LIMITATION OF THE FINE AGGREGATE ANGULARITY (FAA) TEST TO PREDICT THE BEHAVIOR OF ASPHALT MIXTURES

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ABSTRACT: The performance of dense asphalt mixtures is influenced by the shape, angularity and surface texture of fine aggregates. This work aims at verifying if the Fine Aggregate Angularity test (FAA), adopted by Superpave Specifications, is able to identify materials with better qualities for use in asphalt mixtures. Besides the FAA test, other tests are carried out: visual analysis of shape, angularity and surface texture, direct shear test in samples of fine aggregates and Marshall test in samples of asphalt mixtures produced with different fine aggregates. The results indicate the FAA test does not separate the effects of particle angularity from the effect of shape. A fine aggregate with a higher FAA does not necessarily possess larger shear strength and there is no correlation between Marshall stability and FAA values. Therefore, the FAA test seems to be unable to identify aggregates which provide mixtures with better performance.

KEY WORDS: mineral aggregates; shape, angularity, surface texture; Fine Aggregate Angularity (FAA) test; Superpave method.

1. INTRODUCTION

The main mechanisms of pavement deterioration are permanent deformation (rutting), fatigue cracking and raveling. In Brazil, rutting has become a major problem due to traffic growth and higher axle loads. Tire inflation pressures, which average around 880 kPa (120 psi) are much higher than those of the AASHO Road Test reference value of 550 kPa (75 psi).

The following literature review provides an insight into the influence of aggregate characteristics on asphalt mixture properties. Kim et al. [1] investigated permanent deformation of HMA taking into consideration aggregate type, gradation, asphalt cement type (larger and smaller thermal susceptibility), asphalt content, air voids, temperature and stress level. This found that in compacted mixtures angular-shaped particles exhibit greater interlock and internal friction than rounded particles. It was observed that changing the proportions of fine and coarse aggregate with the same nominal maximum aggregate size did not affect significantly permanent deformation. The effect of other variables such as asphalt type, air voids and temperature on permanent deformation were greater with rounded and smooth-texture aggregates. This is probably because the bearing capacity of mixtures with poorer interlock depends more on the binder viscosity than mixtures with angular aggregates.

Schklarsky and Livneh [2] presented an extensive study of the difference between rounded and crushed coarse aggregates in combination with rounded and crushed fine aggregates. Several variables were studied including Marshall stability and flow, friction angle and cohesion as measured in a triaxial test, loaded wheel test and permeability test. The replacement of the rounded aggregates by crushed fine aggregates improved mixture properties (increased stability, reduced rutting, improved water resistance). The replacement of rounded by crushed coarse aggregates had no significant effect.

Kandhal et al. [3] found that although crushed fine aggregates tend to have higher angularities than rounded fine aggregates, some rounded fine aggregates provided a higher friction angle, indicating a greater aggregate interlock (more resistant granular structure), due to shape, surface texture and/or toughness characteristics.

These studies show that good HMA stability can be obtained by controlling fine aggregate properties. Therefore, it is necessary to have a reliable test to screen fine aggregates in terms of performance-related features such as shape, angularity and surface texture for detecting fine aggregates that are likely to result in mixtures with poorer resistance to rutting.

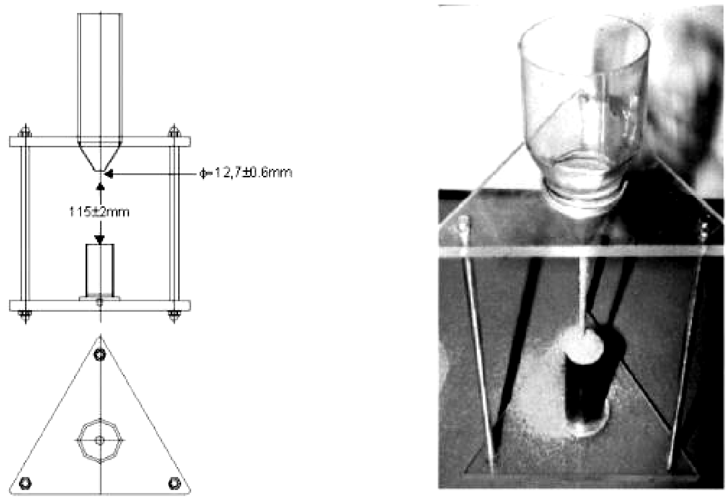
The Fine Aggregate Angularity (FAA) test, adopted by Superpave to evaluate the shape, angularity and surface texture of fine aggregate particles, has created questions regarding its suitability [4]. The questions generated about the reach and validity of the FAA test motivated this study which aims at verifying if the FAA test is able to identify materials with better conditions for use in asphalt mixtures and if it can be used as an indicator of the resistance of asphalt mixtures to permanent deformation.

