EFFECTS OF AGGREGATE-ADDITIVE COMBINATIONS AND GRADATION PROPERTIES FOR ASPHALT MIXTURE STRIPPING

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ABSTRACT

The stripping performance of asphalt mixtures was evaluated. Stone Mastic Asphalt (SMA) mixtures were produced with 19mm and 12.5mm nominal aggregate size and two gradations were also chosen for each nominal aggregate size. Coarse-fine-filler materials were selected as the basalt aggregate in terms of aggregate fractions. Basalt filler material was replaced with limestone filler and the filler effect was investigated. 1%-1.5%-2% hydrated lime contents were selected for each mixture combination and the hydrated lime effects were evaluated. The AASHTO T283 test method was studied. Moisture damage decreased with limestone filler replacement substituted for basalt filler. Mixtures that included basalt filler showed the highest moisture damage ratio for 1.5% hydrated lime incorporation but mixtures with limestone filler gave the highest damage ratio at the 1% percentage. For both basalt and limestone mixtures the moisture damage ratio increased with the translation from 19mm to 12.5mm for coarser and finer gradations separately.

Keywords: Mineral filler, Mixture design, Performance testing, Stone Mastic Asphalt

1. INTRODUCTION

Stripping is an important type of distress about which gaining thorough information can improve pavement design methods. Research studies on stripping can be divided into three categories as field studies, laboratory investigations, and numerical and computational analysis. Laboratory experiments can be also categorized into five groups which are tests on loose mixtures, destructive mechanical tests on asphalt concrete, non-destructive mechanical tests on asphalt concrete, mechanical tests which provide a measure of cohesion in asphalt and adhesion between asphalt and aggregate, non-mechanical tests which provide a measure of cohesion and adhesion based on surface energy theories and non-destructive non-mechanical tests [1].

Creep and stripping are two important related factors and it is thought that moisture damage reveals itself as rutting at high temperatures. This comment can be based on these results: Unconditioned HMA specimens prepared using basalt aggregate resisted creep better than those prepared using limestone. However, after conditioning, mixes prepared using basalt were less resistant to creep strain than those prepared using limestone aggregate. The percentage of absorbed asphalt was found to be directly related to stripping resistance. Also, mixes prepared using aggregate following the ASTM upper limit of dense aggregate gradation presented the highest resistance to stripping. The results of the calculated adhesion work made it possible to detect the effect of stripping on creep behavior for the mixes prepared [2].

Environmental factors such as temperature, air, and water can have a profound effect on the durability of asphalt concrete mixtures. In mild climatic conditions where high quality aggregates and asphalt cement are available, the major contribution to deterioration may be traffic loading, and the resultant distress manifests as fatigue cracking, rutting (permanent deformation), and raveling. However, when a severe climate is in question, these stresses increase with poor materials, inadequate control and with traffic as well as with water which are key elements in the degradation of asphalt concrete pavements. Water causes loss of adhesion at the bitumen–aggregate interface. This premature failure of adhesion is commonly referred to as stripping in asphalt concrete pavements. The strength is impaired since the mixture ceases to act as a coherent structural unit. Loss of adhesion renders cohesive resistance of the interstitial bitumen body useless. Water may enter the interface through diffusion across bitumen films and directly access partially coated aggregate. Water can cause stripping in five different mechanisms namely detachment, displacement, spontaneous emulsification, pore pressure and hydraulic scouring [3].

The type of aggregate, both coarse and fine, must be examined carefully in evaluating the water damage of the mixture. Some aggregates such as granite, gravel and other siliceous type materials are sensitive to moisture and are prone to stripping when incorporated into asphalt concrete. Other aggregates such as limestone are less susceptible to moisture damage. In some cases, the majority of the stripping takes place in the coarse aggregate portion of the mixture. In some cases, the fine aggregate is more moisture sensitive and most stripping occurs in that part of the mixture. The asphalt film thickness also has an influence on the moisture susceptibility characteristics of HMA because it affects the durability of the mixture. Thick films which are associated with black flexible mixtures are known to be durable. On the other hand, thin films which are associated with brownish, brittle mixtures tend to crack and ravel excessively, thus shortening the service life of the pavement. Mixtures with thick asphalt film are less susceptible to water damage than the mixtures with thin asphalt film since very small quantities of water can move through a mixture that contains thick asphalt film thicknesses [4].

Moisture conditioning is used to evaluate the effects of water saturation of compacted bituminous mixtures in the laboratory. Conditioning of hot-mix asphalt specimens is performed according to AASHTO T283 by immersing the specimens in water (sea or tap water) and exposing them to a vacuum for different treatment periods to achieve saturation levels of up to 80%. As a result, the investigated saturation degrees in this study were 0.0%, 10%, 25%, 50% and 80%; by this method the water damage of the specimens became more effective [5]. AASHTO T-283 was used in this test where a tensile strength ratio (TSR) value of less than 70% was considered to be moisture susceptible [6]. The stripping resistance of asphalt mixtures is evaluated by the decrease in the loss of the indirect tensile strength (ITS) according to the AASHTO T283 test procedure. In the indirect tensile strength test, cylindrical specimens are subjected to compressive loads which are parallel to the vertical diametric plane using Marshall loading equipment. This type of loading produces a relatively uniform tensile stress which is perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane [7]. Based upon the maximum load carried by a specimen at failure, the ITS in kPa is calculated from $ITS=(2*F)/(\pi*L*D)$, where F is the peak value of the applied vertical load (repeated load) (kN), L is the mean thickness of the test specimen (m) and D is the specimen diameter (m). The indirect tensile test is used for the determination of the asphalt concrete mixture moisture susceptibility [8]. The moisture susceptibility of the compacted specimens is evaluated by tensile strength ratio (TSR) using $TSR=S_2/S_1$, where TSR is the tensile strength ratio. S_2 is the average indirect tensile strength of conditioned specimens. S_1 is the average indirect tensile strength of dry (unconditioned) specimens [7].

