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섬유보강 친환경 상온아스팔트 혼합물의 역학적 특성에 관한 연구

A Study on Mechanical Characteristics of Fiber Modified Emulsified Asphalt Mixture as Environmentally-Friend Paving Material

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요 지

상온아스팔트 혼합물은 생산공정이나 시공 중에 naphtha나 kerosene을 사용하는 컷백 아스팔트와 같이 환경오염물질을 생성하지 않고 골재와 아스팔트 바인더를 가열하지 않기 때문에 가열아스팔트 혼합물에 비하여 환경친화적이며 경제적이다. 그러나 일반적으로 상온아스팔트 혼합물은 가열아스팔트 혼합물에 비해 내구성이나 수분민감성에서 미흡한 점이 많다.

본 연구에서는 상온아스팔트의 수분민감성과 내구성을 증진시킬 수 있는 섬유보강 상온아스팔트 혼합물(FEAM)에 대한 평가를 하였다. 최적 유화아스팔트량(OEC), 최적함수량(OWC) 그리고 최적 섬유보강제 첨가량(OFC)를 결정하기 위해서 마샬배합설계를 수정 개발하였다. 최적의 섬유보강 상온아스팔트 혼합물과 일반 상온아스팔트 혼합물을 제작하여 마샬안정도 시험, 간접인장강도 시험 및 회복탄성계수 시험을 실시하였고 그 결과를 가열아스팔트 혼합물의 결과와 비교하였다. 결과로 FEAM과 EAM 모두 마샬배합설계 기준으로 중간 교통량에 충분한 것으로 판명되었다. 또한 섬유보강에 의하여 일반 상온아스팔트 혼합물의 수분민감성과 내구성이 증진하는 효과도 얻을 수 있는 것으로 판면되었다.

핵심용어 : 섬유보강상온아스팔트, 수정마샬배합설계, 내구성, 수분민감성

Abstract

Emulsified Asphalt Mixture(EAM) is more environmentally-friendly and cost-effective than typical Hot Mix Asphalt (HMA) because EAM does not produce carcinogenic substances, e.g., naphtha, kerosene, during the both of manufacturing and roadway construction process. Also, it does not require heating the aggregates and asphalt binder. However, EAM has some disadvantages. Generally EAM has a less load bearing capacity and more moisture susceptibility than conventional HMA.

The study evaluated a Fiber modified EAM (FEAM) to increase load bearing capacity and to decrease moisture susceptibility of EAM. Modified Marshall mix design was developed to find Optimum Emulsion Contents (OEC), Optimum Water Contents (OWC), and Optimum Fiber Contents (OFC). A series of test were performed on the fabricated specimen with OBC, OWC, and OFC. Tests include Marshall Stability, Indirect Tensile Strength, and Resilient modulus test. Comparison analyses were performed among EAM, Fiber modified EAM (FEAM), and typical HMA to verify the applicability of EAM and FEAM in the field. Test results indicated that both of EAM and FEAM have an enough capability to resist medium traffic volume based on the Marshall mix design criteria. Also the study found that fiber modification is effective to increase the load bearing capacity and moisture damage resistance of EAM.

Keywords : fiber modified emulsified asphalt mixture, modified Marshall mix design, load bearing capacity, moisture susceptibility

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1. INTRODUCTION

Currently, environmental issues are being more critical than other factors in many industrial fields, e.g., exhaustion of petrochemicals and air pollution. Particularly, typical roadway construction process generates environmentally harmful and a carcinogenic substance, e.g., naphtha and kerosene during the manufacturing and construction process. However, Emulsified Asphalt Mixture (EAM), so called cold mixture, reduces harmful substances and saves petrochemicals because water is added instead of petrochemicals, e.g., naphtha, light oil, and kerosene, in the manufacturing process. Also, EAM is the cost-effective alternative because it does not require heating the aggregates and binder forboth mixing and compaction process. Thus, application of an EAM is more environmentally-friendly, non-harmful, and cost-effective than conventional paving materials (1). EAM has, however, some disadvantages in its application in the field. Generally EAM has a less load bearing capacity and more moisture susceptible than conventional Hot Mix Asphalt (HMA) (2). To resolve the situation, the study utilized a fiber modifier to increase load bearing capacity and decrease moisture susceptibility of EAM. The study modified Marshall mix design (3) to find the Optimum Emulsion Contents (OEC) and Optimum Water Contents (OWC). The Optimum Fiber Contents (OFC) was determined at which the resilient modulus of mixture is maximized.

