Effect of basalt and limestone aggregate combinations on Superpave aggregate properties

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ABSTRACT: This study aims at investigating the effect of basalt and limestone aggregates combinations on the Superpave aggregate properties. The limestone material was obtained from Al-Rjoub quarry in Irbid city in the north part of Jordan, while the basalt aggregate material was obtained from a quarry in Al-Hallabat area in the southeast part of Jordan. Different aggregate combinations were used in this study for basalt and limestone respectively: (0, 100), (20, 80), (30, 70), (40, 60), (50, 50), (60, 40), (70, 30), (80, 20), and (100, 0). The effect of these combinations was investigated on the Superpave aggregate consensus properties: Flat and Elongated (F&E) particles, Coarse Aggregate Angularity (CAA), Fine Aggregate Angularity (FAA), and Sand Equivalent (SE). In addition the source aggregate properties were considered in this study: Los Angeles abrasion, specific gravity and absorption for coarse aggregates, and specific gravity and absorption for fine aggregates. This study is expected to reveal important findings about the effect of aggregate combinations on the Superpave consensus properties as well as source properties.

1. INTRODUCTION

Aggregate is the part of mineral materials and crushed stone that is used in the main part of pavement construction (it is about 92 to 96 percent from Hot-Mix Asphalt (HMA) and in base and sub base layers). In Jordan, there are two main types of aggregate (limestone in the Northern part and basalt in the southeastern part) and each type have distinguished properties that make them good in preventing some pavement distresses different from the other.

Basalt is that type of volcanic rocks, 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 that on surfaces.

For the considered percent of aggregate contained in HMA, base and sub base layers of pavements, the properties of aggregate become crucial in HMA design. These include the Superpave consensus properties that are expected to affect pavement performance, and source properties.

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 a good bonding between limestone and asphalt binder, basalt can perform better than limestone in rutting of pavements. Broad researches are done on basalt to determine the weak and strength points of basalt's performance at pavements.

(Asi et al. 2009) studied the use of basalt in asphalt concrete mixes. Their study focused on skid resistance and stripping and how to reduce them using the optimum replacement percentage of the limestone aggregate by basalt. The Marshall Mix design was used to prepare the asphalt mixes. These mixes were evaluated using Marshals stability, indirect tensile strength, stripping resistance, resilient modulus, creep, fatigue, and permanent deformation. The optimum percentage of replacement to reduce stripping and increase skid resistance while using basalt in pavement construction was found to be 1% by total weight of aggregate by adding fine materials of fly ash or hydrated lime.

(Hanf 2000) used sand and gravel in Superpave mixtures and aimed at finding the best blend of sand and gravel to face the challenging and changing of specifications for aggregates used in HMA considering the Superpave criteria for mix design. The Superpave mix design and Marshall Mix design were used to prepare the samples. The volumetric properties for both mix design methods for a given gradation were compared. The samples were also tested for moisture susceptibility. Findings of the study showed that if Marshall Mix met the VMA and VFA criteria, then the volumetric properties should meet the Superpave design criteria, but probably not with the same gradation. It was also found that meeting the requirements was related directly to fine aggregate angularity, restricted zone, coarse aggregate angularity, sand equivalent, dust to asphalt ratio, VMA, or VFA.

(Yildirm et al. 2004) studied the effect of aggregates on rutting performance. The study was a five-year research project, which was sponsored by the Texas Department of Transportation (TxDOT) to evaluate the correlation between field and laboratory performance of asphalt mixtures tested using the Hamburg Wheel Tracking Device (HWTD) and to determine the relationship between hot mix asphalt concrete (HMAC) field performance and the HWTD test results. Nine test sections were constructed on IH 20 in Harrison County. Three different mix design methodologies and three different aggregates were utilized to construct the test sections, The Superpave gyratory compactor was used to prepare the samples with 7 ± 1 percent air void level. All the tested specimens performed well and satisfied TxDOT specifications for HWTD. The rutting data obtained from test sections showed a very good trend with the HWTD test data, with the highest for rutting data collected from both techniques for mixes prepared with gravel, while mixes prepared from quartzite and sandstone showed very similar rutting at the field and lab.