The purpose of this study is to evaluate a stripping problem in asphalt mixtures with different directions. Two different gradations were produced and both of the different gradations were comprised of two different nominal aggregate sizes; 19mm and 12.5mm. Filler replacement was also evaluated in terms of stripping using hydrated lime and limestone fillers. As an anti-stripping agent, hydrated lime filler was used in both basalt and basalt-limestone combinations and the compatibility interaction between filler type and lime was investigated. Water saturation damage and freeze-thaw cycling conditioning was applied to half of the samples according to the modified Lottman method (AASHTO T-283).

2. MATERIALS

In this study, four aggregate gradations containing 19mm and 12.5mm maximum aggregate sizes were selected. Two aggregate gradations (coarser and finer) were created for both maximum aggregate sizes. The gradations that were used are defined in Table 1. SMA11, SMA12, SMA21 and SMA22 describe the 19mm maximum aggregate size and coarser gradation, 19mm maximum aggregate size and finer gradation, 12.5mm maximum aggregate size and coarser gradation, and 12.5mm maximum aggregate size and finer gradation respectively.

Table 1: Used SMA gradations and fraction proportions

Sieve size		SMA 11		SMA 12		SMA 21		SMA 22	
inch	mm								
3/4	19.0	100	Coarse aggregate, 70.9%	100	Coarse aggregate, 63.9%		Coarse aggregate, 65.9%		Coarse aggregate, 59.6%
1/2	12.5	92.7		96		100		100	
3/8	9.5	63.5		70		92.3		93	
No. 4	4.75	29.1	Fine aggregate, 18.7%	36.1	Fine aggregate, 25.2%	34.1	Fine aggregate, 22%	40.4	Fine aggregate, 25.3%
No. 10	2.00	21.6		27.3		21.3		26.6	
No. 40	0.42	14.8		19.2		14.4		18.1	
No. 80	0.177	12.4		14.4		12.1		15.1	
No. 200	0.075	10.4	Filler, 10.4%	10.9	Filler, 10.9%	10	Filler, 10%	12.5	Filler, 12.5%

Basalt aggregate was defined with mineralogical tests in terms of rock petrography. Chemical analysis for the main oxides and X-ray analysis were conducted. Basalt mineralogical composition was defined with these tests and confirmed by actual material selection. The chemical compositions of the rocks, both basalt and limestone, are presented in Table 2. Basalt and limestone aggregate properties are given in Table 3.

Table 3: Chemical analysis results of used aggregates

		Basalt aggregate		Limestone aggregate	
Components, %	**Formula**	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**
Silicium dioxide	SiO_2	57.28	59.41	5.52	7.53
Aluminum oxide	Al_2O_3	13.58	13.44	0.45	0.53
Ferrous oxide	Fe_2O_3	6.75	6.72	0.88	0.61
Calcium oxide	CaO	5.25	4.49	46.47	39.45
Magnesium oxide	MgO	3.41	3.75	1.83	1.50
Sulfur trioxide	SO_3	0.00	0.00	0.00	0.00
Sodium oxide	Na_2O	1.95	1.68	0.56	0.00
Potassium oxide	K_2O	1.78	2.63	0.83	0.34
Chlorine	Cl^-	0.0216	0.0260	0.0127	0.0064
Loss on heating		4.68	3.01	36.23	33.51
Calcium carbonate + Magnesium carbonate	$CaCO_3$+$MgCO_3$	5.30	2.80	86.90	83.30

Table 2: Properties of used basalt and limestone aggregates

Properties	**Test Method**	**Value**		**Specification limit in Turkey**
		Basalt	**Limestone**	
Specific gravity (coarse agg.)	ASTM C 127			
Bulk		2.684	2.650	
Apparent		2.744	2.716	
Specific gravity (fine agg.)	ASTM C 128			
Bulk		2.656	2.621	
Apparent		2.754	2.737	
Specific gravity (filler)		2.821	2.810	
Los Angeles abrasion (%)	ASTM C-131	12	14	Max 25
Flakiness (%)	BS 812 (Part 105)	14	13	Max 25
Stripping resistance (no additive) (%)	ASTM D-1664	35-40	30-35	

Stripping resistance (Wetfix BE, 0.4% additive) (%)	ASTM D-1664	80-85	80-85	Min 60
Water absorption (%)	ASTM C-127	0.81	1.18	Max 2
Soundness in $NaSO_4$ (%)	ASTM C-88	0.92	4.56	Max 8

Figure 1 and Figure 2 show thin section images of the limestone and basalt aggregates respectively. The basaltic rocks chosen for the aggregate were made up of plagioclase phenoscrysts set in microlitic groundmass, and secondary chlorite and calcite were observed in the samples.