2. EXPERIMENTAL PROGRAM

Twenty samples of fine aggregates were selected and submitted to the FAA test (method A) based on the ASTM C 1252 [5] specification. The fine aggregate angularity is measured by determining the amount of voids when the fine aggregate is poured into the top end of a cylinder with known volume (Figure 1). The higher the amount of voids, the more angular the aggregate. More details about the FAA test can be found in Gouveia [6]. The amount of uncompacted voids (UV) in the cylinder can be calculated from the following equation:

$$UV = \frac{V - \dfrac{W}{G_{SB}}}{V} \times 100 \qquad (1)$$

where:
V = Volume of cylinder (mm^3);
W = Weight of loose fine aggregate to fill the cylinder (g);
G_{SB} = Bulk specific gravity of fine aggregate.



(a) (b)

Figure 1. Fine Aggregate Angularity (FAA) Test Equipment

The twenty samples of fine aggregate were ranked according to FAA test results. Three samples were selected representing materials with high, medium and low FAA values and different mineralogy (basalt, granite and natural sand).

Usually, two laboratory tests are conducted to measure the shear resistance of aggregate samples i.e. direct shear and triaxial tests. In this work, the direct shear test was chosen because it is the most direct and appropriate way to determine the direct shear resistance of fine aggregate [7].

The direct shear tests were conducted according to the ASTM D 3080 [8] specification. The test consists of placing and compacting samples in the direct shear device, applying a predetermined normal stress (confining pressure) and displacing one frame horizontally with respect to the other at a constant rate of shearing deformation. The samples were carefully compacted by vibration, aiming at reaching the highest level of compaction. Normal stresses of 192, 383 and 500 kPa were used to determine the parameters c (cohesion intercept) and ϕ (internal friction angle) related to the Mohr-Coulomb strength envelop.

These tests aimed at verifying if there is a correlation between FAA value and shear strength. The tests were based on the hypothesis that fine aggregate with higher values of FAA produced more angular particles and greater surface texture, resulting in a larger interlock between particles and consequently larger shear strength.

Visual comparative analyses of the fine aggregates were conducted for shape, angularity and texture. The analysis methods are presented by Suguiu [9]. These methods are based on two tables of comparison. The rounding degree table of Russel and Taylor [10] and the sphericity degree table of Rittenhouse [11]. The surface texture of the particles was examined by microscopic observation.

The mixture stability and flow were determined by the Marshall test according to Marshall Method of Mixture Design of the Brazilian Association for Technical Standards (ABNT 12891) [12]. The three fine aggregate samples were combined with the same basalt coarse aggregate.

The gradation was designed according to Superpave volumetric mix design method, above the restricted zone and between the control points (Figure 2).

