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LABORATORY EVALUATION OF THE FINE AGGREGATE ANGULARITY (FAA) TEST

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ABSTRACT
The performance of hot-mix asphalt (HMA) pavements depends on the properties and proportions of the major components, i.e., mineral aggregates, asphalt cement and air voids. The performance of dense asphalt mixtures is influenced mainly by fine aggregate characteristics, such as shape, angularity and surface texture. The Fine Aggregate Angularity test (FAA), adopted by Superpave to evaluate the shape, angularity and surface texture of fine aggregate particles, has left a lot of doubts regarding its suitability. The objective of this work is to verify if the FAA test is really able to classify fine aggregates and identify the good ones to be used in asphalt mixtures. Thus, FAA test, visual analysis of shape, angularity and surface texture, direct shear test with samples of fine aggregates and Marshall test with samples of asphalt mixtures produced with different fine aggregates are performed. The results obtained in the visual analysis indicate that the FAA test is not able to separate the effects of angularity from the effects of shape. The results of the direct shear test demonstrate that a fine aggregate with a higher FAA doesn't present, necessarily, a larger shear strength. The values of the Marshall test indicate that there is no correlation between Marshall stability and FAA values. All the results show that the FAA test is not able to classify fine aggregates appropriately and, therefore, is unable to identify aggregates that provide mixtures with better performance.

Keywords: mineral aggregates; shape, angularity, surface texture; Fine Aggregate Angularity test (FAA); Superpave method; stability of asphalt mixtures.

1. INTRODUCTION

The main mechanisms of pavements deterioration are permanent deformation (rutting), fatigue cracking and raveling. In Brazil, rutting has become a major problem due to traffic growing, higher axle loads and, mainly, higher tire inflation pressures, which average is around 880 KPa (120 psi), much above 550 KPa (75 psi), AASHO Road Test reference value.

[1] presented an evaluation of the aggregate and gradation roles on permanent deformation of HMA, taking into consideration the aggregate type, graduation, asphalt cement type (larger and smaller thermal susceptibility), asphalt content, air voids, temperature and stress level. The obtained results indicate that in compacted mixtures, angular-shaped particles exhibit greater interlock and internal friction, and hence, greater stability than rounded particles do. Additionally, it is observed that changing the proportions of fine and coarse aggregates with the same nominal maximum aggregate size do not affect significantly the permanent deformation. The effects of others variables, such as asphalt type, air voids, and temperature on permanent deformation were amplified with rounded and smooth-texture aggregates. This is probably because the bearing capacity of mixtures with poorer interlock depends much more on the binder viscosity than mixtures with angular aggregates.

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

[3] showed that, although crushed fine aggregates tend to have higher angularities than rounded fine aggregates, some rounded fine aggregates present higher friction angle, indicating a larger interlock (more resistant granular structure), due to shape, surface texture and/or toughness characteristics.

Many works clearly show that good HMA stability can be obtained by controlling fine aggregates proprieties. 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, detecting fine aggregates that are likely to result in mixtures with poor resistance to rutting.

The Fine Aggregate Angularity test (FAA), adopted by Superpave to evaluate the shape, angularity and surface texture of fine aggregate particles, has left a lot of doubts regarding its suitability [4].

The doubts about the reach and validity of the FAA test motivated this research, which aims at verifying if the FAA test can be used as an indicator of the resistance of asphalt mixtures to permanent deformation.

2. EXPERIMENTAL PROGRAM

Initially, twenty samples of fine aggregates were selected and submitted to the FAA test (method A), based on the ASTM specification [5]. 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. The higher the amount of voids the more angular the aggregate. More details about the FAA test can be found in [6].

The twenty samples of fine aggregates were ranked according to FAA test results. Three samples were selected for complementary tests, 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: 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 aggregates [7].

The direct shear tests were conducted according to the ASTM specification [8]. 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 aggregates with higher values of FAA present angular particles and rough surface texture, resulting in a larger interlock between the particles and, consequently, a larger shear strength.

Visual comparison analyses were conducted for shape, angularity and texture evaluation of the three selected samples. The analysis methods are presented by [9]. These methods are based on two tables of comparison: the rounding degree table [10] and the sphericity degree table [11], in order to determine the rounding (angularity) and the sphericity degree (shape) of the fine aggregates. The surface texture of the particles was examined by microscopic observations.