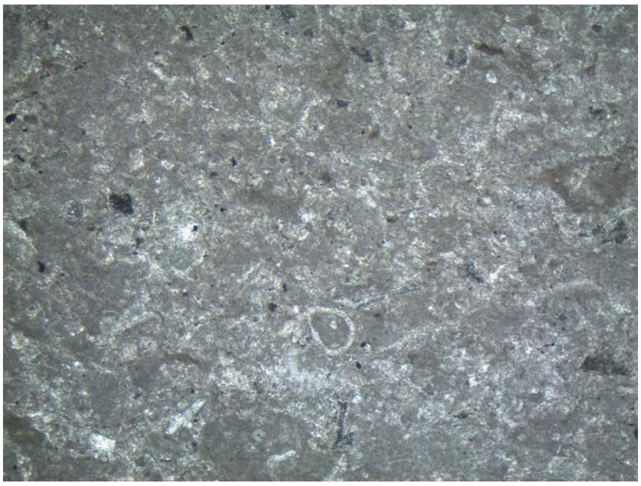

Figure 1: Thin section image of limestone aggregate

Figure 2: Thin section image of basalt aggregate

X-ray diffraction (XRD) was performed on the basalt and limestone samples. The results are given in Figure 3 for the basalt sample and in Figure 4 for the limestone sample.

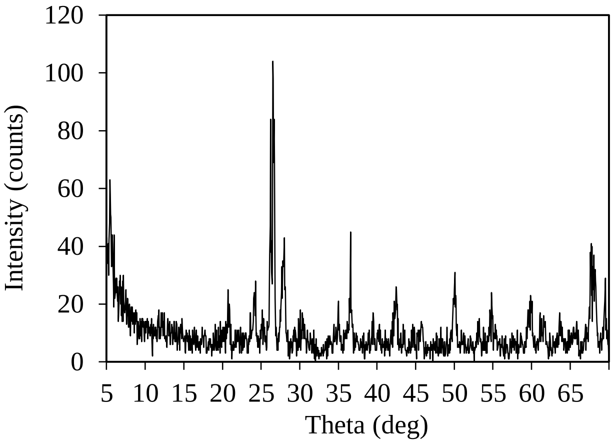

Figure 3: XRD traces of crack surface of basalt sample

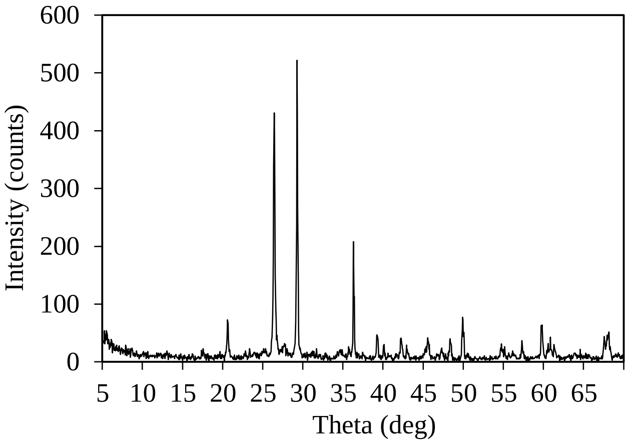

Figure 4: XRD traces of crack surface of limestone

AC50-70 penetration bitumen was used. Bitumen and cellulose fiber properties are given in Table 4 and Table 5. Moreover, hydrated lime (HL) was added as the stripping agent. HL properties are summarized in Table 6. Besides conventional mixtures, three different mixture alternatives modified with hydrated lime were formed. HL was used as a substitute for filler. Filler content was decreased in weight of total dry aggregate at 1%, 1.5%, 2% ratios and HL was added as 1%, 1.5%, and 2% proportions in the dry aggregate mixtures.

Table 4.Asphalt cement test results (AC 50-70)

Properties	Test Method	Unit	Value
Specific gravity (25°C)	ASTM D-70	gr/cm^3	1.025
Softening point (°C)	ASTM D36-76	°C	52
Flash point (Cleveland)	ASTM D-92	°C	240
Penetration (25°C)	ASTM D-5	0.1mm	63
Ductility (25°C)	ASTM D-113	cm	100+

Table 5.Conventional properties of cellulose fiber

Properties	Value
Cellulose content, %	66.7
Bitumen content, %	33.3
Inflammability temperature, °C	~500
Apparent density, gram/liter	480-530
Average particle thickness, mm	4±1
Average particle size, mm	2-8

Marshall design was performed on basalt aggregate for all gradations separately. SMA11-SMA12 and SMA21-SMA22 mixtures were designed. The design results are illustrated in Table 7. The designs were found to be suitable for Turkish specifications. In the sample production stages, mixtures with basalt filler were prepared and tested.

