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The Performance of AC-WC Asphalt Mixture with Eco-Friendly Steel Slag Against Sea Tidal Impact

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***Abstract*— Roadways that located around the beach often have some problems with seawater puddle caused by the tidal condition or commonly known as rob water. Therefore, it is better to apply steel slag with higher quality than ordinary aggregate as an alternative way to prevent the pavement damage. This research substitutes aggregate into the steel slag with 100% coarse aggregate sieve number ½" and 50% fine aggregate sieve number 30 that was soaked in the seawater for about 6 hours, 12 hours, and 24 hours, respectively. From this research, the longer this immersion was conducted, the more significant the Marshall characteristic was affected, resulting in poor quality of asphalt, marked by the declining of stability value, VFWA value, and MQ value. Meanwhile, the value of flow, VITM and VMA tended to rise.**

Keywords— ***immersion, Marshall, sea puddles, seawater, steel slag.***

I. INTRODUCTION

Roadway is one of important facilities for people in supporting their daily activities. One of the common hardening in Indonesia is a flexible hardening. Flexible hardening is defined as the hardening by using asphalt. The construction is lied down on the compacted base course [1]. This type of hardening covers several mixtures, in which Asphalt Concrete Wearing Course (Laston) is considered as one of them.

Asphalt Concrete Wearing Course (Laston) is defined as continuous gradated asphalt concrete that commonly applied to heavy duty roadways [2]. The road hardening will experience decrease over times caused by traffic load and several factors, such as environmental factor that requires sustainable maintenance [3]. Fine and strong aggregate could be applied to hold heavy load activities. Basically, the materials contained by asphalt concrete mixtures are asphalt, coarse aggregate, fine aggregates and filler.

In this research, the mixture of steel slag or steel waste is used as coarse aggregate 100% filter no. ½ and fine aggregate 50% filter no.30 in terms of the easiness of materials replacement. Steel slag is a product originated from steel industry that potentially could replace common aggregate which is usually applied in road construction [4]. Steel slag is formed from minerals used as steel purifier in high temperature furnace [5]. This steel slag has high level of coercion and rough surface; hence it is suitable to be applied as a blend for road hardening [6]. Steel slag aggregate in its combination with the common one, could be used for the road construction in order to make extremely strong hardening [7]. The implementation of steel slag also contributes to waste reduction that could mitigate the numbers of conventional aggregate on the highway construction and could lead to continuous application in highway construction.

Study of adding steel slag to Hot Mix Asphalt (HMA) has been widely carried out in the United States. Their experience on applying steel slags indicated that there was an improvement in the performance of Pavement characteristics. In asphalt mixtures, the steel slag is usually added as part of the coarse aggregate fraction of the mixture at a percentage of 20% to 100%, depends on the application of the mixture. Since the slag is rough, the material improves the skid resistance of the pavement. In addition, because of the high specific gravity and angular, interlocking features of the crushed steel slag resulted in HMA which was more stable and resistant to rutting [8].

They evaluated the effect of steel slag in HMA with 100% coarse aggregate (limestone) which was replaced by Steel Slag Agregate (SSA). They observed improved fatigue resistance as the steel slag mix exhibited higher indirect tensile strength and modulus values than the coarse aggregate mix [3]. Muaya et al. [9] conducted a study on steel slag in HMA by substituting the natural aggregate at 0%, 30%, 60%, and 90% SSA based on the total aggregate weight. The substitution included both coarse and fine aggregate particles. It was found that all the slag mixes exhibited better rutting resistance than the control mix under repeated axial loads. However, the 90% SSA mix performed better than all the other slag mixes.

In Indonesia, several roadways which are located near coastline, often deal with problems related to seawater puddle caused by weather condition. Hence, it leads to issues with sea tidal that commonly known as Rob flood. Rob is defined as the raise of seawater surface that overflows the road construction of asphalt hardening [10]. Generally, the road hardening will experience decreased performance due to traffic load and humidity. Water and air could accelerate the process of asphalt age deterioration; besides, water could cause the effect of asphalt film stripping on an aggregate [11]. In the coastal area, other factor related to seawater tidal could influence the road hardening, which is the existence of Chloride, Natrium and high content of Sulfate [12].