The mixtures stability and flow were determined by Marshall test, in according to [12]. The three fine aggregate samples were combined with only one coarse aggregate (basalt).

The gradation was designed according to Superpave volumetric mix design method, above the restricted zone and between the control points (Illustration 1).

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 relation to the coarse material in the mixture.

The filler (passing 0.075 mm sieve) doesn't affect the mixture performance if its content is less than 4% [13]. It was stipulated, therefore, 4% of filler in the mixtures.

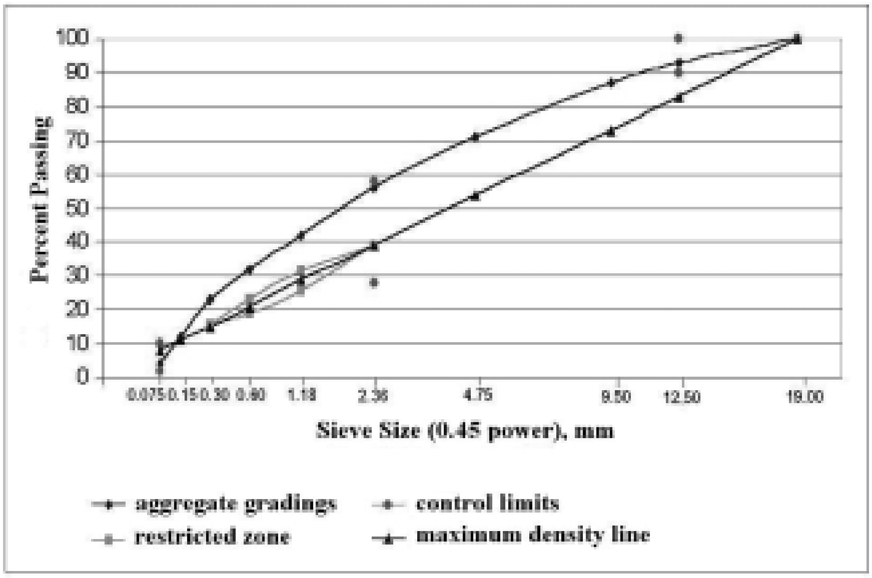

Illustration 1. Gradation according to Superpave requirements

3. MATERIALS

3.1 Asphalt Cement

The asphalt cement used in this research is a AC-20, which properties are controlled by the Technical Regulation DNC n. 01/92 - Rev. 02, March 24, 1993, of the Brazilian Department of Fuels (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/cm3)	1,020*	-	-

* Test result supplied by Petrobras – Brazilian Petroleum Co.

3.2 Aggregates

3.2.1 Fine Aggregates

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

Table 2. Origin and classification of the samples of fine aggregates collected

Sample	Source	Classification
01	Quarry Basalto 05 - Monte Mor	Gneiss
02	Quarry Santa Isabel - Ribeirao Preto	Basalt
03	Quarry Sao Jeronimo - Valinhos	Granite
04	Quarry Sao Roque - Santa Barbara D'Oeste	Granite
05	Quarry Fazenda Velha	Granite
06	Quarry Contil - Itatiba/Bragança Paulista	Gneiss
07	Quarry Bonato - Santa Barbara D'Oeste	Basalt
08	Quarry Basalto - Americana	Basalt
09	Quarry Galvani - Paulinia	Basalt
10	Quarry Basalto 6 - Campinas/Indaiatuba	Basalt
11	Quarry Basalto - Jaguariuna	Gneiss
12	Quarry Edispel - Ribeirao Preto	Basalt
13	Quarry Bandeirantes - Sao Carlos	Basalt
14	Moji Guaçu River - Rincao	Crushed sand
15	Quarry 52.304	Granite
16	Quarry 52.232	Granite
17	Quarry 52.314 AM:01	Granite
18	Quarry 52.314 AM:02	Granite
19	Quarry 52.414	Granite
20	Moji Guaçu River - Rincao	Natural sand

3.2.2 Coarse Aggregate

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

3.3 Mixtures

Three types of mixtures were evaluated. These mixtures were produced with the same gradation (Illustration 1), but different fine aggregates, representing materials with high, medium and low FAA. The mixtures are called MB, MG and MS, corresponding to fine aggregate of Basalt, Granite and natural Sand.

4. RESULTS E AND ANALYSIS OF THE RESULTS

4.1 Fine Aggregate Angularity test (FAA)

The FAA test results, corresponding to the average among three replicates, are presented in Table 3. The selected materials for additional lab tests, which have high, medium and low FAA values, are highlighted.

