Development of Recycled-Modified Asphalt Using Basalt Aggregate

Dong Wook Lee, Seung Hyun Kim, Jeongho Oh

***Abstract*—**With the strengthened regulation on the mandatory use of recycled aggregate, development of construction materials using recycled aggregate has recently increased. This study aimed to secure the performance of asphalt concrete mixture by developing recycled-modified asphalt using recycled basalt aggregate from the Jeju area. The strength of the basalt aggregate from the Jeju area used in this study was similar to that of general aggregate, while the specific surface area was larger due to the development of pores. Modified asphalt was developed using a general aggregate-recycled aggregate ratio of 7:3, and the results indicated that the Marshall stability increased by 27% compared to that of asphalt concrete mixture using only general aggregate, and the flow values showed similar levels. Also, the indirect tensile strength increased by 79%, and the toughness increased by more than 100%. In addition, the TSR for examining moisture resistance was 0.95 indicating that the reduction in the indirect tensile strength due to moisture was very low (5% level), and the developed recycled-modified asphalt could satisfy all the quality standards of asphalt concrete mixture.

***Keywords*—**Asphalt Concrete Mixture, Performance Grade, Recycled Basalt Aggregate, Recycled-Modified Asphalt.

I. Introduction

To achieve low carbon green growth by overcoming ‘environmental crisis’ represented by climate change and ‘resource crisis’ represented by oil, the government has promoted recycling of construction waste by establishing the “Construction Waste Recycling Promotion Act.” As the implementation measure, the Ministry of Environment and the Ministry of Land, Infrastructure, and Transport notified the expansion of target constructions for the mandatory use of recycled aggregate and the usage. Among them, the amount of mandatory recycled aggregate use for asphalt concrete pavement shows an abrupt increase from more than 25% in 2014 to more than 40% in 2016. Thus, the industrial field requires a proactive strategy, and this should be a high value-added green technology.

The production of construction waste in Korea is about half of the total amount of waste production in Korea. The amount of construction waste increased from 78,000 ton/day in 2005 to 183,000 ton/day in 2013, and it is expected to continuously increase in the future [1]. In addition, the recycling rate of construction waste was reported to be about 97% in 2013, but most of them were simply recycled on construction sites by banking, covering, etc. that are not much different from reclamation. In particular, among construction wastes, the amount of waste asphalt concrete more than doubled from 15,000 ton/day in 2005 to 35,000 ton/day in 2013, and the time series analysis of the amount of waste asphalt concrete production for the past 10 years indicated that it would abruptly increase to 53,000 ton/day in 2018. This is because the repair of pavement has continuously increased due to the lack of performance, and it is consistent with experts’ prediction that the pavement repair of existing roads would increase in the future rather than the investment in newly constructed roads.

This study aimed to develop recycled-modified asphalt using recycled aggregate, in order to suggest a green technology depending on the change in government policy and to improve construction waste recycling in a practical direction. For this purpose, the mechanical characteristics of basalt aggregate were examined using general basalt aggregate and recycled aggregate from the Jeju area in Korea, and the applicability of recycled basalt aggregate was evaluated and presented by analyzing the mechanical characteristics of Hot-mix Asphalt Mixture (HAM) and Hot-mix Modified Recycling Asphalt Mixture (HMRAM).

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II. Materials

A. Aggregates

Aggregate accounts for 90~95% of the weight of asphalt mixture, and thus the mechanical characteristics of aggregate are very important. However, general studies on asphalt mixture are focused on the improvement in the performance of asphalt binder. As for studies on asphalt mixture in Korea, most studies on aggregate varied the grading standard or grading characteristics such as dense grade (WC1~6) and SMA grade based on the surface course, and there has been almost no study that varied the rock types of aggregate. However, a study compared the high-temperature behavior of asphalt mixture using 19mm dense grade general mixture with the same AP content by petrologically classifying aggregate and by selecting granite among igneous rocks, limestone among sedimentary rocks, and gneiss among metamorphic rocks, and reported that granite, whose petrological classification is identical to that of basalt, showed relatively superior performance compared to other rocks in terms of dynamic stability, unit settlement, and flow value [2]. Based on the result of the above study, it is expected that the applicability of basalt aggregate, which is petrologically an igneous rock, as asphalt mixture would be relatively outstanding.