II. Research Method

A. Flow Chart

The work step of this research is explained through the flowchart below.

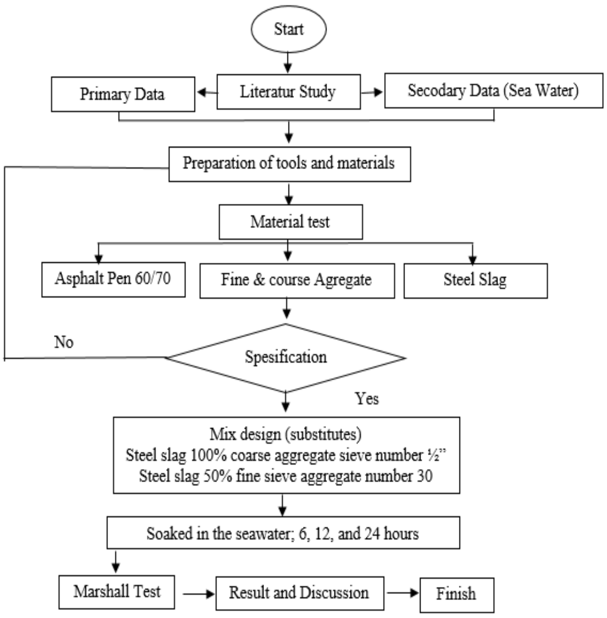

Fig.1. Flow chart

B. Preparation Stage

Literature study is the initial step performed, subjected to collect literatures as the basic of the research. Later, the preparation of tools and materials were carried out. The materials consist of asphalt with penetration of 60/70 produced by PT. Pertamina, as well as coarse and fine aggregate obtained from Clereng, Kulonprogo, Yogyakarta. Meanwhile, steel slag was brought from steel company, PT. Krakatau Steel (Persero) Tbk, while the seawater was from Tanjung Emas port. All tools was in clean and good condition, and well calibrated. Fig. 2 to 5 have shown the materials that was used in this research.

C. Material Testing

Entire tests for materials were performed in laboratory. Before they were applied in the construction; first they were tested through the determined test method. The tests on asphalt would expose its penetration, softening point, weight loss, density and ductility. Meanwhile, the tests for coarse aggregate and coarse steel slag included density, deterioration by using Los Angeles machine, water absorbance, and aggregate attachment.

Fig. 2. Asphalt Pen 60/70

Fig. 3. Course Aggregate

Fig. 4. Steel Slag

Fig. 5. Fine Agregat

D. Planning of Mixtures

On the mixture planning, the determination of optimal asphalt composition was firstly performed by using the measurement of 4, 4.5%, 5%, 5.5%, 6% and 6.5% from total aggregates. As many as 10 samples were derived from above measurement, two samples for each. From the tests, it was expected to obtain optimum value of asphalt that later was applied to design the tested materials.

E. Composition of the Mixture and the Construction of Tested Materials

Aggregate was weighted as the planning of Asphalt Cement Wearing Course (AC-WC) gradation mixture at each fraction. For instance, the number of restrained aggregates on the filter no. ½ was 60 grams out of total aggregates (1200 grams), that later was substituted with 100% steel slag on the filter no.30. The required percentage should match the percentage of aggregate number of each size of filter in order to construct the mixture of AC-WC.

After completing the weight process, aggregate was heated at 160°C, then blended with hot asphalt to reach temperature of 170°C. The asphalt should fulfill the value of optimum asphalt that was determined earlier. Later, the mixture was placed in a heated mold and pounded for 2x75 times. Tested materials were made in 2 pieces on every soaking planning. Total tested materials that dedicated for the tests was 18 pieces (10 samples for optimum asphalt and 8 samples for soaking process).

