel, crushed stone, stone ash, or other material composition used to form a balanced bond combination between the forming material on a mixture of asphalt pavement, mortar, macadam, mastic, and others. As an important part in the pavement, the aggregate composition was generally 92-95% by weight or about 80% by volume.

Based on The Shell Bitumen Handbook Sixth Edition, aggregates can be generated as follows,

a. Natural aggregates
   Aggregates from mineral sources that do not undergo mechanical processing (e.g. crushed stone, sand and gravel, often called primary aggregates).
b. Aggregates are produced
   Aggregates of mineral origin produced by industrial processes involving thermal or other modifications (e.g. blast furnace).
c. Recycled aggregate
   Aggregates resulting from the processing of inorganic or mineral materials previously used in construction (e.g. asphalt reclamation).
   Further aggregate categorization was given by the description of particle size
   1) Crude aggregates essentially retained on a 2 mm test filter;
   2) The fine aggregate substantially passed the 2 mm test filter;
   3) The overall aggregate, a combination of coarse and fine aggregates
   4) The filler aggregate substantially passes the 0.063 mm test filter

Reacted and Activated Rubber (RAR)

According to Sousa et al. (2013), a mixture of Asphalt Rubber (AR) was difficult to produce. AR production requires special plants and equipment, which results in high manufacturing costs. Part of this difficulty was caused by the need to produce AR binders by mixing them at high temperatures for significant periods of time (usually about 190°C for 45 minutes to 1 hour). The complexity in this process causes the AR mixture to be more expensive to produce than the conventional pavement mix. New technology that produces Reacted and Activated Rubber (RAR), which was an elastomeric asphalt solvent, has been developed by hot mixing and activation of rubber granules with selected asphalt binder and active mineral binder stabilizer. RAR achieves results that are comparable to other polymer modification binder types (PMBs). However, the main advantage of RAR was that it can be added easily to Asphalt Mixing Plant with a system designed to facilitate particulate matter into pug mill. Reacted and Activated Rubber (RAR), consisting of soft bitumen, crumb rubber, and Activated Mineral Binder Stabilizer (AMBS) with optimal proportion.

The composition of Reacted and Activated Rubber (RAR)

According to Kedarwasetty et al. (2016), generally, RAR composition consists of crumb rubber of about 62-65%, soft asphalt 20-25%, and AMBS 15-20%. Soft Based on Sousa et al. (2013) explanation of RAR composition as follows:

a. Softer bitumen

Asphalt cement or graded bitumens such as Pen 100-200 to Pen 35/50, or AC 20, PG 52 to PG 70, can be used. The use of bituminous Softer can produce HMA by mixing and rolling temperature in general without losing the ease of work, even if there was a crumb rubber enhancer.

b. Crumb Rubber

The materials used usually consist of used tires that are processed and finely ground with proven industrial methods. Used tires consist of a combination of car tires and truck tires, and should be free of steel, fabric or fiber before milling. For RAR production, crumb rubber particles should be smoother than 1.0 mm. The maximum particle size of filter # 30 was preferred.

c. The Activated Mineral Binder Stabilizer (AMBS)

New micro size binder stabilizer was developed to prevent excessive bitumen melting on mixture blending, storage, and rolling blends. Thwas stabilizer was an active microbial silica mineral (40 μm and finer), which was a waste product from the Phosphate Industry mine.

Production of Reacted and Activated Rubber (RAR)

According to Sousa et al. (2013), RAR was produced by mixing in heat and activated for a short period of time, then specially designed to form dry rubber granulated active rubber. RAR can be added to any type of Hot Mix Asphalt (HMA) to replace the asphalt part of the binder with different proportions. In Asphalt Mixing Plant RAR mixing was added directly to the pug mill or drum dryer. According to Medina and Underwood (2017), the soft asphalt used in RAR aims to reduce some of the increase in hardening caused by rubber, consequently enabling the production of asphalt with RAR at the same mixing and compaction temperatures. Crumb rubber used comes from the truck and car tires, which are processed and milled with ambient or cryogenic processes. RAR has a particle size distribution ranging from 0.595 mm to 0.075 mm sub.