For the aggregate used in this study, basalt aggregate produced from the mine of H industry located at Andeok-myeon, Seogwipo, Jeju Special Self-Governing Province was used; and as shown in Fig. 1, it was located at the boundary of basalt (Qb, III) and trachybasalt (Qtb, VIII) which are volcanic rocks of the late volcanic activity period on the geologic map of Jeju by the Korea Institute of Geoscience and Mineral Resources. Also, as shown in Fig. 2, it was classified as pure basalt when plotted on a TAS diagram (Total Alkali-Silica diagram; [4]), which is a classification system for volcanic rocks, using the SiO_2 and Na_2O+K_2O composition (48.36 Wt,%, 4.41 Wt,%) based on the XRF analysis of the basalt aggregate from this area presented in a previous study [3].

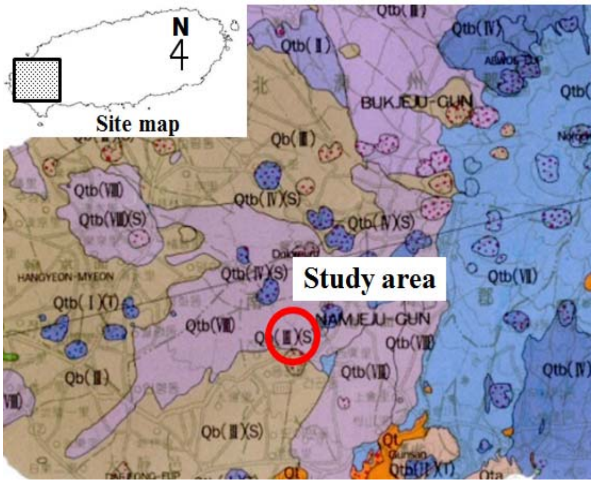

Fig. 1 Geologic map of study area

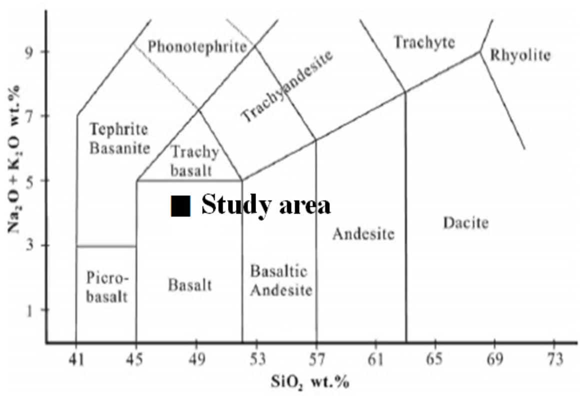

Fig. 2 Classification of the basalt according to TAS diagram

To examine the engineering properties of the basalt from Jeju, various material property and strength tests were performed using Pyoseonri basalt, trachytic basalt, and scoria, and it was reported that the water absorption ratio was inversely proportional to the specific gravity and strength [5]. In addition, the correlations of porosity with unconfined compressive strength, tensile strength, elastic modulus, and seismic velocity were examined using a parameter that expresses the porous structure of the basalt from Jeju as the porosity, and it was reported that a strong correlation was observed where the unconfined compressive strength of the basalt exponentially decreased as the porosity increased [6].

Unlike inland areas, the ground structure of the Jeju area has a layer structure where pyroclastic materials and voids (i.e., weak layer) are irregularly developed between basalt layers, and pores are developed within the basalt bedrock. These pores within the bedrock are reflected in basalt aggregate, and thus they have an absolute effect on the specific gravity of aggregate which is an element that determines the porosity and saturation of asphalt mixture and also have a large effect on the determination of asphalt content during the mix design of asphalt mixture. Table I summarizes the quality test results of general basalt aggregate, and first-grade aggregate with a flat and elongated particle ratio of 7.5% was used. In the case of recycled basalt aggregate, it is difficult to distinguish in terms of location because intermediate waste treatment contractors select and sell waste asphalt produced from the entire Jeju area, and the quality test results showed that the content of recovered asphalt was 4.9% and the penetration index of recovered asphalt (25℃) was 27 (1/10mm).