TABLE I. SAMPLE TEST

Slag Variation	**Amount**	**Immertion Time (Hour)**
100% course, 50% fine	2	0
	2	6
	2	12
	2	24
Total	8	

F. The Tests on Materials

After completing the weight process, aggregate was heated to 160°C, then blended with hot asphalt to reach temperature of 170°C. The asphalt should fulfill the value of optimum asphalt that was determined earlier. Later, the mixture was placed in a heated mold and pounded for 2x75 times. Tested materials were made into 2 pieces on every soaking planning. Total tested materials that dedicated for the tests was 18 pieces (10 samples for optimum asphalt and 8 samples for soaking process).

III. RESULT OF MATERIAL TEST

A. *The Result of Asphalt Test*

Before using the Asphalt, it should be checked to determine its adequacy. By considering the standard determined by Bina Marga [13], it could be seen that the result of asphalt test was described by Table II, demonstrating that the asphalt has fulfilled the requirement to be applied widely

TABLE II. RESULTS OF ASPHALT TEST

No	Properties	Specification	Results
1.	Penetration 25°C	60 – 70	64.4
2.	Softening Point (°C)	> 48	52.5
3.	Specific Gravity	> 1.0	1.08
4.	Loss weight	Max 0.4	0.13
5.	Ductility	Min. 100	154.75

B. *The Result of Test on Aggregate and Filler*

Table III and Table IV show that the performance of aggregate and filler tests have met the standards set by BSN [14, 15]. Therefore, the aggregate could be used in this research. The most striking characteristic was that steel slag did not have a strong specific gravity, both coarse aggregate, and fine aggregate compared to natural agregate.

TABLE III. RESULTS OF AGGREGATES

No.	Test	Specification	Result	Unit
Coarse Aggregate				
1.	Bulk specific gravity	≥ 2.5	2.515	-
2.	Apparent specific gravity	≥ 2.5	2.705	-
3.	Water Absorption	≤ 3	2.6	%
Fine Aggregate				
1.	Bulk specific gravity	≥ 2.5	2.52	-
2.	Apparent specific gravity	≥ 2.5	2.72	-
3.	Water Absorption	≤ 3	3	%
Filler				
1.	Specific grafity	≥ 2.5	2.56	-

C. *The Result of Test on Steel Slag*

The results of the steel slag experiments were provided in Table IV, showing that the steel slag was suitable to the standard to replace the aggregates throughout the hardening mixture.

TABLE IV. THE RESULTS OF TESTS ON STEEL SLAG

No.	Test	Requirement	Result	Unit
Coarse Steel Slag				
1.	Bulk specific gravity	≥ 2.5	3.35	-
2.	Apparent specific gravity	≥ 2.5	3.59	-
3.	Absorption	≤ 3	1.67	%
Fine Steel Slag				
1.	Density Bulk	≥ 2.5	2.9	-
2.	Density apparent	≥ 2.5	3.05	-
3.	Absorption	≤ 3	1.98	%

Steel Slag met the standard aggregate requirements where the specific gravity of steel slag was higher than the standard aggregate. For this reason, an effort was made to partially mix the steel slag aggregate with other ingredients. This sampling reduced the density of the mixture, so that the volume of work would be achieved, and the strength of the pavement mixture is better.

TABLE V. DETERMINATION OF OPTIMUM ASPHALT LEVELS

NO	TEST	TERMS	ASPHALT LEVELS				
			4	5	5.5	6	6.5
1	Density (gr/cm	-					
2	VFWA (%)	Min 65					
3	VMA (%)	Min 15					
4	VITM (%)	3-5					
5	Stability (kg)	Min 800					
6	Flow (mm)	2-4					
7	MQ (kg/mm)	Min 250					

From the results in the Table V above, the optimum asphalt level value for the mixture is 5%.