Table 6.Properties of the used hydrated lime (SKK 80-T)

Properties	Method	Value
Total CaO (%)	EN 459-2	85.78
Active $Ca(OH)_2$ (%)	TS 32	82.04
MgO (%)	EN 459-2	3.52
Total CaO+MgO (%)	TS	89.3
Loss of ignition (%)	EN 459	22.51
Insoluble in acid (%)	TS 32	1.41
R_2O_3 (%)	TS 32	0.47
SO_3 (%)	EN 459	1.47
CO_2 (%)	EN 459	3.89
Sandy-over 90 micron	EN 459	6
Density (kg/m^3)	EN 459	472

Table 7: Marshall Design test results

Design parameters	Mixtures				Board in Turkey	
	SMA 11	SMA 12	SMA 21	SMA 22	Min.	Max.
Bulk specific gravity, G_{mb}	2.433	2.432	2.416	2.415	-	-
Marshall stability, kg	1200	1130	1050	1040	-	-
Air voids, P_a, %	3.0	2.9	3.3	3.4	2	4
Void filled with asphalt, V_f, %	81.4	82.1	80.4	80.0	-	-
Flow, F, 1/100 in.	3.1	3.4	3.3	3.5	-	-
Asphalt cement, W_a	6.10	6.25	6.30	6.45		
Voids in mineral aggregate, %	16.1	16.2	16.8	17.0	16	-
Schellenberg binder drainage test, %	0.19	0.17	0.20	0.16	-	0.3

3. STRIPPING EVALUATION

All samples were compacted using the Marshall compactor in this study. In total 146 samples were produced excluding Marshall Design laboratory samples. 50 blows were applied to both sides of the samples. Laboratory compacted samples were produced using basalt aggregate for coarse and fine fractions. However, for the filler fraction, two different choices were used as basalt and limestone. 19mm and 12.5mm maximum aggregate sizes were selected and four gradation curves were created. Control, 1% hydrated lime (HL) modified, 1.5% HL modified and 2% HL modified mixtures were generated. HL was added as the substitute material for filler. 1%, 1.5% and 2% filler by weight of total dry aggregate was removed respectively and the same quantity HL was added into the dry aggregate mixtures.

To evaluate the moisture damage problem with the combined mixtures shown in the flow chart, the AASHTO T-283 test method was applied. [9]. Tensile strength ratio (TSR) is used to predict the moisture susceptibility of the mixtures. According to previous studies, a TSR of 0.8 or above is typically utilized as the minimum acceptable value for hot mix asphalt. Mixtures with tensile strength ratios less than 0.8 are moisture susceptible and mixtures with ratios greater than 0.8 are relatively resistant to moisture damage [10]. With the Superpave system being adopted by most state highway agencies, AASHTO T283 has become the most widely used test procedure within the industry. Some agencies have reported problems with this test in terms of correlation between the laboratory results and field observations [11].

Four samples were constructed for all mixture types and then the indirect tensile strength test samples were divided into two subsets of two specimens. The first group was the control (unconditioned) group. The second (conditioned) group was saturated between 70 and 80 percent with water and was placed in the freezer –20°C for 22 hours. The cores were placed in a vacuum container filled with distilled water. A vacuum pressure of 0.9 bars was applied for a duration of 15 minutes to provide the 70-80 percent saturation level. The frozen samples then were moved to a water bath at 60°C for 24 hours. Freeze-thaw cycling was repeated twice. After two freeze-thaw cycles, the samples were dried in an environmental chamber at 25°C for 24 hours before performing the indirect tensile strength test. Unconditioned group samples were placed in a water bath at 25°C for 2 hours and then tested.

The indirect tensile strength test measures changes in tensile strength that result from effects of saturation and accelerated water conditioning of compacted hot mix asphalt (HMA) in the laboratory. The results may be used to predict long-term stripping susceptibility of bituminous mixtures and to evaluate liquid anti-stripping additives which are added to the asphalt cement. The numerical indices of retained indirect tensile properties are obtained by comparing the retained indirect properties of conditioned laboratory specimens with the similar properties of dry specimens [12].

The indirect tensile strength test was applied at 25° test temperature for both control and conditioned briquettes. Also the test was applied to the conventional and modified mixture samples. The tension strength ratio (TSR) is normally calculated as follows: TSR=T2/T1, where: T1is the average tension of the dry subset and T2 is the average tension of the conditioned subset. The ratios were obtained with damaged and undamaged mixtures and all values are illustrated in Table 8. The other evaluations that were done are illustrated in Figure 5 – Figure 10. Used abbreviations are as follows: BF: Mixtures with basalt aggregate filler; LF: Mixtures with limestone aggregate filler; 11: SMA coarser gradation (maximum aggregate size: 19mm); 12: SMA finer gradation (maximum aggregate size: 19mm); 21: SMA coarser gradation (maximum aggregate size: 12.5mm); 22: SMA finer gradation (maximum aggregate size: 12.5mm); A: Control mixtures; B: 1% Hydrated lime-filler replacement; C: 1.5% Hydrated lime-filler replacement; D: 2% Hydrated lime-filler replacement.

Table 8: Tensile strength and TSR values for mixture combinations

Mixtures with Basalt Filler				Mixtures with Limestone Filler			
Sample ID	Indirect tensile strength (Control group) (kN)	Indirect tensile strength (Conditioned group) (kN)	ITSR	Sample ID	Indirect tensile strength (Control group) (kN)	Indirect tensile strength (Conditioned group) (kN)	ITSR
F11A	10.66	7.945	0.745	LF11A	10.705	8.945	0.836
BF11B	10.695	8.56	0.800	LF11B	10.78	9.905	0.919
BF11C	10.69	9.57	0.895	LF11C	10.77	9.825	0.912
BF11D	12.075	9.81	0.812	LF11D	12.54	11.42	0.911
BF12A	10.04	7.995	0.796	LF12A	10.23	8.755	0.856
BF12B	10.99	9.76	0.888	LF12B	11.05	10.365	0.938
BF12C	10.895	10.135	0.930	LF12C	12.12	11.27	0.930
BF12D	12.105	10.91	0.901	LF12D	12.555	11.575	0.922
BF21A	9.425	7.725	0.820	LF21A	9.575	8.465	0.884
BF21B	9.31	8.255	0.887	LF21B	9.565	9.325	0.975
BF21C	9.7	9.23	0.952	LF21C	9.755	9.355	0.959
BF21D	10.09	9.245	0.916	LF21D	11.385	10.76	0.945
BF22A	10.02	8.23	0.821	LF22A	10.5	9.525	0.907
BF22B	9.94	9.205	0.926	LF22B	10.43	11.005	1.055
BF22C	10.17	9.7	0.954	LF22C	10.88	10.81	0.994
BF22D	10.26	9.65	0.941	LF22D	11.42	11.425	1.000