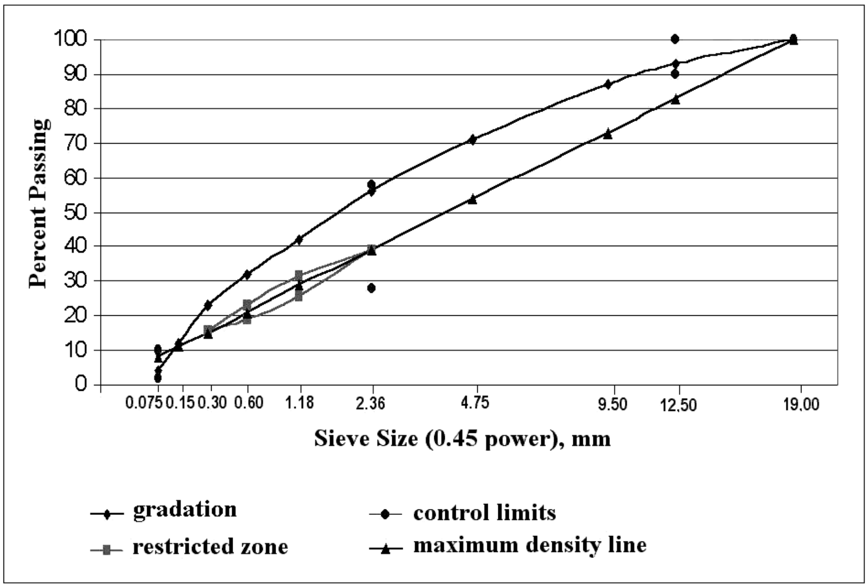


Figure 2. Gradation According to Superpave Requirements

To increase the fine aggregate effects, the amount of material passing the 2.36 mm sieve was maximized. Thus, there was a larger amount of fine material in the mixture than coarse material.

The filler (passing 0.075 mm sieve) does not affect mixture performance if it has a content less than 4% [13]. Therefore it was stipulated that 4% of filler should be in the mixtures.

3. MATERIALS

3.1 Asphalt Cement

The asphalt cement used in this research was an AC-20 conforming to the properties specified by the Technical Regulation DNC n. 01/92 - Rev. 02, March 24, 1993, of the Brazilian Department of Fuels. The properties required for AC-20 are presented in Table 1.

Table 1. AC-20 Properties

Test	Result	DNC 01/92	Method
Absolute viscosity at 60 ºC (poise)	3200	2000 to 3500	MB-827
Viscosity (Saybolt Furol) at 135 ºC (s)	120	120 min.	MB-517
Viscosity (Saybolt Furol) at 177 ºC (s)	38	30 to 150	
Index of thermal susceptibility	-0.45	-1.5 to 1.0	-
Penetration, 25 ºC, 100g, 5s (0.1 mm)	48	50 min.	MB-107
Cleveland Open Cup method (ºC)	262	235 min.	MB-50
Apparent specific gravity (g/cm^3)	1.020*	-	-

* Test result supplied by Petrobras – Brazilian Petroleum Co.

3.2 Fine Aggregate

Table 2 presents the source and classification of the twenty samples of fine aggregate which are representative of the materials used in paving construction in the State of Sao Paulo, Brazil.

3.3 Coarse Aggregate

The coarse aggregate used in the asphalt mixtures was a crushed basalt from Quarry Bandeirantes, located in Sao Carlos, State of Sao Paulo, Brazil.

4. HMA MIXTURE PREPARATION AND COMPACTION

Three types of HMA mixture were evaluated. These mixtures were produced with the same gradation (Figure 2), but different fine aggregates representing materials with high, medium and low FAA. The mixtures are called MB, MG and MS corresponding to fine aggregates of Basalt, Granite and Natural Sand.

The HMA samples were produced according to the Marshall Method of Mixture Design of the Brazilian Association for Technical Standards. The Marshall samples were compacted with 75 blows on each side. The samples were tested for Marshall stability and flow at 60ºC. The samples for the evaluation of stability, flow and volumetric properties (VMA, VFA, etc.) were produced with an asphalt content corresponding to 4% air voids.

5. RESULTS AND ANALYSIS OF TEST RESULTS

The statistical analysis was based on hypothesis tests for differences among averages of small samples.

5.1. Fine Aggregate Angularity test (FAA)
The FAA test results, corresponding to the average of three replicates, are presented in Table 2. The selected materials for additional lab tests, which have high, medium and low FAA values, are highlighted.

The basalt obtained from Quarry Santa Isabel was selected because it had the highest value of FAA. The natural sand from Moji Guacu river was selected because it had the lowest FAA and was the only sample to yield a FAA below the Superpave requirement (45% minimum) for highways with high traffic volume. A representative sample of medium value FAA was the granite from Quarry Sao Roque.

The results presented in Table 2 show that all fine aggregates, excluding the natural sand from Moji Guaçu river, satisfy the Superpave requirements for high traffic volume whose minimum FAA is 45%. However, the natural sand is considered acceptable for mixtures used in highways with medium traffic volume.