2. MATERIAL

The study utilized single source of aggregate with Nominal Maximum Aggregate Size (NMAS) of 12.5mm, Medium Setting (MS) type cationic emulsion, and polypropylene 3010 fiber. Modified Marshall mix design was applied to determine the Optimum Emulsion Contents (OEC) and Optimum Water Contents (OWC). The optimized mixtures were fabricated to perform various tests, e.g., Marshall stability and indirect tensile test at dry and saturated condition to evaluate the water susceptibility. Details are described in the following sections.

2.1 Aggregates

Aggregate test results are summarized in Table 1. All test results satisfied the corresponding specifications. Figure 1 shows the BB-2 gradation in accordance with Korean Standards (KS) master ranges. It should be noted that fine gradation was selected, because the finer gradation is expected to provide the mixture with the higher emulsion contents and less water penetration into the mixture.

Table 1. Aggregate Test Results

Test Type	AASHTO Designation	Test Run No./Material	Test Results	Spec.
LA Abrasion Test	AASHTO T- 96	Run #1 Run #2	31.5% 33.2%	Max. 35%
Bulk Specific Gravity	AASHTO T- 85	Coarse Fine	2.61 2.51	N/A
Crushed Surface	KHC Recommendation	Batch #1 Batch #2	85% 90%	Min. 65%
Sand Equivalent	AASHTO T-176	Run #1	47%	Min. 35%

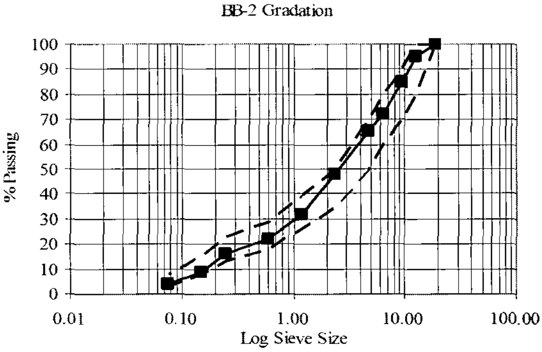

Figure 1. BB-2 Gradation

2.2 Emulsified Asphalt (Emulsion)

Emulsified Asphalt binder, simply called emulsion, is made of straight asphalt, water, and emulsifying agent. All constituents are mixed in the colloid mill at high shear and high pressure to produce extremely small asphalt droplets, which are suspended in water (4). There are two categories depending on electronic condition of asphalt droplets, e.g., Anionic and Cationic. For each of categories, there are typically three types of emulsion according to their setting time, e.g. Rapid Setting (RS), Medium Setting (MS), and Slow Setting (SS). The study utilized cationic medium setting emulsion, MS-2, in accordance with ASTM D3628. Typically, MS-2 is used for the aggregate mixtures. Table 2 shows the emulsion property test results.

Table 2. Emulsified Asphalt Binder Property Test Results

Test	Test Item	Test Results	ASTM D977	
			Min	Max
on Emulsion	Engler Viscosity, at 25℃	50	20	100
	Sieve Test 1190㎛ %	0.0072	-	0.1
	Storage Stability, 1days	2.8	1	-
	Coating Test	Pass	-	-
	Particle Charge	(+)	-	-
on Residue from Distillation	Residue, %	64.2	-	-
	Penetration Depth, 1/10mm	194	100	250
	Ductility, 25℃ cm	74.2	40	-
	Solubility, %	99.88	97.5	-

2.3 Fiber Modifier

Asphalt modification is one of the most popular techniques to improve the strength, resistance to micro-cracking, and resistance to plastic deformation of bituminous mixture (5). A study found that fiber modification generally increases the micro-cracking resistance and moisture damage resistance. (6). The study utilized polypropylene 3010, which is produced by H Company in Kentucky, U.S. Table 3 shows the test results of polypropylene 3010.