19mm nominal aggregate sized SMA mixtures gave a 0.745 damage ratio for coarser gradation and a 0.796 damage ratio for finer gradation in view of control mixtures or else basalt filler (BF) aggregate blending. In addition to this, these same mixtures revealed 0.836 for coarser and 0.856 for finer respectively for water conditioned mixtures with limestone filler replacement (LF). Similarly, 12.5mm nominal aggregate sized mixtures showed values such as 0.820 and 0.821 for control samples (BF) and 0.884 and 0.907 for LF samples. Moisture damage resistance increased with limestone filler replacement substituted for basalt filler. AASHTO T283 was found to be distinctive in terms of filler effect evaluation.

Basalt is a type of volcanic rock which is grey to black in color, contains less than 20% quartz, 10% feldspathoid and at least 65% of the feldspar of its volume. Basalt is considered an igneous rock with fine grains due to the rapid cooling of lava. On the other hand, limestone is a sedimentary rock mainly composed of mineral calcite and aragonite. Due to impurities (clay, sand, iron oxide) in limestone, more than one color can be found especially on the surface. Superpave tests results classified basalt to be stronger than limestone, while limestone is more likely to be better in bonding due to the fine filler materials that limestone can have. Although there is good bonding between limestone and asphalt binder, basalt can perform better than limestone in the rutting of pavements [13].

Rutting evaluation of SMA mixtures designed with basalt and limestone aggregates was investigated. The coarse aggregate in the mixture was selected as basalt. Four different rock combinations were designed with basalt and limestone aggregates for filler and fine fractions. In addition to the evaluation of gradation, the maximum aggregate size effects were studied with four gradations. Design processes were obtained from basalt aggregates for four gradations. Decreasing the maximum aggregate size had the utmost importance on rutting resistance in terms of the gradation and aggregate mineralogy factors. It was stated that limestone aggregates as fine or filler parts together with basalt aggregates can be used as filler and fine fractions in the SMA process. This issue is of great importance considering the shortage of basalt aggregate quarries and the management difficulties in these quarries. The rutting resistance of the

SMA mixture relatively decreased with the incorporation of limestone aggregate into the SMA mixture gradation as fine or filler aggregate [14].

For both basalt and limestone mixtures the moisture damage ratio increased with the translation from 19mm to 12.5mm for coarser and finer gradations separately, as is shown in Table 8. Besides this, tensile strengths decreased because of the tight structure of the 12.5mm SMA mixtures as far as 19mm.

The three mix parameters that lab tests indicate may influence stripping propensity are gradation, asphalt film thickness (asphalt content) and voids. Gradation alone is probably not that important, although well graded mixtures tend to show a lower tendency to strip than mixes with basically one size material. Gradation, as it relates to asphalt film thickness and the voids in a mix, is important. Mixes with finer gradations (surface mixes) tend to have larger asphalt film thicknesses and lower stripping propensity. Coarser gradations (base/binder mixes) tend to have smaller asphalt film thicknesses and greater stripping propensity. Gradation will also affect the nature of the voids in a compacted mix. Although voids are normally controlled at 6-8% for indirect tensile strength retention tests, coarser gradations will produce fewer but larger voids. Larger voids will permit easier access (greater permeability) to water and thus, increase the potential for stripping. The effect of void size on permeability is apparent during vacuum saturation. It is much easier to achieve 60-80% saturation for a coarse mix with 6-8% voids than for a fine mix with 6-8% voids. Tensile strength ratio is a function of voids, with higher voids resulting in lower retained strength. This influence is minimized in laboratory testing procedures where voids are controlled at 6-8%, but implications are that field performance will be affected by compaction [15].

Figure 5- Figure 6 illustrate the indirect tensile strength values of all combined mixtures. Conditioned mixtures give lower indirect tensile strengths. It was concluded that the moisture damage environmental conditioning system revealed observable damage on the compacted samples. The selected test method has the ability to show water damage on the asphalt briquettes. With an increase in hydrated lime content, the strengths of unconditioned mixtures and conditioned mixtures increased. It was concluded that hydrated lime shows a positive effect for both passive and active adhesion in the context of stripping propensity.