(Masad et al. 2003) evaluated the aggregate characteristics affecting HMA concrete performance. The study assessed the HMA sensitivity to aggregate shape characteristics. Aggregate shape was characterized through detailed measurements of angularity, form, and texture using the Aggregate Imaging System (AIMS). The shape characteristics were presented in terms of the distribution of the property in an aggregate sample rather than an average index of this property. A viscoplastic model for permanent deformation was also developed in their study. The model accounted for the aggregate structure in the mix, which was related to the shape properties measured using AIMS.

In this study, Superpave tests were conducted on blended samples using different aggregate combinations for basalt and limestone respectively: (0, 100), (20, 80), (30, 70), (40, 60), (50, 50), (60, 40), (70, 30), (80, 20), and (100, 0). The effect of these aggregate combinations on the Superpave aggregate consensus properties as well as source properties was investigated.

3. OBJECTIVES

The main objective of this study was to investigate the effect of limestone and basalt aggregate combinations on the Superpave aggregate consensus properties as well as source properties.

4. MATERIALS

Both limestone and basalt aggregate materials were used in this study. The limestone material was obtained from Al-Rjoub quarry in Irbid city in the north part of Jordan, while the basalt aggregate material was obtained from a quarry in Al-Hallabat area in the south-eastern part of Jordan. The used aggregate gradation had a 12.5 mm Nominal Maximum Aggregate Size (NMAS), and 19.0 mm Maximum Aggregate Size (MAS). This gradation is shown in Table 1 below. Different aggregate combinations were used for basalt and limestone respectively: (0, 100), (20, 80), (30, 70), (40, 60), (50, 50), (60, 40), (70, 30), (80, 20), and (100, 0).

Table 1: Aggregate Gradation

Sieve Size (mm)	Sieve Size (in)	% Passing
19.0	3/4	100
12.5	1/2	93.0
9.5	3/8	66.9
4.75	No. 4	53.0
2.36	No. 8	34.3
1.18	No. 16	20.4
0.600	No. 30	12.9
0.300	No. 50	7.8
0.150	No.100	5.1
0.075	No. 200	2.4

5. METHODOLOGY

5.1 *Preparation of Aggregate Samples*

Aggregate samples were prepared using crushed limestone and basalt by weighing each fraction for each combination of limestone and basalt from every sieve individually and mix them together to get nine blended samples for each test. The final mass was 705 grams for each coarse aggregate sample and 795 grams for each fine aggregate sample.

5.2 *Description of Tests Methods*

5.2.1 *Coarse Aggregate Specific Gravity and Absorption:*

The samples were prepared and the test was done according to the AASHTO T 85. It was conducted on the prepared samples for the portion retained on No. 4 (4.75 mm) sieve.

5.2.2 *Flat and Elongated (F&E) particles:*

The test F&E particles test was done according to the ASTM D 4791 on the blended samples for the portion retained on No. 4 (4.75 mm) sieve.

5.2.3 *Coarse Aggregate Angularity (CAA):*

The CAA test was done on the prepared sample according to the AASHTO TP 61 for the portion retained on No. 4 (4.75 mm) sieve.

5.2.4 *Fine Aggregate Specific Gravity and Absorption:*

The specific gravity and absorption test was done on the blended samples according to the AASHTO T 84 for the portion passing No.4 (4.75 mm) sieve.

5.2.5 *Fine Aggregate Angularity (FAA):*

The FAA test was conducted on the prepared samples according to the AASHTO T 304 for the portion passing No.4 (4.75 mm) sieve.