RESULTS AND DISCUSSIONS

Results

1. Research Materials

   Research materials used for laboratory research, are:
   a. Aggregate from Majalengka, West Java
   b. Penetrated Asphalt 60/70 Shell
   c. RAR from Spain imported by PT Conbloc Infratecno
2. Target Gradation Plan

   In accordance with the gradation envelope and the mean or graded target gradient, so that the weight of each filter size of the AC-WC gradation for one sample of an aggregate of the Marshall test mixture was obtained as can be seen in Table 1.

Table 1
The composition of Designed Aggregate

Fraction	Filter size		Specification			Weight of Fraction		
	mm	ASTM	Range	Middle Value	Restrained (%)	gram	gram	%
CA	19	3/4 "	100	100	0	0	468	39
	12,5	1/2 "	90-100	95	5	60		
	9,5	3/8 "	77-90	83,5	16,5	138		
	4,75	No. 4	53-69	61	39	270		
FA	2,36	No. 8	33-53	43	57	216	654	54,5
	1,18	No. 16	21- 40	30,5	69,5	150		

Fraction	Filter size		Specification			Weight of Fraction		
	mm	ASTM	Range	Middle Value	Restrained (%)	gram	gram	%
	0,6	No. 30	14-30	22	78	102		
	0,3	No. 50	9-22	15,5	84,5	78		
	0,15	No. 100	6-15	10,5	89,5	60		
	0,075	No. 200	4-9	6,5	93,5	48		
FF	< 0.075	Pan	0	0	100	78	78	6,5
Total						1200	1200	100

Referring to the gradation for the AC-WC pavement contained in Table 1, the target gradation used was the middle value of the AC-WC gradation envelope. When the gradation envelope and gradation target are put into the Fuller curve, it will be illustrated as in Fig 1.

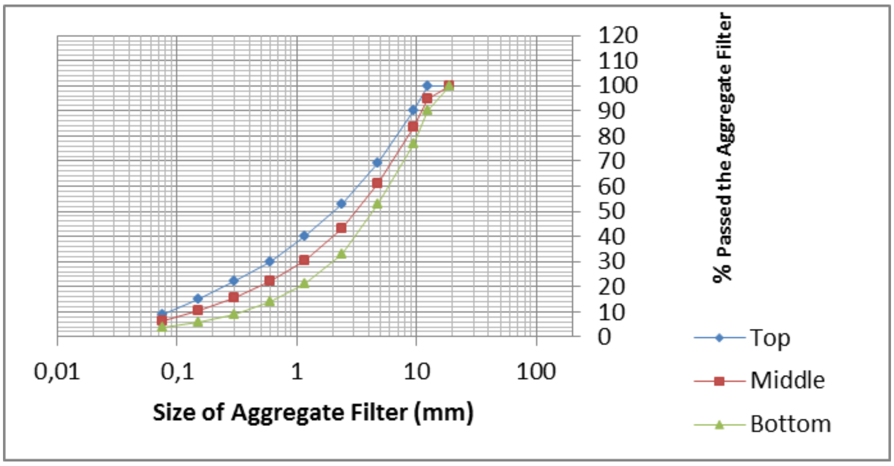

Fig 1. *Gradation AC-WC and Gradation Control Point*

3. Asphalt test results in Pen 60/70
   Researcher performed a pre-test of the 60/70 Shell Penetration Asphalt material used in the study. The standard used was the penetration asphalt 60/70 from the General Specification of Directorate General of Bina Marga 2010 revision 3. The results obtained from the testing of asphalt characteristics are adjusted to the standards, whether the results obtained already meet the standards used. The results of asphalt test can be seen in Table 2.