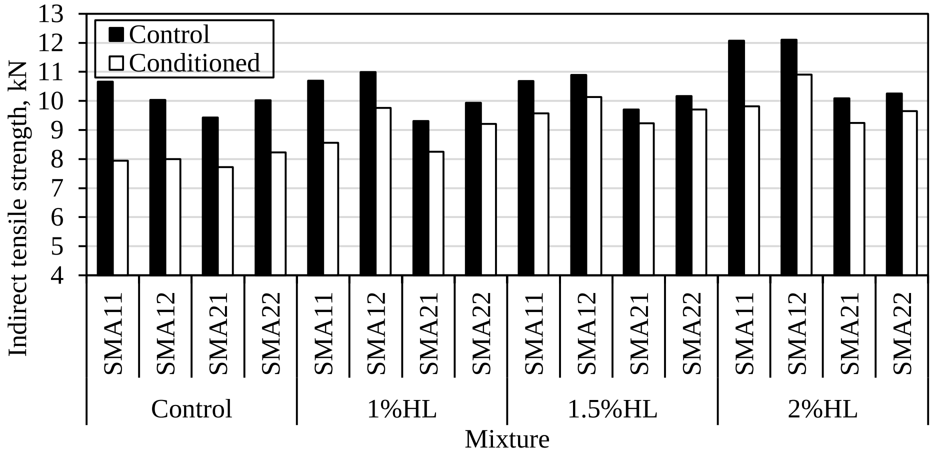

Figure 5: Indirect tensile strengths for unconditioned and conditioned mixture (basalt-basalt)

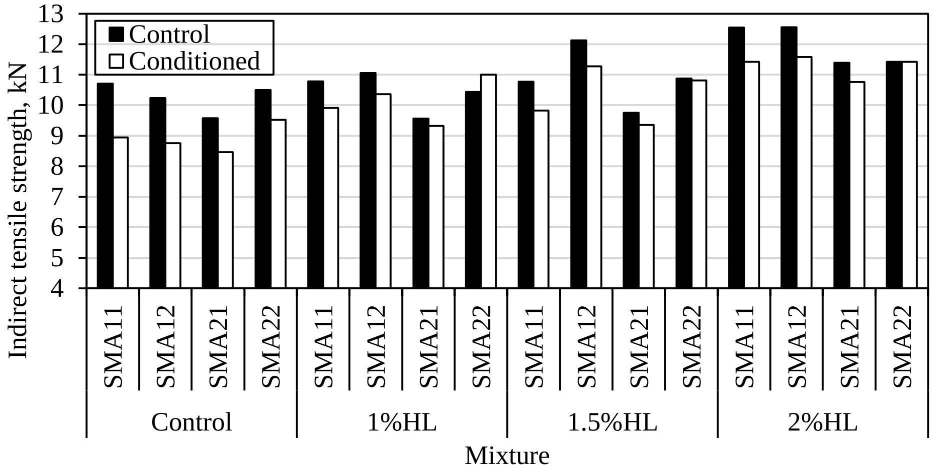

Figure 6: Indirect tensile strengths for unconditioned and conditioned mixture (basalt-limestone)

Mixtures including basalt filler showed the highest moisture damage ratio for 1.5% hydrated lime incorporation but mixtures with limestone filler gave the highest damage ratio at 1%. As a result of the carbonate components in limestone filler, the effectual hydrated lime content decreased. Based on the mineralogical and chemical structure of the filler materials, this reduction was found to be logical. With the adding of hydrated lime, the damage ratios for both basalt filler and limestone filler increased and also the indirect tensile strengths increased.

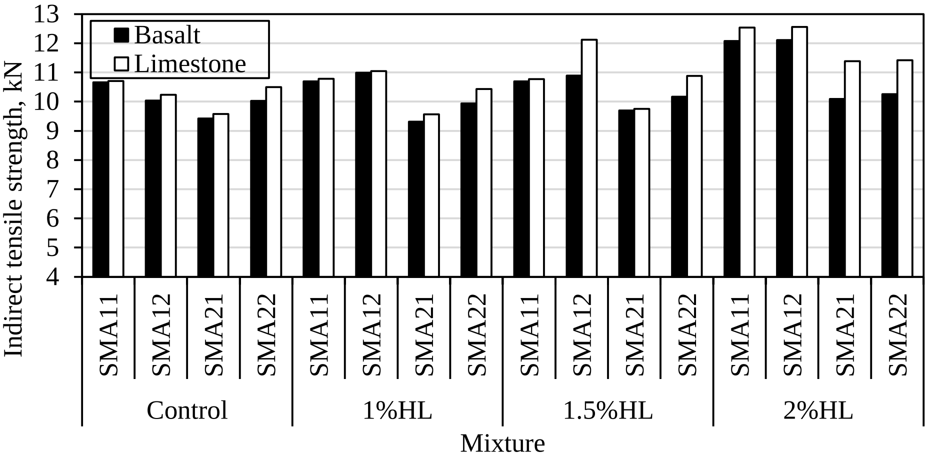

Figure 7: Indirect tensile strengths for unconditioned mixture (basalt-limestone)

