EVALUATION OF CONSTRUCTION LIMESTONE AGGREGATE SOURCED IN THE NORTHERN PART OF JORDAN USING SUPERPAVE TESTS

Ghazi Al-Khateeb[1], Turki Obaidat[2], and Taisir Khedaywi[3]

[1] *Assistant Professor of Civil Engineering, Email: ggalkhateeb@just.edu.jo, Cell.: 00962-79-659-9507, Tel.: 00962-2-720-1000 Ext. 22129, Fax: 00962-2-720-1074.*
[2] *Professor of Civil Engineering, Email: turk957@just.edu.jo*
[3] *Professor of Civil Engineering, Email: khedaywi@just.edu.jo*
Jordan University of Science and Technology
P.O. Box 3030, Irbid, 22110 Jordan

SUPERPAVE is an acronym that stands for SUperior PERforming asphalt PAVEments. Superpave system is the outcome of a 5-year, $150 million research program (the Strategic Highway Research Program or SHRP) that was conducted during the time period of 1987-1992 in the United States (US) to enhance the performance of asphalt pavements. Superpave system developed and used consensus properties tests as well as source properties tests for the aggregate materials to improve the specifications and criteria used for aggregate properties. The end result will be improved performance for asphalt pavements of highways.

In this study, limestone aggregate sourced in the northern part of Jordan was evaluated according to the Superpave tests. Therefore, the study aimed at evaluating the limestone aggregate material available in the northern part of Jordan for Superpave consensus aggregate properties as well as source aggregate properties to investigate the suitability of this type of aggregate for pavement construction of highways in Jordan.

Limestone is considered the most common aggregate type that is used for pavement construction; all the highway pavements in Jordan are asphalt-surfaced pavements except for one highway in the southern part of the country, which has a rigid concrete pavement. The Superpave tests for consensus aggregate properties were used to evaluate the aggregate material. Those tests include: coarse aggregate angularity (CAA), flat and elongated (F&E) particles, fine aggregate angularity (FAA), and sand equivalent (SE) tests. In addition, other tests for source aggregate properties including: Los Angeles (LA) abrasion, specific gravity and absorption of coarse aggregate, specific gravity and absorption of fine aggregate, and deleterious materials tests were used in the evaluation.

Basalt aggregate was also used in this study for comparison with the limestone aggregate. Basalt aggregate exists heavily in the eastern part of Jordan. Therefore, basalt aggregate sourced in the eastern part of Jordan was evaluated in this study. In the last few years, the Ministry of Public Works and Housing (MPWH) in Jordan started to search for new aggregate materials to be used for highway pavements due to the high abrasion value for the currently-used limestone aggregate that leads to polished pavement surface. As a result, skid resistance values on highway pavements are usually lower than the minimum requirement leading to lower road safety on these highways.

Keywords: Superpave, Aggregate, Limestone, Basalt, Consensus Properties, Source Properties, Construction.

1. Introduction

In this study, Superpave aggregate tests were used to evaluate limestone aggregate sourced in the northern part of Jordan as well as basalt aggregate sourced in the eastern part of the country. The Superpave tests included: coarse aggregate angularity (CAA), flat and elongated (F&E) particles, fine aggregate angularity (FAA), and sand equivalent (SE) tests. In addition, other tests for source aggregate properties including: Los Angeles (LA) abrasion, specific gravity and absorption of coarse aggregate, specific gravity and absorption of fine aggregate, and deleterious materials tests were used in the evaluation.

The coarse aggregate angularity test estimates the amount of aggregate particles with crushed (fractured) faces for the aggregate portion retaining on sieve No. 4 (4.75 mm). This test is important to ensure adequate aggregate interlock and prevent hot-mix asphalt (HMA) permanent deformation (rutting) under traffic loading. The flat and elongated (F&E) particles test estimates the amount of flat or elongated particles having a maximum to minimum dimension of 5:1 or more in the aggregate material portion retaining on sieve No. 4 using a standard proportional caliper. Flat and elongated particles have the tendency to fracture along their weak, narrow dimension when subjected to traffic loading, and if they present in large enough quantities, this fracturing can lead to a change in the gradation and reduction in the voids in mineral aggregate (VMA). Consequently, this will lead to less effective asphalt content (coating the aggregate particles), which can result in asphalt mixture instability, rutting, and shoving. On the other hand, the fine aggregate angularity test estimates the angularity of fine aggregate (the aggregate portion passing sieve No. 4) by measuring the uncompacted void content of a fine aggregate sample. Fine aggregate angularity is important due to the fact that high FAA values will result in a stable asphalt mixture if other mixture properties are satisfactory. The sand equivalent test measures the relative proportion of plastic fines, dust, and clay material in fine aggregate. The existence of dust or clay materials can coat the aggregate particles and prevent proper asphalt binder-aggregate bonding resulting in stripping of asphalt binder in some cases.