Table 3. Polypropylene 3010 Test Results

Test Item	Test Results
Length, mm	10±2
Color	Black
Tensile Strength, psi	40,000
Elongation Rate, %	100
Specific Gravity	0.91
Alkali Resistance, %	100
Acid Resistance	100
Glass Transient Temp., ℃	-18

3. MIX DESIGN

3.1 Modified Marshall Mix Design

The Marshall mix design method has been widely used to design Hot Mix Asphalt (HMA) for over half century. It determines the proper combination of asphalt binder and aggregate that will provide asphalt pavement structure long lasting performance. The main procedures of Marshall mix design includes determining an appropriate aggregate gradation and asphalt binder contents, with which the mixture satisfies the volumetric criteria, plastic flow, and stability.

For the expanded application of Marshall mix design to Fiber modified Emulsion Asphalt Mixture (FEAM), modified Marshall mix design was developed in the study. The modification included additional processes to the original Marshall mix design, which includes: Aggregate-Emulsion coating test, Determination of Optimum Water/Fiber Content (OWC/OFC), and curing of compacted mixture. Detailed discussion on modified Marshall mix design is described as follows.

3.1.1 Aggregate-Emulsion Coating Test (Determination of Optimum Water Contents)

The study utilized Aggregate-Emulsion Coating (AEC) test to determine the optimum water contents, at which the coating rate is maximized. Figure 2 illustrates the aggregate-emulsion coating test results. This test was performed at the constant emulsion contents of 4 percent while the water contents varying 0.5 ~ 4.0 percent by 0.5 percent increment. It should be noted that both of the emulsion and water contents are computed by the total weight of aggregates. The mixture of aggregate, emulsion, and water were hand-mixed approximately 1 minute. The mixture was placed in the shaded area for 1 hour after mixing. Then, the emulsion coating rates was estimated by visual inspection. AEC test determined OWC of 2.5 percent because the test result showed that the coating rate is maximized at 6 percent water contents. Test result also indicated that when the water contents exceed the OWC, the coating rates decreases.

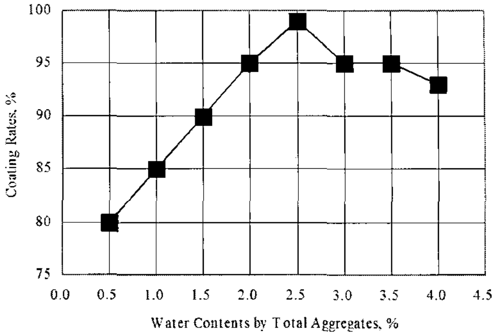

Figure 2. Aggregate-Emulsion Coating Test Results

3.1.2 Determination of Optimum Emulsion Contents

The Marshall mix design was performed to determine Optimum Emulsion Contents (OEC). 4 inch diameter (101.6 mm) specimens were compacted with 50 blows per each side, which is corresponding to medium traffic level.