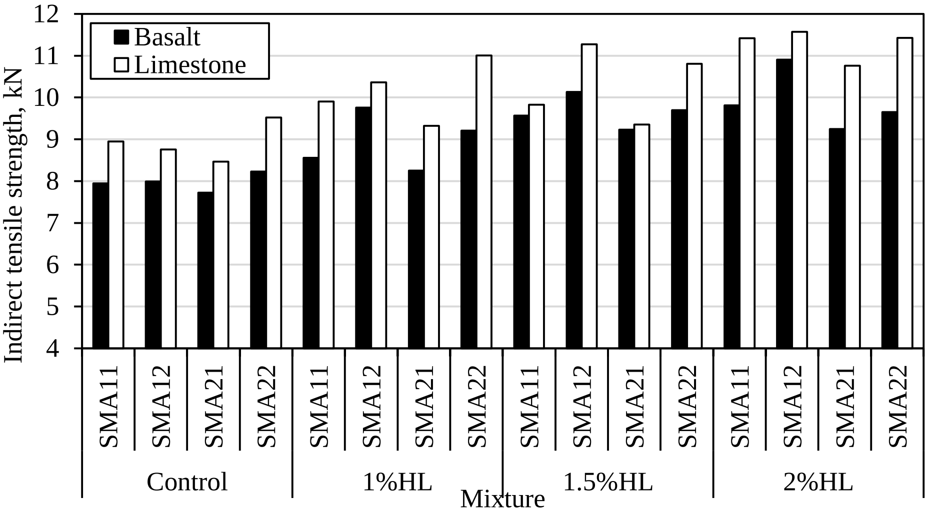

Figure 8: Indirect tensile strengths for conditioned mixture (basalt-limestone)

The AASHTO T 283 method is an effectual stripping test in the context of observing moisture damage conditioning based on vacuum saturation. Stripping evaluation can be possible with the AASHTO T283 method with regards to lime additive alternatives, different SMA gradations and moisture conditioning based on vacuum saturation.

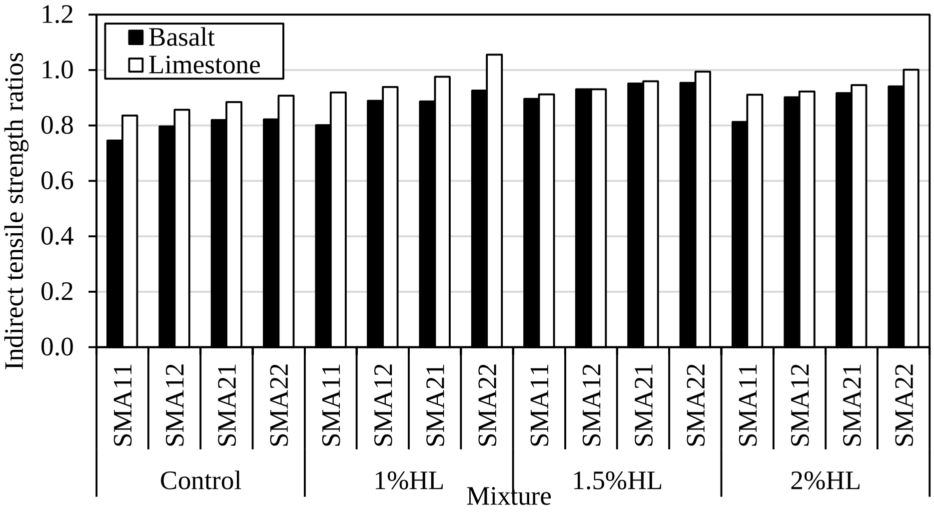

Figure 9: Indirect tensile strength ratios according to hydrated lime content for basalt and limestone aggregates

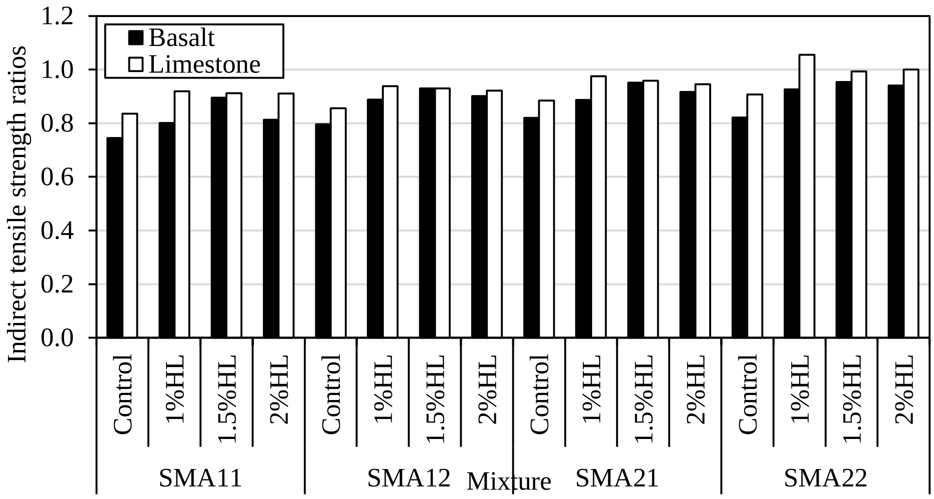

Figure 10: Indirect tensile strength ratios connected with aggregate size and gradation

Testing for stripping in asphalt concrete is, of course, made difficult by the many interacting factors that may influence moisture damage, such as asphalt cement and aggregate (filler, fine and coarse) properties/characteristics, hot-mix design, hot-mix production, placement and service conditions, particularly the availability of moisture. There is strong technical support for the Tunnicliff-Root (ASTM D 4867), Modified Lottman (AASHTO T 283) and Ontario MTO Immersion Marshall (LS-283) tests [16].