The LA abrasion test estimates the resistance of coarse aggregate to abrasion and mechanical degradation during handling, construction, and in-service. Aggregate should be hard and tough enough to resist crushing, degradation, and disintegration from any associated activities including manufacturing, stockpiling, production, placing, and compaction. The deleterious materials test can be conducted on both coarse and fine aggregates. Deleterious materials are defined as the percentage of contaminants such as clay lumps, shale, wood, mica, and coal in aggregate. The test is performed by wet sieving aggregate size fractions over specified sieves (for clay materials lumps and friable materials, No. 200 (0.075 mm) sieve is used).

2. Objectives

The main objectives of this study are:

1. To evaluate different limestone aggregate materials acquired from different sources in the northern part of Jordan.
2. To evaluate basalt aggregate sourced in the southeastern part of Jordan.
3. To utilize the Superpave system in the evaluation process and the new test methods developed in this system.
4. To compare limestone and basalt as aggregate materials used for highway pavement construction in Jordan.

3. Materials

Limestone aggregates from four different quarries located in the northern part of Jordan were obtained and used in this study. These quarries were: (1) Al-Rojoub quarry in Irbid city, (2) Al-Rojoub quarry in Rehab area in Al-Mafraq city, (3) Al-Sharu’ quarry in Shatana area in Al-Huson town, and (4) Abo-Obaid quarry in Shatana area in Al-Huson town. On the other hand, basalt aggregate was obtained from quarries in Al-Hallabat area in Al-Azraq city in the southeastern part of Jordan.

The limestone and basalt aggregate materials were acquired from these quarries and brought to the Highway Laboratory at Jordan University of Science and Technology (JUST). Sieve analysis was conducted for these aggregates to obtain the different aggregate size portions using the Superpave standard sieve sizes (50.0, 37.5, 25.0, 19.0, 12.5, 9.5, 4.75, 2.36, 1.18, 0.600, 0.300, 0.150, and 0.075 mm).

4. Methodology

4.1 CAA Test

The CAA test was performed on coarse aggregate retained on No. 4 (4.75 mm) sieve according to the test method described in the AASHTO TP 61 and ASTM D 5821, or in the Pennsylvania Department of Transportation (DOT)’s test method No. 621. CAA is defined as the percentage of fractured particles in coarse aggregate. A fractured face in a particle is defined as the face with a projected area at least as large as one quarter of the maximum projected area of the particle and the face has sharp and well-defined edges and rough texture.

A sample of coarse aggregate (100 particles from each size fraction) was tested for CAA. Each aggregate particle was visually inspected for fractured faces. Particles (pieces) with one fractured face and those with two or more fractured faces were separated and counted. At the end, the percentage of coarse aggregate particles having one or more fractures faces and the percentage of those particles with two or more fractured faces were determined.

4.2 F&E Particles Test

The F&E particles test is conducted on coarse aggregate according to the test method outlined in the ASTM D 4791. A particle is considered a flat and elongated particle if the ratio of the maximum to minimum dimension of the particle is 5:1 or more.

100 aggregate particles were obtained for each size fraction and tested for the F&E particles test using the proportional caliper shown in Figure 1.

The aggregate particles in each group were either counted or weighed. The percentage of flat and elongated aggregate particles (by count or mass) was then determined.

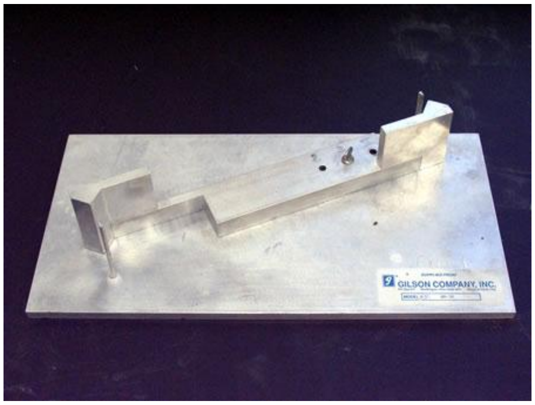

Figure 1: F&E Particles Proportional Caliper

4.3 FAA Test

The FAA test is performed on fine aggregate passing No. 4 (4.75 mm) sieve according to the test method described in the AASHTO T 304. FAA is measured by the percentage of uncompacted void content in fine aggregate.