Table 2
Asphalt Test Result Pen. 60/70

No.	Checking Type	Unit	Specification	Result
1	Penetration 25°C	0,1 mm	60-70	61
2	Soft Point	°C	> 48	48,3
3	Flash Point	°C	≥ 232	248
4	Ductility	cm	-	145
5	Lose Weight	%	≤ 0,8	0,197
6	Solubility in CCL4	%	-	99,114
7	Penetration after losing weight	% pure	≥ 54	85
8	Specific gravity of asphalt	gr/cm^3	≥ 1,0	1,065

4. Aggregate test results
   The test was first performed to a mixed binder comprising a coarse aggregate, fine aggregate, and filler. In this study, the aggregate used was from Majalengka, West Java. The results of the aggregate test can be seen in Table 3.

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Table 3
Aggregate test Result

No	Type of Checking	Unit	Specification	Result
Coarse Aggregate				
1	Engine wear Los Angeles	%	Max. 30	22,36
2	Water absorption	gr/cm^3	Max. 3	0,998
3	Pseudo Specific gravity	gr/cm^3	Min. 2	2,760
5	Soundness Test	%	Max. 12	9,16
6	Flat and oval particles	%	Max. 10	7,21
7	Sieve-passed material No.200	%	Max. 2	0
Fine Aggregate				
1	Sand Equivalent	%	Min. 60	62,49
2	Water absorption	%	Max. 3	1,233
3	Pseudo-Weight	gr/cm^3	Min. 2,5	2,785
4	Sieve-passed material no.200	%	Max. 10	0,27
Filler				
1	False type weight	gr/cm^3	Min. 2,5	2,819

5. Testing Variation
Determination of Virgint Asphalt level and RAR level of combination Pb value Then we got the weight value for Virgint Asphalt and RAR Weight level required for one specimen with a total weight of 1200 gram mixture, the weight calculation results for the mixture as seen in Table 4.

Table 4
The weight of RAR and Virgint Asphalt

Wight (gram)	Pb Combination %				
	5	5,5	6	6,5	7
RAR 20%	12,0	13,2	14,4	15,6	16,8
Virgint Asphalt	48,0	52,8	57,6	62,4	67,2
RAR 25%	15,0	16,5	18,0	19,5	21,0
Virgint Asphalt	45,0	49,5	54,0	58,5	63,0
RAR 30%	18,0	19,8	21,6	23,4	25,2
Virgint Asphalt	42,0	46,2	50,4	54,6	58,8
RAR 35%	21,0	23,1	25,2	27,3	29,4
Virgint Asphalt	39,0	42,9	46,8	50,7	54,6
Total Weight	60	66	72	78	84

Furthermore, the number of specimens to be designed and made was 105 pieces. The number of specimens for each variation can be seen in Table 5.

6. Marshall Characteristics Test Result Against Asphalt Level Plan with Variation of RAR Mixture
Marshall testing was performed to obtain Marshall characteristic values against a predetermined combination of asphalt grade and variations of the Reacted and Activated Rubber (RAR) added mixture used in laboratory studies. The results of Marshall characteristics from the test adapted to the standards used to determine the Optimum Asphalt Level (KAO) for each RAR Mixed Variation. Test results can be seen in Table 6 to Table 9.

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Table 5
Number of Specimens

Steps of Testing		Variation	The composition of Reacted And Activated Rubber (%)				Total
			0	20	25	30	
Marshall Standard Optimum Asphalt Level	Pb combination	-1,0	3	3	3	3	15
		-0,5	3	3	3	3	15
		Pb	3	3	3	3	15
		+0,5	3	3	3	3	15
		+1,0	3	3	3	3	15
Marshall Immersion Test	Duration of Immersion (hour)	0,5	3	3	3	3	15
		24	3	3	3	3	15
Specimens Total							105