Table 2. Results of FAA[a]

Source	Mineralogy	G_{SB}	FAA (%)
01. Quarry Santa Isabel	*Basalt*	*2.830*	*51.1*
02. Quarry Fazenda Velha	Granite	2.890	50.4
03. Quarry Contil	Gneiss	2.709	49.7
04. Quarry Sao Jeronimo	Granite	2.596	49.1
05. Quarry Basalto - Americana	Basalt	2.917	49.0
06. Quarry Bonato	Basalt	2.903	48.7
07. Quarry Sao Roque	*Granite*	*2.732*	*48.3*
08. Quarry Bandeirantes	Basalt	2.835	48.3
09. Quarry Basalto 6	Basalt	2.690	48.2
10. Quarry 52.314 AM:02	Granite	2.701	48.2
11. Quarry 52.314 AM:01	Granite	2.654	47.9
12. Quarry Basalto - Jaguariuna	Gneiss	2.891	47.8
13. Quarry 52.414	Granite	2.660	47.8
14. Quarry Galvani	Basalt	2.974	47.4
15. Quarry Basalto 05	Gneiss	2.941	47.0
16. Quarry 52.232	Granite	2.630	47.0
17. Quarry Edispel	Basalt	2.818	46.9
18. Quarry 52.304	Granite	2.738	46.8
19. Moji Guacu River	Crushed sand	2.632	46.7
20. Moji Guacu River	*Natural sand*	*2.632*	*44.0*

[a] Average of three series of tests, performed in accordance with the ASTM C1252, Method A.

5.2 Visual analysis of shape, angularity and surface texture
Table 3 shows the average values obtained from visual analysis of shape, angularity and surface texture. This analysis was conducted with basalt, granite and natural sand samples. A sample 200 particles of fine aggregate was separated into size fractions used in the FAA test, method A. The comparisons are made for each individual size fraction because some aggregates show degrees of angularity and shape as a function of size particle.

The basalt particles (highest value of FAA) were classified as angular according to the classification table of Russell and Taylor [10] showing no worn corners. These particles showed a sphericity of 0.65 according to the classification table of Rittenhouse [11]. This is associated with flat and elongated particles. The basalt particles showed rough surface texture.

The granite particles (medium value of FAA) were classified as sub-angular with incipient worn corners. The particles showed a sphericity of 0.84 which is associated to rounded particles. The granite particles showed rough surface texture.

The natural sand particles (lowest value of FAA) were classified as rounded with worn corners. The particles of natural sand showed sphericity of 0.84 and smooth surface texture.

Table 3. Results of Shape, Angularity and Surface Texture

	Angularity	Shape	Surface Texture
Natural Sand	rounded	0.84 (cubic)	smooth
Granite	sub-angular	0.84 (cubic)	rough
Basalt	angular	0.65 (lamellae)	rough

5.3 Direct Shear Test

Table 4 gives the average values of peak shear strength obtained from the three specimens of granite, basalt and natural sand. Statistical analysis of the results verified that the natural sand yields smaller shear strength than the granite and basalt. For normal stresses of 191 and 500 kPa, the peak shear strength of the granite and basalt samples can be considered similar. For the normal stress of 383 kPa, the granite has larger shear strength than the basalt.

The natural sand has a reduced shear strength because it consists of rounded particles with smooth surface texture resulting in less interlock between its particles.

Table 4. Peak Shear Strength at Different Normal Stresses

Normal stress	Material		
	Natural Sand	Granite	Basalt
191	207	242	234
383	380	445	425
500	481	566	559

Note: Average of three replicates.

The internal friction angle and the cohesion intercept from direct shear tests are given in Table 5. The strength envelop from the direct shear test results is presented in Figure 3 which illustrates the determination of the shear strength parameters. The higher internal friction angle of the granite and basalt samples indicates that better interlock results in a more resistant granular structure.

Table 5. Results of Mohr-Coulomb Parameters

Sample	Cohesion intercept (c)	Internal friction angle (ϕ)	Coefficient of Determination (R^2)
Natural Sand	38.05	41.6	0.99
Granite	41.98	46.4	1.00
Basalt	31.48	46.3	0.99