Enough fine aggregate sample was obtained and tested for FAA using the device shown in Figure 2. A sample of as-received aggregate material passing No. 4 sieve was poured into the funnel of the device, and then it was released into the cylindrical measure beneath the funnel. Excess fine aggregate material in the cylindrical measure was leveled off by a straight edge (Figure 3). Finally, the mass of the fine aggregate in the cylinder was measured. The uncompacted void content in the fine aggregate sample was calculated as follows:

$$Uncompacted\,Voids = \frac{V - \frac{M}{G_{sb}}}{V} \times 100\,\%$$

Where:
V = volume of cylindrical measure,
M = mass of fine aggregate sample, and
G_{sb} = specific gravity of fine aggregate.

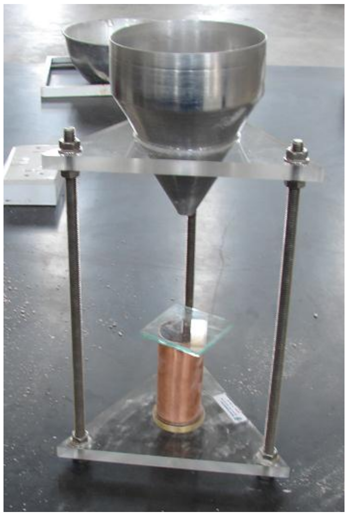

Figure 2: FAA Device

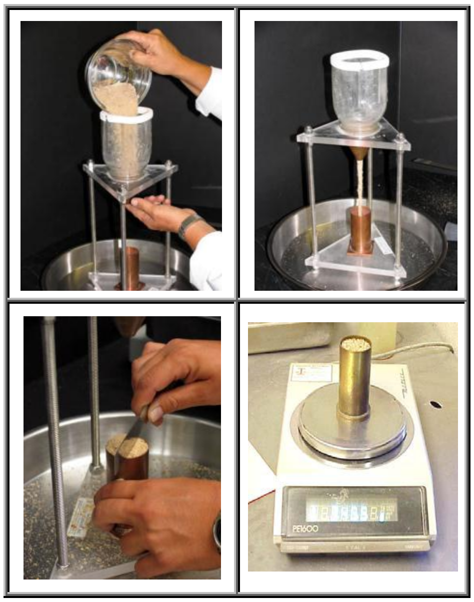

Figure 3: FAA Test Procedure

Angular materials are desirable in asphalt paving mixtures because they tend to lock together and resist deformation after initial compaction. On the other hand, rounded materials can lead to asphalt mixture instability and shoving, and may not produce sufficient inter-particle friction to prevent rutting.

obtained. The uncompacted void content in the fine aggregate sample was calculated as follows:

4.4 SE Test

The SE test was conducted on fine aggregate passing No. 4 (4.75 mm) sieve according to the test method described in the AASHTO T 176. SE measures the percentage of clay material contained in the fine aggregate fraction. The clay materials existing in fine aggregate can coat aggregate particles and prevent proper asphalt binder-aggregate bonding leading to stripping of asphalt binder in asphalt mixtures.

Four 85-ml cans of fine aggregate were obtained and placed in a graduated cylinder as shown in Figure 4. It was then mixed with flocculent Calcium Chloride solution to help separate clay material from sand material. The cylinder with the sample was shaken by hand in a horizontal linear motion for 30 seconds or using mechanical or manual shaker for 100 cycles as that shown in Figure 5. The sample was then irrigated using a tube inserted inside the cylinder to make sure that the fines were flushed up. The sample, after it was shaken and irrigated, was allowed to sit for 20 minutes. The height readings of the clay and the sand were then recorded directly from the graduated cylinder or by the aid of a weighted foot assembly inserted into the cylinder as shown in Figure 6.

4.5 LA Abrasion Test

The LA abrasion test was performed on coarse aggregate retained on No. 8 (2.36 mm) sieve according to the test method described in the AASHTO T 96.