Table 6
Test of Variation 1 with RAR mixture 0%

No.	Marshall Characteristics	Specification	Asphalt Rate Variation RAR 0 %				
			5	5,5	6	6,5	7
1	Density	-	2,361	2,380	2,397	2,423	2,435
2	VIM (%)	3 – 5	7,20	5,72	4,32	2,54	1,31
3	VMA (%)	Min. 14	16,68	16,45	16,30	15,83	15,86
4	VFB (%)	Min. 65	56,87	65,22	73,48	83,93	91,76
5	Stability (kg)	800	1211,3	1297,5	1315,6	1229,4	1147,8
6	*Flow* (mm)	Min.3	3,47	3,56	3,73	3,89	3,64
7	MQ (kg/mm)	Min.	349,98	366,64	354,51	315,84	315,37

Table 7
Test of Variation 2 with RAR mixture 20%

No.	Marshall Characteristics	Specification	Asphalt Rate Variation RAR 20 %				
			5	5,5	6	6,5	7
1	Density	-	2,326	2,339	2,349	2,355	2,359
2	VIM (%)	3 – 5	7,16	5,93	4,82	3,89	3,01
3	VMA (%)	Min. 14	17,91	17,88	17,96	18,21	18,50
4	VFB (%)	Min. 65	60,05	66,86	73,18	78,66	83,75
5	Stability (kg)	800	1179,5	1206,8	1311,1	1333,8	1315,6
6	*Flow* (mm)	Min.3	4,40	5	5,08	4,83	4,32
7	MQ (kg/mm)	Min.	268,41	243,13	258,41	279,54	306,20

Table 8
Test of Variation 3 with RAR mixture 25%

No.	Marshall Characteristics	Specification	Asphalt Rate Variation RAR 25 %				
			5	5,5	6	6,5	7
1	Density	-	2,310	2,320	2,333	2,328	2,342
2	VIM (%)	3 – 5	8,24	7,16	6,12	5,17	4,15
3	VMA (%)	Min. 14	18,46	18,55	18,69	18,90	19,07
4	VFB (%)	Min. 65	55,37	61,40	67,25	72,69	78,24
5	Stability (kg)	800	1052,5	1088,8	1102,4	1120,6	1170,5
6	*Flow* (mm)	Min.3	5,33	5	4,57	4,40	4,32
7	MQ (kg/mm)	Min.	199,42	219,16	249,54	257,79	276,20

Table 9
Test of Variation 4 with RAR mixture 30%

No.	Marshall Characteristics	Specification	Asphalt Rate Variation RAR 30 %				
			5	5,5	6	6,5	7
1	Density	-	2,312	2,320	2,329	2,336	2,379
2	VIM (%)	3 – 5	8,63	7,62	6,56	5,57	3,11
3	VMA (%)	Min. 14	18,39	18,55	18,66	18,85	17,79
4	VFB (%)	Min. 65	53,09	58,91	64,85	70,46	82,53
5	Stability (kg)	800	893,7	966,3	1029,8	1079,7	1138,7
6	*Flow* (mm)	Min.3	4,57	4,74	4,32	4,66	4,15
7	MQ (kg/mm)	Min.	196,26	206,65	238,92	232,19	274,41

Discussions

Comparison of Marshall Immersion Test from the use of Optimum Asphalt Level (KAO) and any variation of RAR mixture with 0.5 h immersion conditions and 24 hours immersion can be seen in Fig 2.