TABLE I
PROPERTY OF AGGREGATE

Classification	Apparent specific gravity	Absorption (%)	Abrasion (%)	Stability (%)	Flat and elongated Particles (%)
Coarse aggregate	2.70	1.76	21.5	5.0	7.5
Fine aggregate	2.69	1.83	-	4.8	-

B. Asphalt Binders

For the asphalt binder, two types were used: general asphalt AP-5 and SBS PMA which is polymer modified asphalt with added styrene-butadiene-styrene (SBS). Table II summarizes the basic quality provided by the manufacturer. The general asphalt AP-5 corresponds to the penetration index of AC60-80 and the performance grade of PG64-22. In the case of SBS PMA, the binding methods can be classified into physical binding and molecular binding, and the latter method is known to be superior in terms of storage stability.

TABLE II
PROPERTY OF ASPHALT BINDERS

Classification	Unit	Asphalt Binder		Test Method
		AP-5	SBS PMA	
Performance grade	-	PG64-22	PG76-22	KS F 2389
Penetration (25℃)	-℃	74	60	KS M 2252
Softening Point	℃	47.2	80.4	KS M 2250
Ductility (15℃)	cm	150	80	KS M 2254
Density (15℃)	g/cm^3	1.040	1.044	KS M 2201
Viscosity (135℃)	cP	419	1,656	KS F 2392

In this study, SBS PMA with molecular binding was used where the performance grade was PG76-22 and the viscosity at 135℃ was 1,656 cP which was higher than that of general asphalt binder. Thus, during the compaction and mixing of asphalt mixture, the temperature needs to be about 10℃ higher than that of general asphalt mixture.

III. Mix Design

The optimal usage range of recycled waste asphalt aggregate suggested by domestic and foreign literature is 10%~70% of total asphalt mixture based on weight ratio; but in the case of general batch plant, it can be used up to 50%. A 100% recycling technique was also studied through the development of an additive, but 10%~35% is considered the most appropriate proportion without an auxiliary device that preheats recycled waste asphalt aggregate [7].

In this study, combined grading that mixed coarse aggregate, fine aggregate, and filler was made by applying the dense grade asphalt (WC-2) grading standard for surface course with a maximum particle size of 13mm. To determine the optimal usage range of recycled basalt aggregate from the Jeju area for HMRAM, it was set to 27% of aggregate ratio and the ratio of general aggregate to recycled aggregate was set to 7:3 based on basic research that had previously been performed in a laboratory. In the case of HAM, 100% of general aggregate was used. Table III summarizes the mix design for HAM and HMRAM. The mixing temperature of HAM (AP-5) was set to 150±5℃, and the heating temperature of asphalt was heated up to 160±5℃. The mixing temperature of HMRAM (SBS PMA) was set to 160±5℃, and the heating temperature of asphalt was heated up to 170±5℃. The two types of asphalt mixture specimens were compacted 50 times on both sides using a Marshall compactor, and three specimens were manufactured for each test group and an average value was calculated. In addition, in the case of the quality standard for evaluating the performance of asphalt mixtures, the group standard (Hot mix asphalt mixture; SPS-KAI0002-F2349-5687) was applied; and for the asphalt tests, the Marshall stability and flow test (KS F 2337), the indirect tensile strength test (KS F 2382), and the moisture resistance test (KS F 2398) were performed following the KS standard.

TABLE III
Mix Design of HAM and HMRAM

Classification	Aggregate Size	HAM		HMRAM	
		Cold-Bin Materials Mixing Ratio (%)	Materials Mixing Ratio (%)	Cold-Bin Materials Mixing Ratio (%))	Materials Mixing Ratio (%)
Coarse aggregate	13 ~ 2.5	44.0	41.7	34.0	32.6
Fine aggregate	5 ~ 0.08	52.0	49.2	36.0	34.6
Recycled aggregate	13 ~ 0			27.0	25.9
Filler	0.3~0.08	4.0	3.8	3.0	2.9
AP-5 content (%)			5.3		
Recovered asphalt content (%)					1.3
SBS PMA content (%)					4.0
Total		100.0	100.0	100.0	100.0