Approximately 5,000 g of coarse aggregate were obtained and placed in a large drum with a specified number of steel balls rotating at a speed of 30-33 rpm for 500 revolutions. The aggregate was then extracted from the LA machine and separated using No.12 (1.70 mm) sieve. The percentage of the material passing this sieve to the original mass of the sample was determined and recorded as the LA mass loss as shown below:

$$LA\ Mass\ Loss = \frac{M_{Passing\ No.12\ Sieve}}{M_{Original}} \times 100\%$$

Figure 4: SE Device

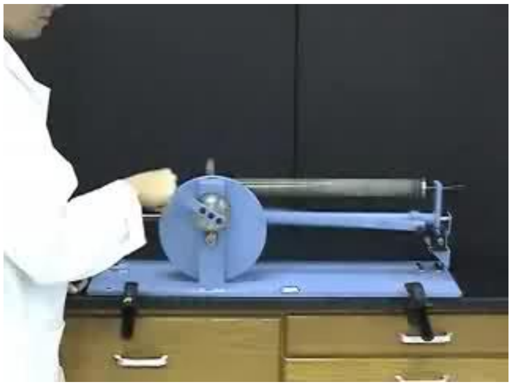

Figure 5: Manual Shaker

Figure 6: SE Clay and Sand Readings

5. Results and Discussion

The test results for the consensus aggregate properties of the four limestone aggregates acquired from four sources and the basalt aggregate used in the study are summarized in Table 1 below.

Table 1: Consensus Aggregate Properties

Property	Limestone				Basalt
	1	2	3	4	
CAA[1]	96	97	100	98	97
CAA[2]	90	91	91	90	95
F&E	0	0	0	0	0
FAA	41	45	45	44	46
SE	50	58	58	52	84

1 one or more fractured faces, 2 two or more fractured faces

One the other hand, the test results for the source aggregate properties are shown in Table 2 below.

Table 2: Source Aggregate Properties

Property	Limestone				Basalt
	1	2	3	4	
$G_{sb\text{-}CA}$	2.427	2.542	2.605	2.434	2.677
Absorp. $_{CA}$ (%)	3.54	3.42	3.62	3.46	2.24
$G_{sb\text{-}FA}$	2.368	2.614	2.507	2.355	2.789
Absorp. $_{FA}$ (%)	5.57	1.01	4.70	3.95	2.46
LA Abrasion (%)	25	27	27	26	27

The test results are also presented in the following three figures. Figure 7 illustrates the differences between the consensus properties for the different aggregates, whereas, Figures 8 and 9 present the differences between the source properties for the different aggregates.

The test results for consensus properties showed no significant difference in the CAA, FAA, and F&E particles test results between limestone aggregates from the four sources. However, there was a little difference in the SE test result between the four sources of limestone aggregate. Limestone aggregate from sources 2 and 3 (Al-Rojoub-Rehab and Al-Sharu'-Shatana) showed slightly higher SE values than limestone aggregate from sources 1 and 4 (Al-Rojoub-Irbid and Abo-Obaid-Shatana). On the other hand, basalt aggregate showed significantly higher SE value (SE = 84) than the SE values of the limestone aggregates from the four sources. Basalt aggregate was not unique in the other consensus properties (CAA, FAA, and F&E particles); its values were not so different from those of limestone.

Comparison of the source aggregate properties indicated that the basalt aggregate was unique in the lowest value of percent absorption for both the coarse and fine portions. The bulk specific gravity for the basalt aggregate (both coarse and fine portions) was also higher than those of the limestone aggregates from the different four sources as shown in Table 2 and Figure 8. The limestone aggregates from sources 2 and 3 showed higher bulk specific gravity values than those of the limestone aggregates from sources 1 and 4. All other source properties were found similar for the limestone aggregates from the different sources.