IV. RESULT OF MARSHALL TEST

A. *Density*

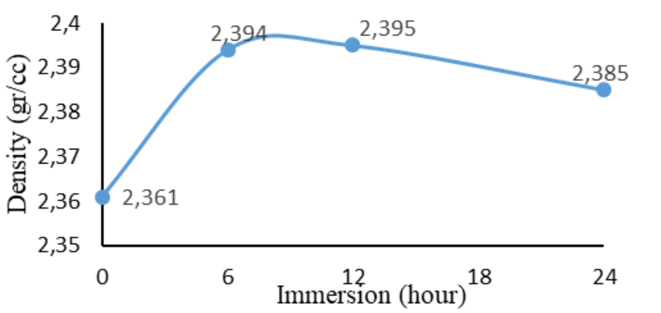

Fig. 6. The graph of the correlation between density and immersion intensity

Density is a density level of the mixture after it is compacted. Density is the weight of the mixture in each unit of volume. Factors that can influence density are aggregate specific gravity, asphalt content, asphalt gradation, constituent quality and compaction process which includes temperature and the amount of impact.

From Fig. 6 above, the density of the sample without sea water immertion has the lowest density about 2.362, but in 6 hours, the value increases significantly and after 12 and 24 hours the value decreases. Reduced density is caused by the length of bath which affects the density value. There is no requirement that govern this density, both for minimum values and maximum values. Thus, the density values above can be considered fulfilling the requirements.

B. Stability

Stability is defined as an ability of road hardening in receiving traffic load without significant change on formation, such as wavy road, corrugated road or bleeding. Once a traffic volume of a road is considered high, a higher stability also required for road hardening consideration.

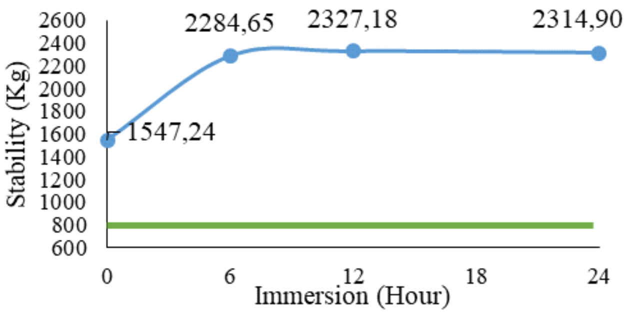

Fig.7.The graph of the correlation between stability and immersion intensity

From Fig. 7 above, the highest stability value is positioned on the hour of 12th. Meanwhile, the lowest value of stability was demonstrated on the hour of 0 (un immersion) but it was still considered above minimum limitation. The increasing value on stability was caused by the coarse surface of steel slag that provided stable bound and resistant to temperature change. When the immersion was conducted for 24 hours, the stability level decreased. It was caused by the characteristics of steel slag that absorbs the temperature faster than coarse stones. Hence, on the hour of 24th during the test, the material became cold and rough. Based on the general specification of Bina Marga [4], in terms of characteristics of the mixture, it could be concluded that all stability values of entire soakings have fulfilled the required specification.

C. Flow

Flow is described as the amount of decline or deformation on a hard layer owing to excessive load. Lower flow value with high stability on the mixture of the hard layer tends to make it stiff and brittle, while increased flow value with low stability of the mixture tends to create it more plastic.

Based on Bina Marga [13], the minimum flow value was determined as 2 mm, while the maximum flow value was 4 mm. According to Fig. 8 below, it could be concluded that only flow value on the hour of 0 (unimmersion) was considered as fulfilling the specification. The most striking feature was sample whose short immersion have a lower value compared to the other, but interestingly the value increased significantly after immersion 12 and 24 hours.