IV. Results and Methods Of Test

A. Marshall Stability and Flow Test

The Marshall stability test is part of Marshall mix design for determining the design asphalt content by measuring the stability and flow of asphalt mixture, and it is also used for the quality control of asphalt mixture. In the test, compressive load was applied to a cylindrical specimen with a diameter of 101.6mm and a height of 63.5mm at a loading rate of 50mm/min through a loading head with a circular arc shape that is separated into an upper part and a lower part. The maximum load at the failure of the specimen is called the stability which represents the strength of the asphalt mixture, and the vertical displacement until the point is called the flow value (1/100cm). In general, when the flow value is low, the mixture lacks the content of asphalt necessary for securing the durability and thus premature cracks could occur. Before the test, the specimen is immersed in a constant-temperature water tank (60±1℃) for 30 minutes to maintain the test temperature. This is the maximum temperature of pavement during the summer season, and thus is to simulate the worst condition for the heated asphalt mixture.

Table IV summarizes the results of the test. Both HAM and HMRAM satisfied the quality standard of the Marshall stability (above 5000N). However, the HMRAM had a value of 17,771N indicating that the strength of the asphalt mixture was about 27% higher than that of the HAM. The quality standard of the flow value is 20~40 (1/10mm). The HAM and HMRAM showed similar flow values at an appropriate level, and thus it is thought that there is no problem in plastic deformation resistance or durability.

TABLE IV
Comparisons of Marshall Stability and Flow for HAM and HMRAM

Mix Type	Marshall Stability (N)	Flow (1/10mm)	Remark
HAM	15,700	34	
	13,289	25	
	12,955	30	
	13,981	**30**	Average
HMRAM	17,998	35	
	17,770	30	
	17,544	34	
	17,771	**33**	Average

B. Indirect Tensile Test

To analyze the crack resistance, the indirect tensile strength and toughness were obtained through an indirect tensile strength test. In the indirect tensile strength test, two (upper and lower) loading frames having a curvature with a width of 12.7mm were vertically supported in parallel against a cylindrical specimen with a diameter of 101.6mm and a height of 63.5mm. Then, uniform tensile force was applied at a loading rate of 50mm/min along the diameter surface, and the strength at the time of failure was measured. The indirect tensile strength was calculated as shown in (1). Toughness is a scale that represents the resistance to deformation (i.e., the degree to which deformation energy can be absorbed), and is a representative measurement that evaluates the crack resistance of mixture. The toughness value was calculated based on the area of the load-displacement curve obtained from the indirect tensile strength test.

Fig. 3 shows the results of the test. The tensile strength of the HAM was 1.27MPa on average (1.21MPa~1.33MPa), and that of the HMRAM was 2.27MPa on average (2.08MPa~ 2.33MPa). This exceeds the quality standard of tensile strength (0.8MPa), and the value increased by about 1.8 times compared to that of the HAM. The toughness of the HAM was 13,644N·mm on average (12,509N·mm~14,704N·mm), and the toughness of the HMRAM was 29,395N·mm on average (27,672N·mm~31,404N·mm) which roughly doubled compared to that of the HAM, showing outstanding crack resistance.

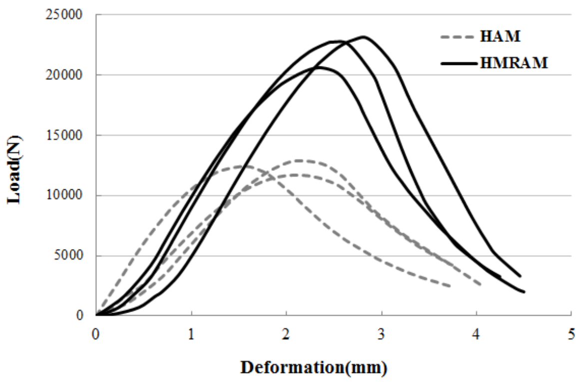

Fig. 3 Comparisons of indirect tensile strength for HAM and HMRAM

$$S_T = \frac{2P}{\pi D h} \quad (1)$$

where, S_t: indirect tensile strength (MPa), P: failure load (N), D: specimen diameter (mm), h: specimen height (mm),