The effect of lime content and grading on the dry and saturated indirect tensile strength as well as tensile strength ratio of hot mix asphalt was evaluated with response surface methodology. Dense grading aggregates including three levels of dense aggregates, i.e. fine, medium and coarse grading were selected. Hydrated lime was utilized as an anti-stripping agent. The results indicated that the increase in the amount of mastic asphalt in the dense graded mix made it more prone to stripping. This could be attributed to the fact that in dense graded mixes, the void sizes are more minute and widely spread throughout the mix with more overall void surface area. Therefore, despite less permeability in fine graded mixtures, if saturated the moisture access to the asphalt is far greater which leads to more potential for stripping. Finally, it can be concluded that within the range of materials tested, an increase in fine material will require additional lime to prevent and/or control the stripping effect in the mixtures. It was further concluded that decreasing the aggregate size and increases in mastic asphalt would increase the stripping potential of hot mixes asphalt [17].

The effect of using different evaluation techniques on the predicted stripping of 24 different HMA combinations prepared using different mix parameters was studied. Similar mix parameters were used. The stripping evaluation techniques included percentage reduction in both indirect tensile strength and Marshall stability, percentage increase in creep due to stripping, in addition to stripping visual evaluation using the Texas boiling test. The findings indicated that the estimated stripping is affected significantly by the method of evaluation. The reductions in indirect tensile strength and Marshall stability were found to be less sensitive to stripping than the percentage increase in creep [2]. Indirect tensile strength ratios of asphalt paving specimens were found to be lower than the Marshall stability ratios in terms of stripping interrogation [18].

For the same kind of design method, the homogeneity of large stone asphalt mixtures becomes worse with an increase in maximum nominal aggregate size [19].

The effects of aggregate type on HMA stripping and creep behavior were evaluated at different mix parameters including three aggregate gradations, two types of asphalt and two modes of conditioning. Basalt and limestone aggregates were used. Aggregate gradations were found to have a very strong effect on stripping resistance. HMA prepared using aggregate gradation that followed the upper limit of ASTM specification for dense gradation showed the highest resistance to stripping, followed by HMA prepared using aggregate gradation which followed mid limits of ASTM specification for dense gradation. HMA prepared using aggregate gradation that followed mid limits of ASTM specification for open graded aggregate gradation showed the least stripping resistance [2].

The reason why siliceous aggregates result in lower TSR values is because silica mineral (SiO_2) which is found in abundance in quartz constitutes the bulk of granite and quartzite. During quarrying, unsatisfied charges are formed by breaking the silicon–oxygen bonds. Hydration occurs when water vapors release OH^- and H^+ ions to the unsatisfied charges on silicon and oxygen, respectively. This results in a hydroxylated surface with surface silanol groups. Equilibrium is established between these silanols and water depending on the pH of the contact water. Water with a high pH (OH^- ions) stimulates the dissociation of H^+ ions from silanol groups, causing the surface to become more negatively charged. At low water pH, silica surfaces become positively charged. Water molecules can form strong hydrogen bonds with siliceous surface silanols which may cause the replacement of the bitumen polar parts. By contrast, marble is mainly comprised of $CaCO_3$ which after crushing reveals electropositive surface characteristics. This is because its interior bonds are broken, leaving calcium and carbonate ions on the newly formed surfaces. Hydration of these ions by water vapors results in a characteristic electropositive surface. These surface species are available for competition between water and bitumen polar functionalities [20].

The possibility of improving the properties of local asphalt concrete mixes by replacing different portions of the normally used limestone aggregate by basalt was investigated. The replacement included total replacement of the limestone by basalt, replacing the coarse aggregate, and replacing the fine aggregate. The results showed that total replacement of the limestone aggregate by basalt in the asphalt concrete mixes was not effective since it adversely affected some of the mechanical properties of the asphalt concrete mixes when compared with the control mix. Due to the physical properties of the basalt rock, anti-stripping agents have to be added to the basaltic-asphalt concrete mixes to enhance the mixes resistance to stripping. The asphalt concrete mix which was found to be the optimal mix was the one that had basalt coarse aggregate, limestone fine aggregate and mineral filler, and 1% hydrated lime by total weight of aggregate, i.e., this mix had the best mechanical properties among all the included mixes [21].

4. CONCLUSIONS

A moisture damage problem in SMA mixtures was investigated over extensive scope. Four different gradations were constructed. Both nominal aggregate sizes were changed and coarser and finer gradations were plotted. For all graded mixtures filler replacement was also applied. SMA mixtures were prepared with basalt in view of coarse-fine-filler materials. Also, filler material was changed with other external limestone filler, and limestone filler effects on performance were interrogated. In addition to this, for all combinations the hydrated lime effects on moisture damage were commented on. The following considerations can be drawn with this research.

Moisture damage resistance increased with limestone filler replacement substituted for basalt filler. AASHTO T283 was found to be distinctive in terms of filler effect evaluation.

Effectual hydrated lime content decreased with limestone filler unlike basalt filler because of carbonate origins. Based on the mineralogical and chemical structure of the filler materials, this reduction was found to be logical.

With the adding of hydrated lime, the damage ratios for both basalt filler and limestone filler increased and also indirect tensile strengths increased. Hydrated lime relatively increases stripping resistance.

For both basalt and limestone mixtures, the moisture damage ratio increased with the translation from 19mm to 12.5mm for coarser and finer gradations separately. In addition to this, tensile strengths decreased because of the tight structure of the 12.5mm SMA mixtures as far as 19mm.

AASHTO T 283 method is an effectual stripping test with regards to observing moisture damage conditioning based on vacuum saturation. Stripping evaluation can be possible with the AASHTO T283 method with regards to lime additive alternatives, different SMA gradations and moisture conditioning based on vacuum saturation.

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