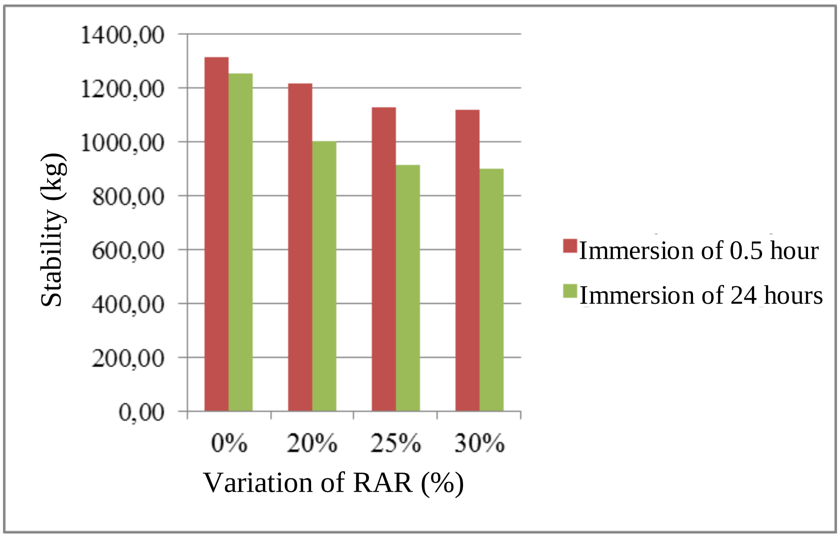

Fig 2. *Comparison of 0.5 hour immersion with 24 hours of Stability*

Fig 2 showed the stability value of each mixing variation that had been determined and performed in the Laboratory. Mix using RAR and 60/70 penetration asphalt from Shell. The stability value using the standard of the General Specification 2010 was at least 800 kg. Based on the test results and calculations, the stability value for each variation meets the specified standard. For the highest value of Marshall Immersion Test at 0.5 h immersion was founded in variation 1 (RAR 0 %%) while for the lowest was in variation 4 (RAR 30%). For the 24 hours immersion, the highest value obtained Variation 1 (RAR 0%) while for the lowest obtained in variation 4 (RAR 30%).

Fig 3 shows the percentage of Retained Marshall Stability (RMS) for each variation of a predetermined pavement mixture. The specified RMS standard value was at least 90%. From the test results, the eligible RMS value only produced variation 1 (RAR 0%), whereas for variations 2, 3, and 4 using RAR were not qualified.

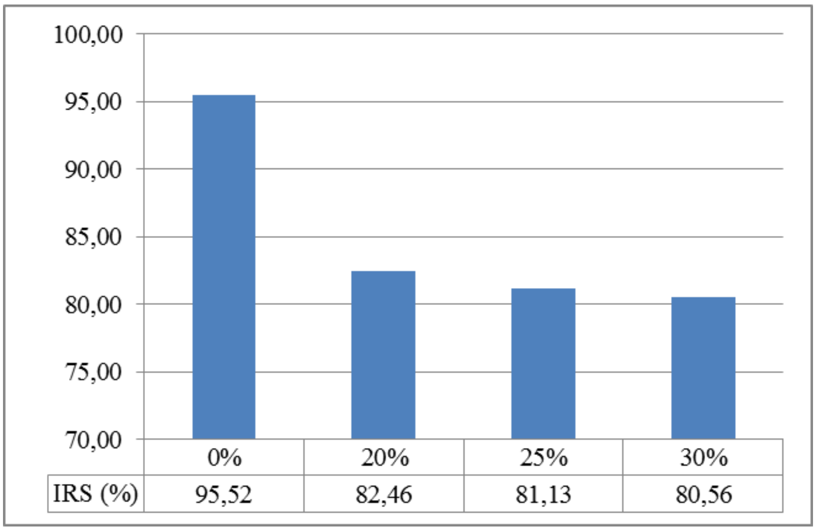

Fig 2. *Retained Marshall Stability (RMS) of Every Mixture*

CONCLUSIONS

The highest stability value is in variation 1 (RAR 0%). The highest Retained Marshall Stability (RMS) value is found in variation 1 (RAR 0%) and only variation 1 meets the specified standard. The pavement mix using Reacted and Activated Rubber (RAR) added materials is not better than ordinary pavement mixes without RAR added materials. It is necessary to do a test using added materials of Reacted and Activated Rubber (RAR) with mix rate below 20%.

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