5.2.6 *Sand Equivalent (SE):*

The SE test was performed on the prepared samples according to the AASHTO T 176 for the portion passing No.4 (4.75 mm) sieve.

5.2.7 *Los Angeles Abrasion (LAA):*

The LAA test was conducted on the prepared samples according to the AASHTO T 96 for the portion retained on sieve No. 12, (eleven steel balls were used). Three samples were used with limestone and basalt percentages of (100, 0), (50, 50), and (0, 100) (Grade B).

6. RESULTS AND DISCUSSION

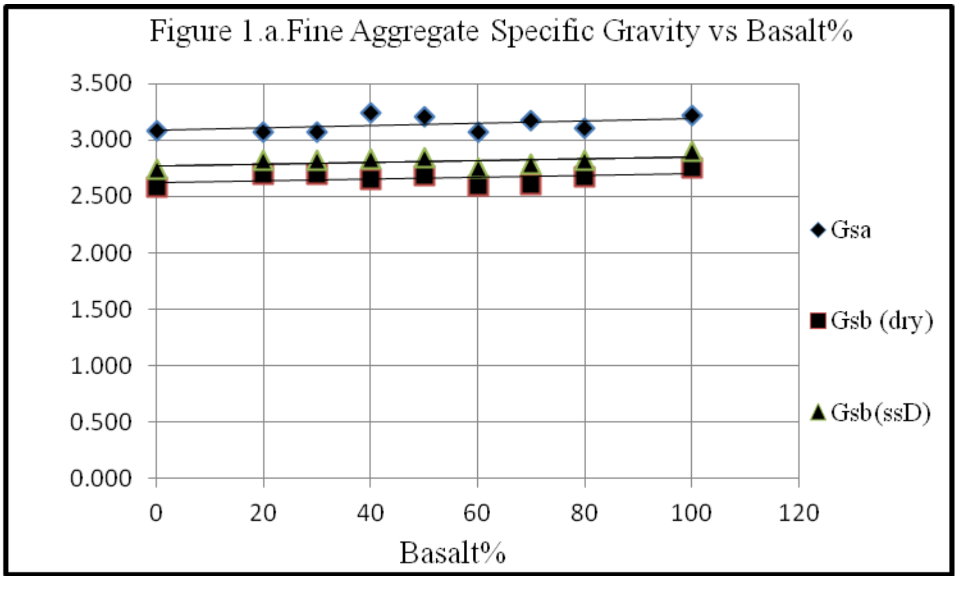
6.1 *Coarse and Fine Aggregate Specific Gravity and Absorption*

Slight change in specific gravity and absorption values for both coarse and fine aggregates (as shown in Figure 1.a and Figure 1.b) was obtained for the different aggregate combinations. The values of apparent, dry and SSD specific gravities for the coarse aggregate were about 2.800, 2.650, and 2.700, respectively. Fine aggregate apparent specific gravity values ranged from 3.069 to 3.243, bulk SSD and bulk oven dry fine aggregate specific gravities ranged from 2.745 to 2.902 and from 2.585 to 2.759, respectively. The durability of aggregate and the absorbed asphalt binder in HMA are mainly controlled by the absorption value for aggregate. These values were almost close and around 2% for coarse aggregate samples, and around 5% for fine aggregate samples. Table 3 below summarizes the regression models for the different specific gravities for coarse and fine aggregates.

6.2 *Flat and Elongated (F&E) Particles*

Figure 2 shows the exponential decrease of F&E particles with the increase of basalt content, which was expected due to the shape of basalt.

The maximum value were 16.4% for 0% basalt (more than the maximum value in superpave specifications which equals to 10%) and decreases to reach 8.5% and 5.7% for 50% and 100% basalt respectively. The F&E particles were tested using the ratio 3:1 rather than 5:1, which is commonly used in Superpave. Basalt aggregate is known to have a good resistance to degradation during construction. The presence of flat and elongated particles in HMA increase the probability of degradation during compaction due to the weak flat particles, Which tend to break under compaction or/and traffic loadings. Table 4 shows the regression models developed for F&E particles. The exponential model was the best model to describe the relationship between the F&E particles and the %basalt.