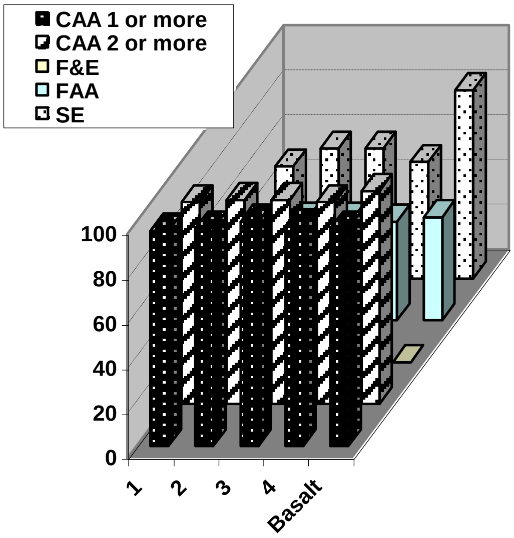

Figure 7: Histogram for Consensus Properties

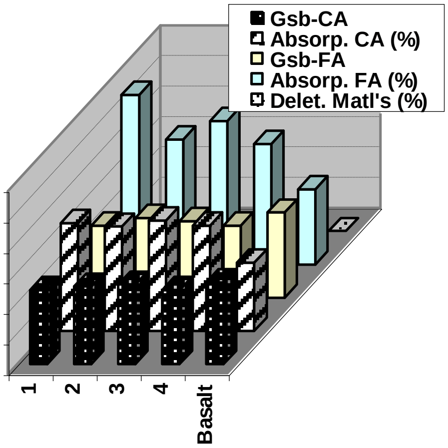

Figure 8: Histogram for Source Properties

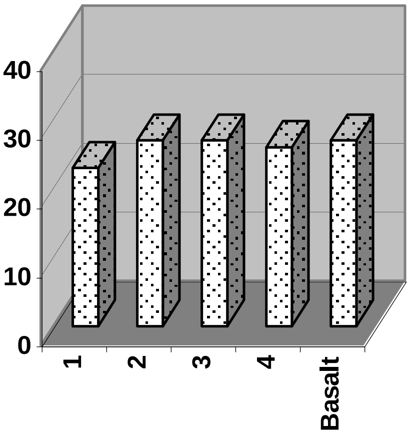

Figure 9: Histogram for LA Abrasion

LA abrasion for the basalt aggregate was similar to that of the limestone aggregate from three sources. However, the limestone aggregate from source 1 showed the lowest LA abrasion value. It is unlikely that limestone has lower LA abrasion values than basalt. However, basalt has different types and sources, and its properties vary with the type and source. Therefore, this basalt from Al-Hallabat area might be different than basalt from other areas in Jordan.

The Superpave specifications for consensus aggregate properties and source aggregate properties for a medium traffic loading of 10-<30 million ESALs (equivalent single axle loads) are shown in the table below:

Table 3: Consensus Aggregate Properties

Superpave Criteria	Consensus Property			
	CAA	F&E	FAA	SE
Value at a Depth <100 mm	≥95/90	≤10	≥45	≥45
Value at Depth >100 mm	≥80/75	≤10	≥40	≥45
	Source Property			
Superpave Criteria	LAA		Deleterious Materials	
Value	≤35-40		≤0.2-10	

6. Conclusions and Recommendations

The following conclusions were drawn based upon the results of the study:

1. In general limestone aggregate sourced in the northern part of Jordan had similar consensus aggregate properties except for SE values that might differ slightly between the different sources.
2. Limestone aggregate from different sources in the northern part of Jordan showed similar results for the source aggregate properties.
3. Basalt aggregate sourced in Al-Hallabat did not differ significantly from limestone sourced in the northern part of Jordan in terms of the consensus aggregate properties: CAA, FAA, and F&E particles.
4. However, basalt aggregate had much higher SE values than limestone aggregate from the four different sources.
5. The bulk specific gravity of basalt aggregate in general was higher than that of limestone aggregate sourced in the northern part of Jordan.
6. The absorption of basalt aggregate was lower than that of limestone aggregate from the four sources.
7. The limestone aggregates from sources 2 and 3 showed higher bulk specific gravity values than those of the limestone aggregates from sources 1 and 4. All other source properties were found similar for the limestone aggregates from the different sources.
8. It was unlikely that limestone aggregate from three sources and basalt aggregate from Al-Hallabat had similar LA abrasion values.
9. The lowest LA abrasion value was that of the limestone from source 1.
10. In general, limestone and basalt aggregates considered in this study passed the Superpave criteria for a medium traffic loading.

It is recommended that limestone aggregate from different parts of Jordan and basalt aggregate from different areas be considered in further future research.

7. Acknowledgment

The authors of this paper are grateful to the Scientific Research Fund (SRF) of the Ministry of Higher Education and Scientific Research in Jordan for their financial support. This paper is part of a research project funded financially from the SRF.

8. References

1. American Association of State Highway and Transportation Officials (AASHTO). Standard Test Method for Determining the Percentage of Fracture in Coarse Aggregate. AASHTO TP 61, 1995.
2. AASHTO. Plastic Fines in Graded Aggregate and Soils by Use of the Sand Equivalent Test. AASHTO T 176, 1995.
3. AASHTO. Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in Los Angeles Machine. AASHTO T 96, 1995.
4. AASHTO. Uncompacted Void Content of Fine Aggregate. AASHTO T 304, 1995.
5. American Society of Testing Materials (ASTM). Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate. ASTM D 5821, 2000.
6. ASTM. Flat particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate. ASTM D 4791, 2000.