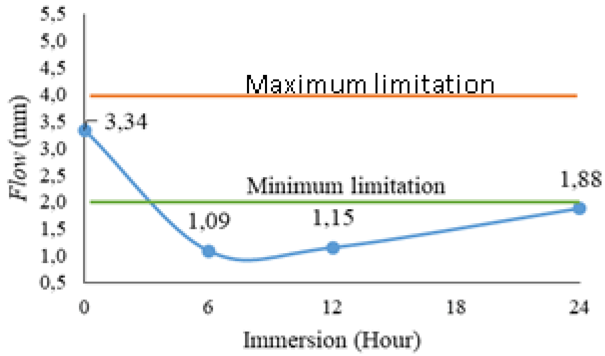

Fig. 8. The graph of correlation between flow and immertion intensity

In this research, the value of flow tended to have smaller value than determined specification. It was then led the asphalt with substitute aggregate became stiff and the roadways that used the mixture will easily broke, for instance the deformation of aggregate and the crack will happen once it received excessive load. These are caused by negligence of the researcher or by the factor of gradation, the composition of asphalt as well as the surface of the aggregates.

D. Void In The Mix (VITM)

VITM (Void in the Mix) is defined as numbers of pores existed in the hot asphalt mixture that stated in percentage. There are air pores in the mixture to ensure the space for particles to move, that consistent with their elastic characteristics. The value of VITM could be influenced by aggregate gradation, the composition of asphalt and density.

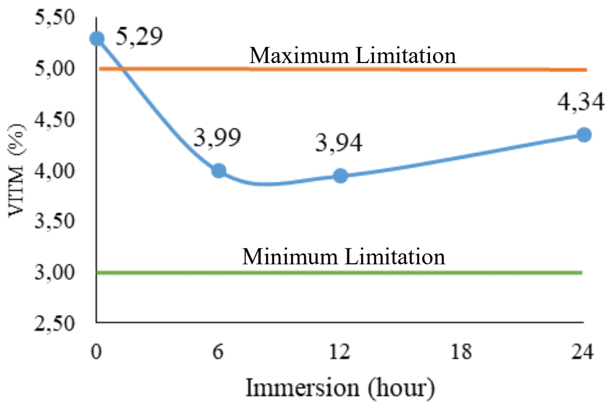

Fig. 9. The graphs of correlation between VITM and immersion intensity

Fig. 9 describes the reduction of VITM value in the mixture could be caused by the massive number of asphalt composition that reduces the size of pores in the mixture. Then, the longer immersion process was conducted on mixed asphalt with slag waste, the higher the value of VITM would be.

Based on Bina Marga [13], on the determination of the Asphalt Concrete Wearing Course (Laston) mixture characteristics, the VITM value that met the requirement ranges from 3% to 5%. Based on that specification, VITM's value on all immersions was regarded fulfilling the specification. In addition, VITM's Value for unimmersion passed the maximum limitation which might be caused by dial error at the first test in marshall.

E. Void In Mineral Aggregate (VMA)

Based on Fig. 10 below, it can be recognized that VMA's value tended to increase for samples soaked by seawater. Due to the longer immersion duration, the higher VMA value was yielded. The value of VMA was extremely affected by the features of steel slag that own numbers of pores, in which the number of current holes can be added. The VMA value on the Asphalt Concrete Wearing Course (Laston) mixture was determined as >15% so it could be resumed that the VMA value on all tasted products met the standard [10].

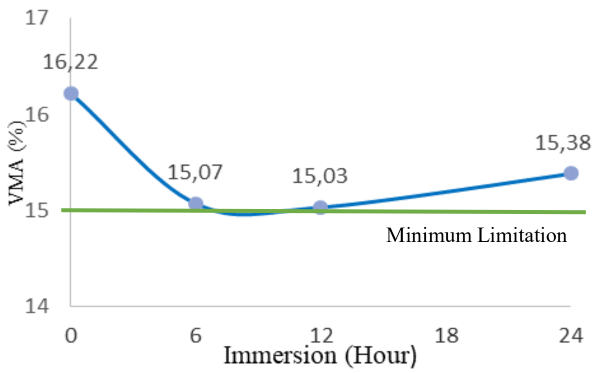

Fig. 10. The graph of correlation between VMA and immersion intensity

F. Void Filled With Asphalt (VFWA)

VFWA (Void Filled with Asphalt) is described as the percentage of holes that existed among aggregates particles (VFWA) filled by asphalt but excluding the asphalt that has been absorbed by aggregate.