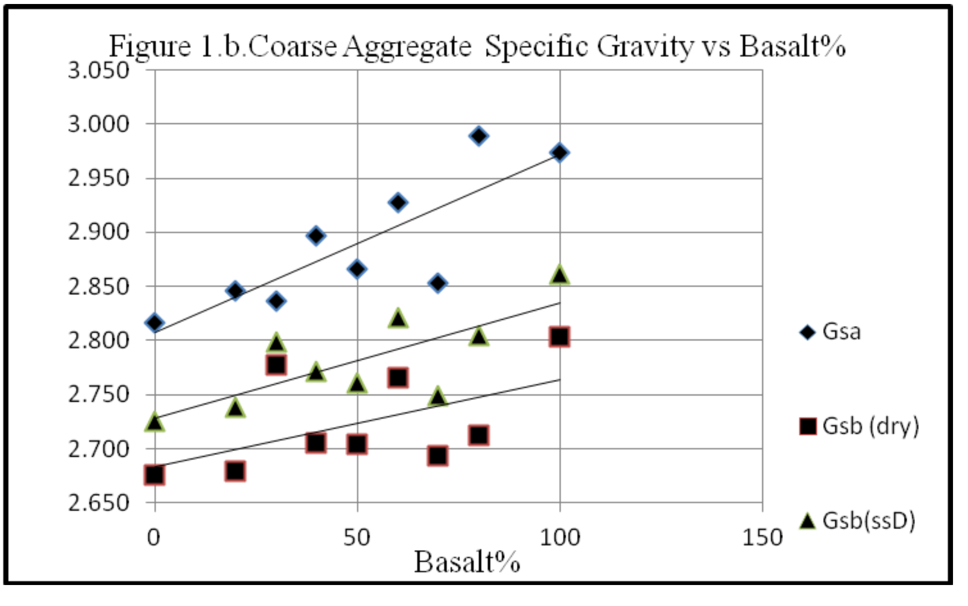


Table 3: Regression Models for Specific Gravity (Coarse and Fine Aggregates)

	Regression Model	r^2
Coarse	$G_{sa} = 0.0016\ (\text{Basalt\%}) + 2.8071$	0.694
	$G_{sb(SSD)} = 0.001\ (\text{Basalt\%}) + 2.728$	0.576
	$G_{sb(dry)} = 0.0008\ (\text{Basalt\%}) + 2.6838$	0.297
Fine	$G_{sa} = 0.0011\ \text{Basalt\%}) + 3.083$	0.232
	$G_{sb(SSD)} = 0.0008\ (\text{Basalt\%}) + 2.774$	0.268
	$G_{sb(dry)} = 0.0007\ (\text{Basalt\%}) + 2.6267$	0.1594
Coarse	$G_{sa} = 2.81e^{0.00057\ (\text{Basalt \%})}$	0.695
	$G_{sb\ (SSD)} = 2.73e^{0.0004\ (\text{Basalt \%})}$	0.5764
	$G_{sb\ (dry)} = 2.684e^{0.0003\ (\text{Basalt \%})}$	0.298
Fine	$G_{sa} = 3.083e^{0.0004\ (\text{Basalt \%})}$	0.234
	$G_{sb\ (SSD)} = 2.7745e^{0.0003\ (\text{Basalt \%})}$	0.266
	$G_{sb\ (dry)} = 2.6266e^{0.0003\ (\text{Basalt \%})}$	0.158