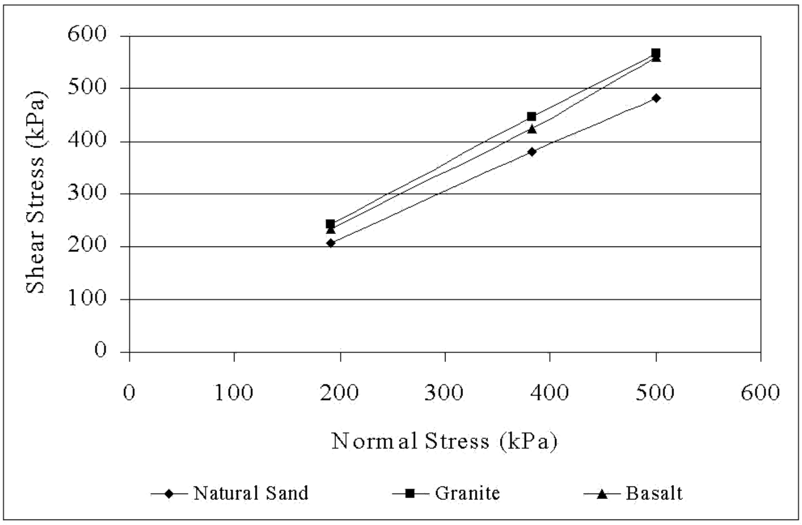


Figure 3. Strength Envelop from Direct Shear Test Results

5.4 Marshall Test

Table 6 shows the results of Marshall tests HMA mixtures with basalt (MB), granite (MG) and natural sand (MS) fine aggregates and asphalt content corresponding to air voids of 4 percent.

Table 6. Results of Marshall tests

Mixture	MB	MG	MS
Percentage of Coarse Aggregates (%)	44	44	44
Percentage of Fine Aggregates (%)	52	52	52
Percentage of Filler (%)	4	4	4
Asphalt Content (%)	6.0	6.0	5.0
Bulk Specific Gravity	2.440	2.420	2.410
Air Voids (%)	4	4	4
Voids in Mineral Aggregate - VMA (%)	18.39	18.50	15.93
Voids Filled with Asphalt - VFA (%)	78.08	76.98	74.14
Marshall Flow (mm)	3.8	3.8	3.0
Marshall Stability (N)	10081	14171	9150

The data for the three mixes were compared by statistical analysis. It was observed that the values of VMA and VFA of mixtures MB and MG were similar, but higher than the value of mixture MS.

The values of Marshall flow for mixtures MB and MG were similar, but larger in relation to the value of mixture MS. The values of Marshall stability show the best performance of mixture MG.

The Brazilian Specification for compacted HMA requires a minimum Marshall stability of 350 kgf, flow between 2.0 and 4.6 mm, air voids between 3 and 5%, and VFA between 75 and 82%. Mixtures MB, MG and MS satisfy the requirements, except for the VFA value of the MS mixture.

The Superpave volumetric mixture design for mixtures containing about 4% of air voids are a minimum VMA of 14% for 12.5 mm nominal maximum aggregate size and VFA between 65 and 80% depending on the traffic volume. It can be verified that mixtures MB, MG and MS satisfy the minimum VMA. However, regarding the VFA for high traffic volume only mixture MS satisfies the Superpave specification.

Mixtures MB and MG consumed more asphalt cement than mixture MS. Most likely this occurred because mixtures containing rounded and smooth-textured aggregates have smaller percentages of VMA and consequently require less asphalt for the same value of air voids.

6. CONCLUSIONS

Twenty fine aggregates that encompassed a broad range of material type, angularity and texture were used in this investigation to evaluate the FAA test and its relationship to fine aggregate direct shear strength, visual analysis of shape, angularity, surface texture and Marshall stability and flow for asphalt mixtures produced with different fine aggregates.

This work analyzed the hypothesis that fine aggregates with high FAA have angular particles and rough surface texture, indicating that they result in better interlock between particles, higher shear strength and higher mix stability.

The conclusions based on the results obtained in this work are:

1. Visual analyses of shape, angularity and surface texture indicated that the FAA test is not able to separate the effects of angularity and shape. Cubic particles with a suitable angularity and texture can give lower values of FAA than flat and elongated particles;
2. The results of the direct shear test indicated that fine aggregates with higher FAA do not necessarily have higher shear strength;
3. The Marshall stability results demonstrated poor correlation between FAA and Marshall stability. In other words, the FAA test does not appear to be a good indicator of aggregate that provide mixtures with higher stability.

The FAA test is simple to perform and highly reproducible. Direct shear strength tests were reproducible but strengths were more variable than FAA values. Even so, it appears that implementation of the FAA test in Brazil as a tool for screening or accepting fine aggregates for use in asphalt mixtures must be preceded by additional studies.

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