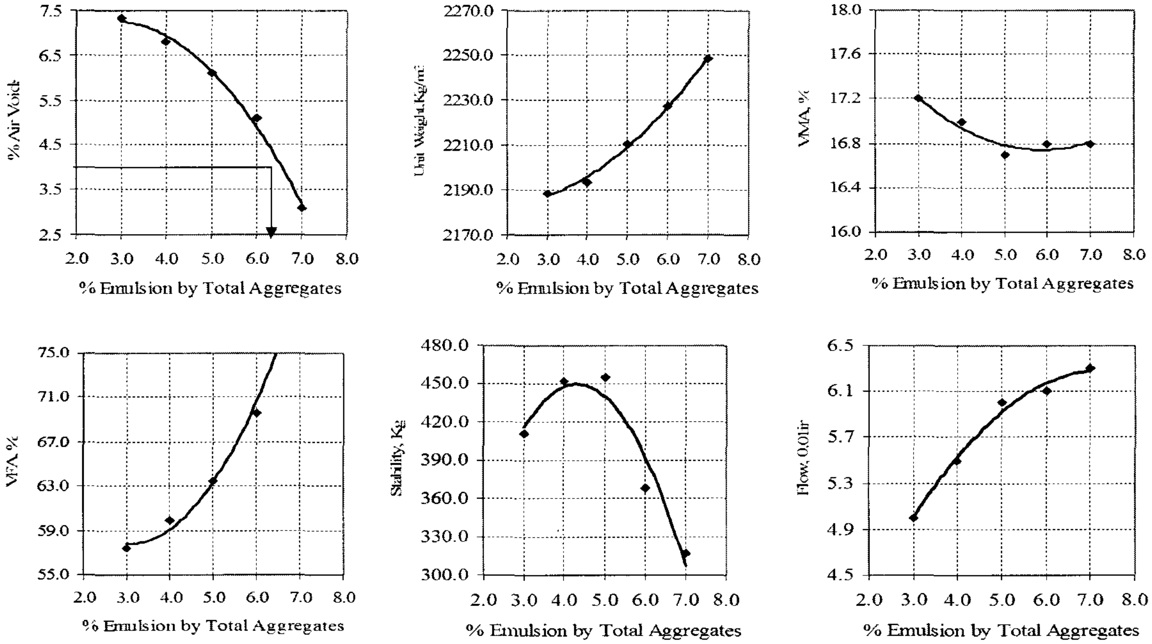

Figure 3. Marshall Mix Design Results on Emulsified Asphalt Mixture

Triplicate specimens, for each asphalt binder contents varying 3.0 percent to 7.0 percent by the increment of 1.0 percent, were fabricated at the room temperature. The volumetric properties, e.g., bulk specific gravity test (Gmb) and maximum theoretical specific gravity test (Gmm), were determined in accordance with AASHTO T166-93 and AASHTO T209-94 respectively. Then, the Air Void (Av), Void in Mineral Aggregate (VMA), and Void Filled with Asphalt (VFA) were computed. Marshall stability and flow were determined on the compacted samples in accordance with the test method AASHTO T245-94 (ASTM D1559-76). It should be noted that Asphalt Institute (AI) procedure recommends performing Marshall stability test on the cold mixture at the temperature of 25oC, and also recommended that the minimum criteria of Marshall stability is 250 kg (7).

Figure 3 show the Marshall mix design results to determine OEC with 2.5 percent water contents. The results determined OEC of 6.2 percent (Residue 3.84 percent). The mixture properties at OEC are summarized in Table 4.

Table 4. Mixture Properties at Optimum Emulsion Content of 6.2 percent (Residue 3.84 Percent)

Base Course HMA	Results	Criteria	
		Min	Max
Compaction Level	50	50 (Medium Traffic)	
%Air	4	2	8
Unit Weight, kg/m3	2230	N/A	
%VMA	16.7	N/A	
%VFA	72.0	N/A	
Stability, kgf	370	250	
Flow, 0.025mm	6.2	N/A	
Coating Rate, %	100	50	

3.1.3 Determination of Optimum Fiber Contents

The indirect tensile resilient modulus test was performed utilizing Nottingham Asphalt Tester (NAT) on the 4 inch diameter Marshall compaction mixtureswith varying fiber contents by total aggregates weights from 0.20 to 0.45 percent by 0.05 increments. The test was performed in accordance with standard test method, ASTM D4123-82 (8). The schematic of test equipment and test setup are summarized in Figure 4 and Table 5, respectively. Figure 5 shows the indirect tensile resilient modulus test results of mixtures with varying fiber contents. The test results determined the optimum fiber contents of 0.30, at which the maximum value exhibited. It should be noted that as the