Figure 2. Flat and Elongated % vs Basalt %

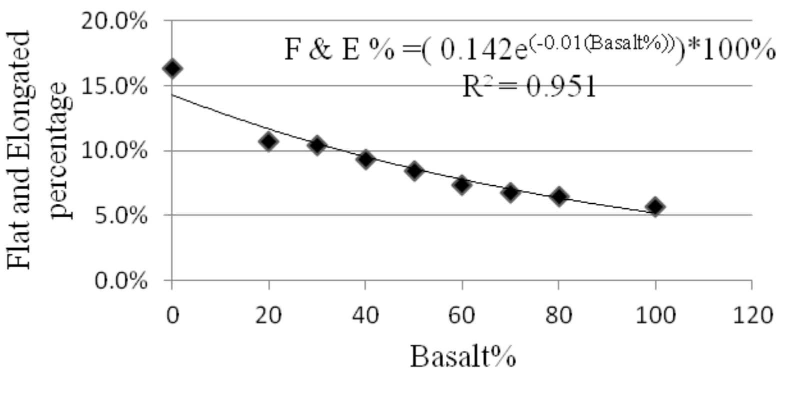


Table 4: Regression Models for F&E Particles.

Regression Model	r^2
F&E = -0.001(Basalt%) + 0.1387	0.86
$F\&E = (0.142e^{(-0.01(Basalt\%))})*100\%$	0.95

6.3 *Coarse Aggregate Angularity (CAA)*

The CAA increased exponentially with the increase of basalt content (as shown in Figure 3), which indicates that increasing the basalt content in the aggregate sample increased the CAA. And therefore, asphalt mixtures produced using higher percentage of basalt aggregate would be more resistible to permanent deformation (rutting) under repeated traffic loadings. That was obvious from the exponential increase in the percentage of one fractured face and also two or more fractured faces with the increase in the %basalt (Figure 3). The regression models developed for the CAA are shown in Table 5 below. The maximum number of fractured faces were for the 100% basalt sample which equals to 217, and 348 for one or more and two or more fractured faces respectively, and decreases to reach 33, and 217 for 0% basalt. That should indicate to more aggregate interaction and bonding when using more basalt in HMA.

Table 5: Regression Models for Coarse Aggregate Angularity

Type	Regression Model	r^2
Exponential	$CAA_{1\ FF} = 196.76e^{0.0042\ (Basalt\ \%)}$	0.51
Exponential	$CAA_{2\ or\ more\ FF} = 33.165e^{0.014\ (Basalt\ \%)}$	0.72

6.4 *Fine Aggregate Angularity (FAA)*

The uncompacted void content (FAA) decreased exponentially with the increase of the portion of basalt (as shown in Figure 4), which means that the increase in basalt content reduced the angularity of fine aggregate. Consequently this would work towards decreasing the resistance of asphalt mixtures to permanent deformation (rutting). Table 6 shows the regression models developed for the FAA and their associated r^2 values.