C. Moisture Resistance Test

To evaluate the moisture sensitivity, a tensile strength ratio (TSR) test was conducted. Six specimens were manufactured for each mixture, and they were divided into three dry specimens and three moisture-treated specimens. In this regard, their porosities were made to be 7.0±0.5%. The dry specimen was wrapped with a plastic wrap and put into a plastic bag. It was cured for about two hours in a constant-temperature water tank (25°C), which was then used for the indirect tensile strength test. The moisture-treated specimen was saturated by adjusting the vacuum pressure so that the water saturation could be 70~80%. It was wrapped with a plastic wrap and cooled for more than 16 hours at –18±3°C in a plastic bag along with 10ml of water. Then, the specimen was taken out, and the plastic wrap and bag were removed. It was immersed in a constant-temperature water tank (60±1°C) for 24 hours, and was cured for about two hours in a constant-temperature water tank (25°C) which was then used for the indirect tensile strength test. The TSR was calculated as shown in (2). In this regard, to increase the reliability of the result, the average porosities of the two specimen groups (dry/moisture-treated) should be similar [8].

The results of the analysis showed that the TSR value of the HAM was 0.87 and that of the HRAM was 0.95 as shown in Fig. 4. Thus, both exceeded and satisfied the tensile strength ratio quality standard in Korea (0.75). However, the strength loss due to moisture treatment was about 13% for the HAM and about 5% for the HMRAM compared to the dry specimen, indicating that the HMRAM with a high TSR value had high resistance to moisture.

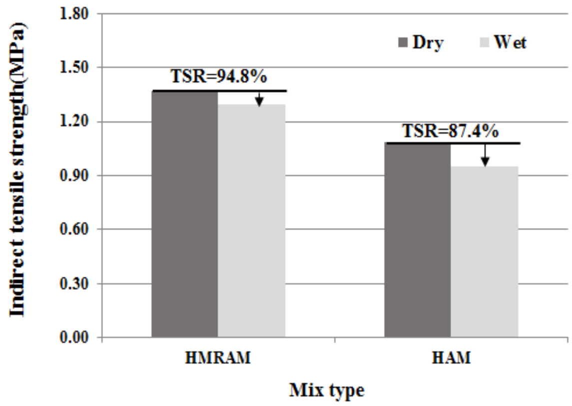

Fig. 4 Comparisons of TSR Values at Dry and Wet Conditions

$$TSR = \frac{Wet}{Dry}(indirect\ tensile\ strenght) \quad (2)$$

V. Conclusion

In this study, the characteristics of general basalt aggregate and recycled aggregate were examined in order to use them for asphalt mixture, and the indoor performances of Hot-mix Asphalt Mixture (HAM) where the proportion of general aggregate was 100% and the asphalt binder AP-5 was mixed and of Hot-mix Modified Recycling Asphalt Mixture (HMRAM) where the proportion of recycled aggregate was 27%, SBS PMA was mixed, and the general aggregate-recycled aggregate ratio was 7:3 were evaluated. The results of this study can be summarized as follows.

1) The general basalt aggregate used in this study was pure basalt (Qb, Ⅲ) formed during the late volcanic activity period (Qb, Ⅲ). The strength was not lower than those of other igneous rocks, but pores are developed within the rock. Thus, when used as aggregate, it affects the specific gravity of aggregate for determining the asphalt content in the mix design stage, which requires attention. Also, the content of recovered asphalt in recycled basalt aggregate should be examined.
2) The results of the Marshall stability and flow test showed that the Marshall stability of the HMRAM was 17,771N indicating that the strength of the asphalt mixture was about 27% higher than that of the HAM. The two mixtures had satisfactory flow values (30~33 (1/10mm)), and thus it is thought that there is no problem in the durability.
3) The results of the indirect tensile strength test indicated that the value of the HMRAM was 2.27MPa which was about 1.8 times higher than that of the HAM (1.27MPa).

The toughness of the HAM was 13,644N·mm, and the toughness of the HMRAM was 29,395N·mm which roughly doubled compared to that of the HAM. Therefore, it is thought that the HMRAM has outstanding crack resistance.

4) In the moisture resistance test, the tensile strength ratios (TSR) of the specimen where freezing and thawing was reproduced in water and of the dry specimen were calculated and compared. The TSR of the HAM was 0.87 indicating a strength loss of about 13%, and that of the HMRAM was 0.95 indicating a strength loss of about 5%. Therefore, it is thought that the HMRAM has outstanding resistance to moisture.

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