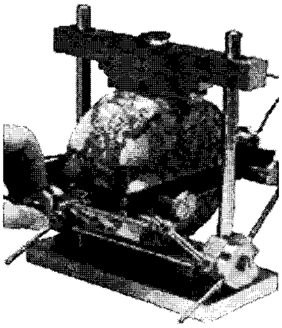

Figure 4. Schematic of NAT

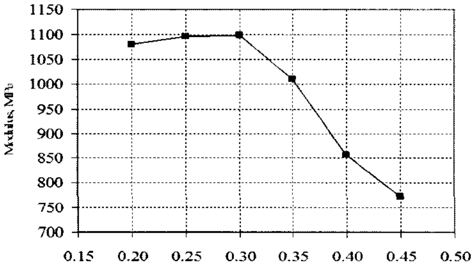

Figure 5. Resilient Modulus of Mixtures with Varying Fiber Contents

Table 5. NAT Test Setup

Setup Item	Value
Vertical Load, KN	0.1
Test Temperature, oC	25
Target Horizontal Deformation, micron	5
Loading Time (millisecond)	124
Unloading Time (millisecond)	876

fiber contents exceeds the optimum, the resilient modulus of mixtures were decreased rapidly. Thus, caution should be taken in controlling an exact amount of fiber in use.

4. TEST RESULTS AND INTERPRETATIONS

The study performed a series of mechanical tests, e.g., indirect tensile test, resilient moulus test, and Marshall stability test. Also, the experimental design investigated the effect of fiber modification on moisture damage,because the moisture susceptibility is one of the major considerations in designing asphalt mixture (9). To evaluate the moisture susceptibility of mixtures, the study developed mixture saturation equipment, which is simulating the field saturated mixture condition (Figure 6).

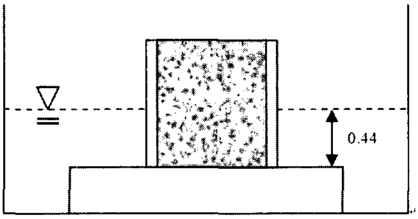

Figure 6. Schematic of Mixture Saturation Equipment

4.1 Indirect Tensile Test (IDT)

Indirect tensile test was developed independently by Akazawa of Japan and Carneiro of Brazil in 1953 (10). It was found that when a load is applied to a cylindrical specimen through its diametrical axis, uniform stresses are generated at the center of specimen. Currently, this test is utilized to determine tensile strength of brittle material, e.g., asphalt mixture. The present study performed indirect tensile test at the test temperature of 25oC and loading rate of 2inches/minute (50.8mm/minute) on the triplicate test samples. Indirect tensile test was performed on EAM and FEAM in both of dry and wet conditions to investigate the enhancement of moisture damage resistance from fiber modification. Also, indirect tensile test was performed on typical HMA mixtures as control mixtures. Figure 7 illustrates the indirect tensile test results. Test results indicated that the indirect tensile strength of EAM and FEAM exhibited 42.4 and 53.4 percent of that of HMA, respectively. Fiber modification increased indirect tensile strength of emulsified mixture by 125.8 percent of dry condition. Figure 8 shows that moisture damage resistance increased from 70 percent to 87 percent by fiber modification.