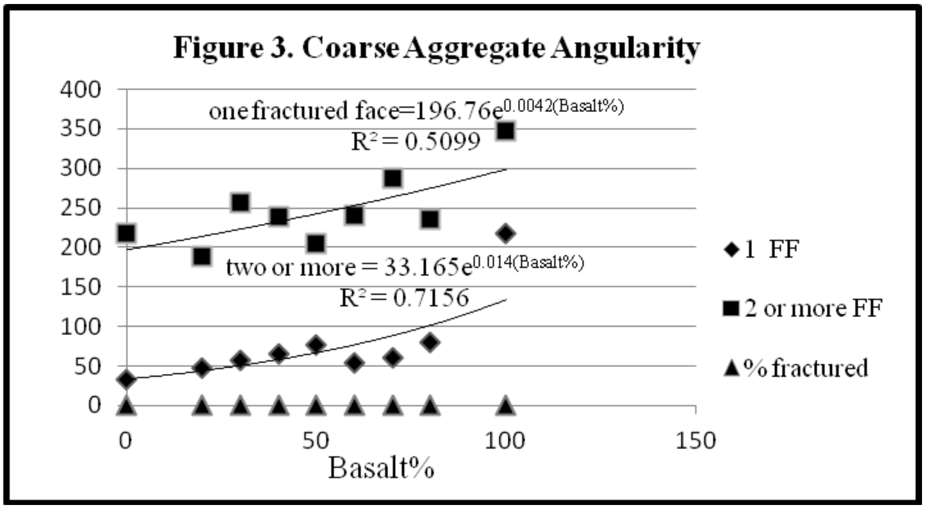


Table 6: Regression Models for Fine Aggregate Angularity

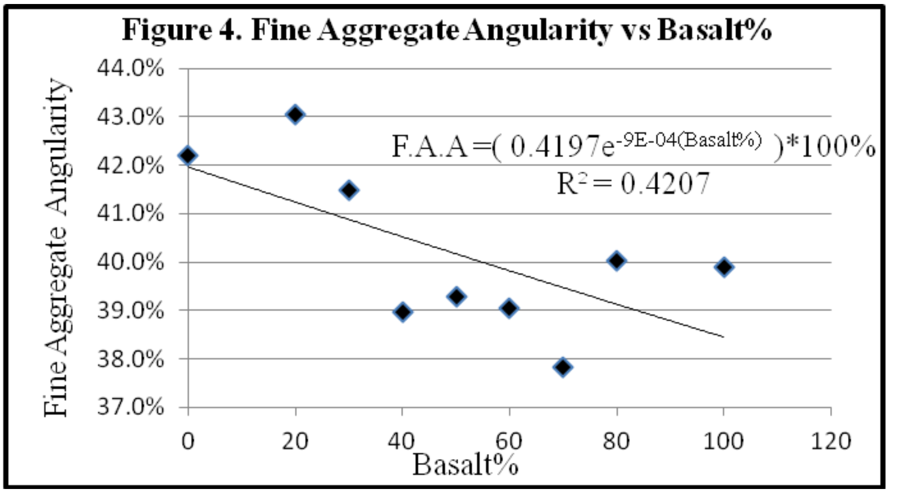
Type	Regression Model	r^2
Linear	FAA = -0.0004(Basalt%) + 0.4199	0.43
Exponential	FAA = $(0.4197e^{-9E-04(Basalt\ \%)})$*100%	0.42

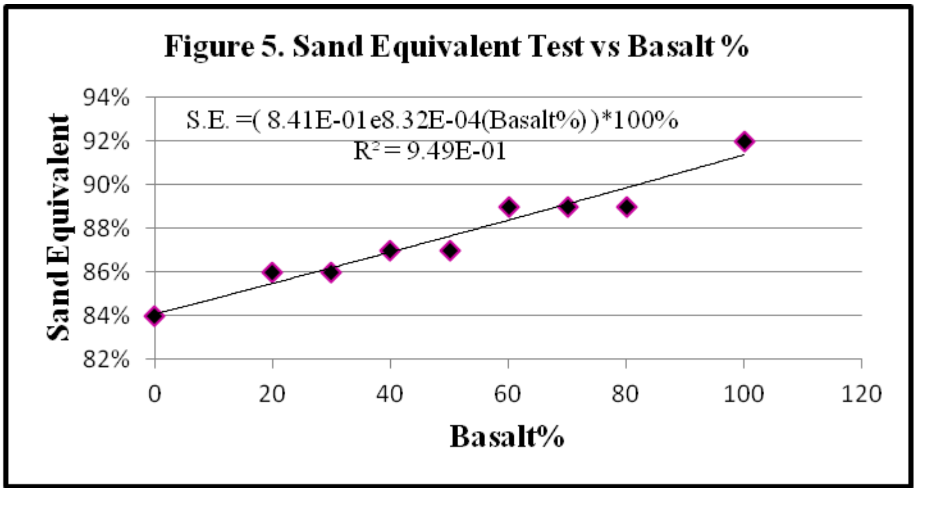
6.5 *Sand Equivalent (SE)*

The SE values increased with the increase of basalt percentage (84%, and 89% of SE for 0% and 100% basalt respectively), which indicated that the clay content decreased with the increase of basalt percentage. As a result, more stable, less moisture susceptible, and high stripping resistant asphalt mixtures would be produced using higher basalt content. Figure 5 and Table 7 show the regression models developed for the SE values.