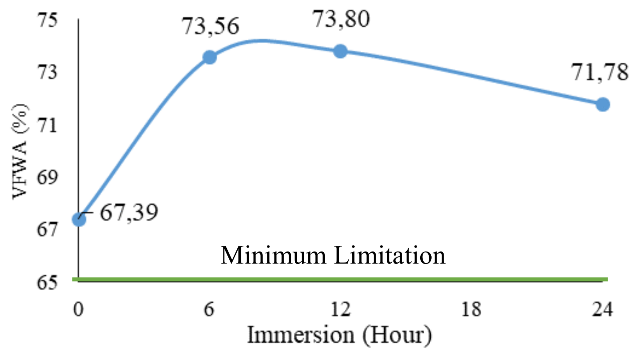

Fig. 11. The graph of correlation between VFWA with immersion intensity

From Fig. 11 above, the value of VFWA tended to experience increase on the immersion at the hour of 6th and 12th, yet it resulted in declining on the immersion at the hour of 24th. It was caused by smaller size of holes in the mixture that affected by the value of VITM, which apparently the divider value to obtain VWMA value.

G. Marshall Quotient (MQ)

Marshall Quotient (MQ) was obtained from the division of stability value over flow. Hard layer pavement will become more rigid if the value of Marshall Quotient (MQ) is large, while the hard layer pavement will become more flexible if the value of Marshall Quotient (MQ) is small.

Based on Fig. 12 below, it could be stated that the MQ value experienced significant increase at the 6th hour of immersion as the MQ value was derived from the stabilization over flow comparison. If the MQ value was getting higher, the pavement will become more rigid. On the contrary, if the MQ value is lower, then the pavement mixture will become flexible.

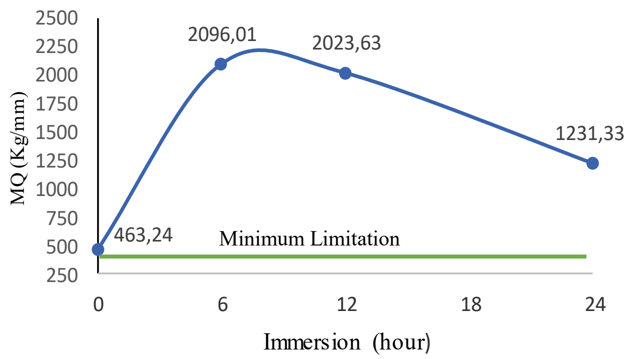

Fig. 12. The graph of correlation between MQ with immersion intensity

Even though steel slag has good physical properties as a substitute for natural aggregates in asphalt mixture, it can be seen from the graph above (0 hour), the mixture using steel slag shows good Marshall Characteristics. The research [7], suggested that utilization of steel slag aggregate can benefit the environment and at the same time reduce the amount of granite application in highway construction. With its excellent results in terms of the resilient modulus and lower rutting potential, it is recommended that steel-slag is used as an aggregate replacement for sustainable development in highway construction. However, the treatment of seawater immersion using steel slag in this study showed that the characteristics of the mixture became worse. This was caused by chemical compound of tidal water and long immersion which caused damage to the mixture [12].

V. CONCLUSION

Based on the research that have been conducted, the use of steel slag as a mixture and material modification met the standard Marshall qualifications, but in the treatment of immersion carried out in this research, it became an unsuitable for road use. This situation was influenced by seawater containing various minerals and immersion duration which made the characteristics of asphalt modification was not in accordance with Marshall test standards such as additional immersion duration, increased value of VMA, VITM which creates larger holes in the mixture. On the other side, it will reduce the stability and VFWA. Short immersion will lead to a decrease in the flow value as the brief immersion will create a flexible pavement that leads to rapidly broken roads such as rutting.Authors and Affiliations.

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