The basalt, obtained from Quarry Santa Isabel, located in the city of Ribeirao Preto, was selected because it presents the highest value of FAA. The natural sand, from Moji Guaçu river, located in Rincao (Mandi Farm), was selected because it presents the lowest value of FAA and also for being the only sample to present FAA below the Superpave requirement (45% minimum) for highways with high traffic volume. As a representative sample of medium FAA value was chosen a granite from Quarry Sao Roque, located in Santa Barbara do Oeste, because it also presents different mineralogy from the samples previously selected.

Table 3. Results of FAA

Source	Mineralogy	ρ_{ap} (g/cm^3)	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 Guaçu River	Crushed sand	2,632	46,7
20. Moji Guaçu River	**Natural sand**	**2,632**	**44,0**

The results presented in Table 3 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.

4.2 Visual analysis of shape, angularity and surface texture

Table 4 shows the average values obtained from visual analysis of shape, angularity and surface texture of fine aggregates particles. This analysis was conducted with basalt, granite and natural sand samples. An amount of 200 particles of each sample of fine aggregate is separated in the size fractions used by the FAA test, method A. The comparisons are made for each individual size fractions because some aggregates present degrees of angularity and shape as a function of the size of the particles.

Table 4. 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

4.3 Direct Shear Test

Table 5 presents the average values of maximum shear strength obtained from three specimens of granite, basalt and natural sand. From the statistical analysis of the results, it is verified that the natural sand presents smaller shear strength than the granite and the basalt. For normal stresses of 191 and 500 kPa, the maximum shear strength of the granite and the basalt samples can be considered similar. For the normal stress of 383 kPa, the granite presents larger shear strength than the basalt.

Table 5. 1Results of shear strength

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

The natural sand presents reduced shear strength because it has rounded particles with smooth surface texture, which results in smaller interlock between its particles.

In Table 6 is presented the internal friction angle and the cohesion intercept. The higher internal friction angle of the granite and the basalt samples indicates a better interlock that results in a more resistant granular structure.

Table 6. Results of Mohr-Coulomb Parameters

Sample	Cohesion intercept (c)	Internal friction angle (ϕ)	Coefficient of Determination (R^2)
Natural Sand	38.05	41.6	0.9999
Granite	41.98	46.4	1.0000
Basalt	31.48	46.3	0.9985

4.4 Marshall Test

Table 7 shows the results of Marshall tests, considering mixtures with basalt (MB), granite (MG) and natural sand (MS) fine aggregates and asphalt content corresponding to air voids of 4%.

Table 7. 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
Content of Asphalt Cement (%)	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 (0.01")	15	15	12
Marshall Stability (kgf)	1028	1445	933

The mixtures MB, MG and MS, respectively with basalt, granite and natural sand fine aggregates, were compared by statistical analyses. It can be observed that the values of VMA and VFA of mixtures MB and MG are similar, but higher than the values of mixture MS.

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

The Brazilian Specification [12] for compacted HMA requires: minimum Marshall stability of 350 kgf, flow between 8 and 18 hundredths of an inch, 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: 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, but 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 did, probably because mixtures containing rounded and smooth-textured aggregates have smaller percentages of VMA and, consequently, they need less asphalt for the same value of air voids.

5. CONCLUSIONS

This work analyzed the hypothesis that fine aggregates presenting high FAA have angular particles and rough surface texture, resulting in a better interlock between the particles, a higher shear strength and, consequently, a higher stability of the mixture.

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

1. The results of the visual analyses, considering shape, angularity and surface texture of the particles, indicate that the FAA test is not able to separate the

effects of angularity and shape. Cubic particles with a suitable angularity and texture can present lower values of FAA than flat and elongated particles;
2. The results of the direct shear test indicate that fine aggregates with higher FAA don't necessarily present higher shear strength;
3. The Marshall stability results demonstrate that there is no correlation between the FAA and the Marshall stability. In other words, the FAA test doesn't seem to be a good indicator of aggregates that can provide mixtures with higher stability.

The FAA test is simple to perform and highly reproducible, but unfortunately, there are doubts about the added practical value of this test. Considering that many countries are implementing the Superpave Mix Design Specifications, it appears that the implementation of FAA test in those countries as a tool for screening or accepting fine aggregates for use in asphalt mixtures must be preceded by additional studies.

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