Table 7: Regression Models for Sand Equivalent

Type	Regression Model	r^2
Linear	SE = 0.0007(Basalt%) + 0.8401	0.95
Exponential	SE = $(0.841e^{0.0008.32\ (Basalt\ \%)})$*100%	0.95





6.6 *Los Angeles Abrasion (LAA)*

In LAA test, three samples of limestone and basalt (Grade B) (100, 0), (50, 50), (0, 100) were used. With the increase of basalt percentage, the sample's resistance to abrasion increased. That was clear from Figure 6; the LAA values decreased exponentially with a high simple of determination (r^2) of 0.99. And therefore, the increase of the basalt content in the aggregate would produce asphalt mixtures with high resistance to crushing, degradation, and disintegration. Table 8 shows the regression models developed for the LAA values.

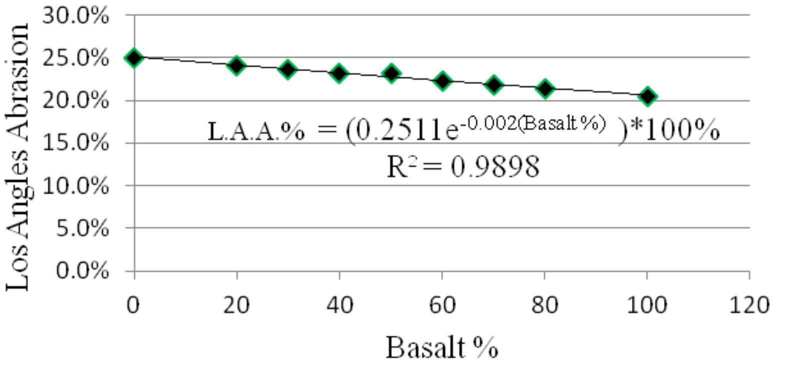


Figure 6. Los Angles Abrasion Test vs Basalt %

Table 8: Regression Models for Los Angeles Abrasion

Type	Regression Model	r^2
Linear	LAA = (-0.0004(Basalt%) + 0.2508)*100%	0.99
Exponential	LAA = 2.51E-01e$^{-1.95(Basalt\%)-03x}$)*100%	0.99

7. CONCLUSIONS

Based on the analysis of this study, the following conclusions were drawn:

1. The basalt portion in the blended aggregate had insignificant effect on the change of specific gravity and absorption for both coarse and fine aggregates as discussed in section 6.1 and shown in figures 1.a and 1.b.

2. The increase in basalt content in aggregate samples exponentially decreased the F&E particles (section 6.2) and LAA (section 6.6) values with coefficient of simple determination (r^2) values of 0.95 and 0.99, respectively.

3. The increase in basalt content in aggregate samples exponentially increased the CAA (1 or more fractured faces and 2 or more fractured faces) and SE values with coefficient of simple determination (r^2) values of 0.51, 0.72, and 0.95 for CAA with 1 or more fractured faces, CAA with two or more fractured faces (section 6.3, table 5), and SE values (section 6.5, table 7), respectively.

4. As the basalt content increased, the FAA decreased but with low coefficient of simple determination (r^2) of 0.42 (section 6.4, table 6). Thus, this relationship was not sound. So, in general, the basalt content increased the angularity of the aggregate blended samples.

5. The basalt content in the blended aggregate enhanced some properties, but as a result other properties were worsen. In general, the improvement was dominant, for that improvement, combination of basalt and lime stone will lead to effective changes in HMA properties.

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