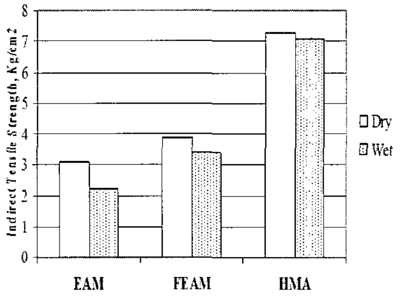

Figure 7. Indirect Tensile Strength Test Results

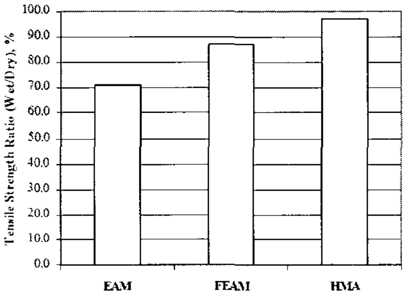

Figure 8. Wet/Dry Indirect Tensile Strength Raties

4.2 Resilient Modulus Test

As discussed in the section 3.1.3, resilient modulus test was performed to determine optimum fiber contents. Also, it was performed on EAM and FEAM in both of dry and wet conditions, to investigate the enhancement of moisture damage resistance of fiber modification. Figure 9 shows the resilient modulus test results. Test results indicated that fiber modification slightly increased the resilient modulus of emulsified mixtures. However, the moisture damage resistance of emulsified mixtures was increased from 49.6 to 61.2 percent by the fiber modification as shown in Figure 10.

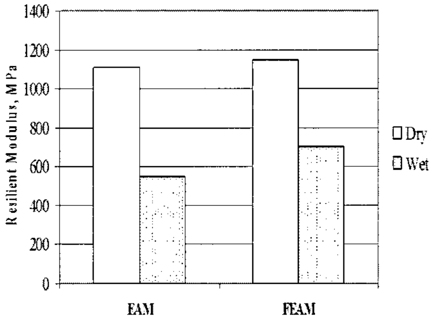

Figure 9. Resilient Modulus Test Results

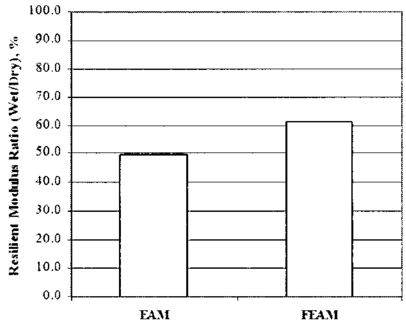

Figure 10. Wet/Dry Resilient Modulus Ratios

4.3 Marshall Stability Test

Marshall stability test was performed on the EAM, FEAM, and HMA to evaluate the applicability of emulsified asphalt mixtures for the base course in terms of Marshall stability criteria. Figure 11 shows the test results. The test results indicated that the Marshall stability of both EAM and FEAM are satisfactory to meet the design criteria. However, the Marshall stabilities of EAM and FEAM were 40.7 and 49.9 percent of those of HMA, respectively.

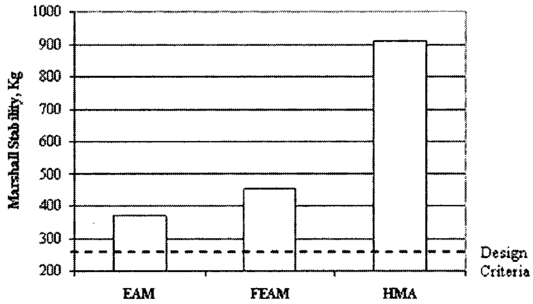

Figure 11. Marshall Stability Test Results

CONCLUSIONS AND RECOMMENDATIONS

- Modified Marshall mix design was developed to design Fiber modified Emulsified Asphalt Mixture (FEAM)
- In accordance with design criteria (MS-19), the Marshall stability of both EAM and FEAM were satisfactory to be used in the field.
- It has been observed that fiber modification is effective to increase the indirect tensile strength and moisture damage resistance of emulsified mixtures, whereas it is not effective to increase the resilient modulus of emulsified mixtures.
- According to the Marshall stability test results, the FEAM is suitable for the secondary or tertiary roadway in the comparison of typical HMA.
- Based on the coating test results, it is found that the water contents are sensitive to the mixture coating rate. Thus, special care should be taken on the water contents for the construction of emulsified asphalt in the field application.
- Further research can be devoted to increase the strength of emulsified asphalt mixtures and to decrease the sensitivity of water contents on the emulsified asphalt mixtures in order to populate the application of them in the field.

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