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COMPARISON OF COMPACTED AGGREGATE RESISTANCE TEST METHOD WITH ASTM C1252

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ABSTRACT

This paper describes the determination of shape and surface texture characteristics of different mineralogical type and shape (both angular and round) of fine aggregates which were received from fourteen different sources. The ASTM C1252 methods (methods A, B, and C) were used to determine the uncompacted void content of fine aggregates. The compacted aggregate resistance (CAR) test was also conducted on the same group of fine aggregates with as received and standard gradation as well as on the aggregate blends (M0, M25, M50, M75, M100) to provide a more performance-based aggregate parameter. In this way, the CAR test and ASTM C 1252 methods for evaluating the shape and surface texture characteristics of fine aggregates can be compared.

Key Words : CAR test, ASTM C1252, Fine aggregate, Shape, Surface texture.

SIKIŞTIRILMIŞ AGREGA DAYANIMI VE ASTM C1252'NİN KARŞILAŞTIRILMASI

ÖZET

Bu çalışma, farklı mineralojik köken ve şekil özelliklerine sahip 14 farklı kaynaktan temin edilen ince agregaların şekil ve yüzey pürüzlülüğü özelliklerinin belirlenmesini kapsamaktadır. Bu amaçla, ASTM C1252 yöntemleri (yöntem A, B ve C) ince agregaların sıkışmamış boşluk yüzdelerini belirlemede kullanılmıştır. Aynı agregalar ve agrega karışımları (M0, M25, M50, M75, M100) üzerinde, standart boyut dağılımında ve ocaktan alındıkları hali ile sıkıştırılmış agrega dayanımı (CAR Test) deneyleri uygulanmıştır. Böylece, ince agregalarda şekil ve yüzey pürüzlülüğü özelliklerinin değerlendirmekte kullanılan CAR Test ve ASTM C1252 deney yöntemleri karşılaştırılabilecektir.

Anahtar Kelimeler : CAR test, ASTM C1252, İnce agrega, Şekil, Yüzey pürüzlülüğü.

1. INTRODUCTION

The shape and surface texture characteristics of aggregate affect the asphalt mixture properties which include dynamic stiffness, stability, durability, permeability, resistance to moisture damage and air voids in the mixture. Additionally, it affects the workability and optimum asphalt cement content of the mixture. Cubicle-like particles, rather than flat, thin, and elongated particles are recommended for use in hot-mix asphalt (HMA). Angular particles, a property found in most crushed stone, provide a better interlocking property than rounded particles. This provides better performance and less rutting under repetitive traffic loads. However, this property makes the workability more difficult during the compaction stage of construction. Rounded particles provide better workability during compaction, but tend to continue to compact under traffic loading due to the lack of interlocking particles (Zaniewski and Rafferty, 2004). Because of this reason, in recent years highway engineers have preferred less workable asphalt mixtures (Topal and Sengoz, 2005).

The texture of aggregates is also important on the workability and performance of HMA (Roberts et al. 1996). Rough surfaces are found in fine aggregates produced by crushing stone. Smooth-surfaced particles are often found in natural sand and gravel. A rough surface provides a greater bonding strength with asphalt cement and frictional resistance between particles, thus maintaining mixtures with higher rutting resistance. Due to the greater frictional resistance, fine aggregate with high texture require a greater amount of asphalt cement to increase the workability during construction, relative to the requirements for a smooth texture fine aggregate. A rougher texture is preferred in HMA where friction between particles is needed to provide stability.

It has been well documented that the characteristics fine aggregates play a significant role in the rutting resistance of HMA because the fine aggregate is a primary constituent in asphalt mixtures (White, 1998; Chowdury et al., 2001; Purcell and Cross, 2001; Stakston et al., 2002; Topal and Sengoz, 2005).

The successful quantification of aggregate geometric irregularities is essential for understanding their effects on pavement performance and for selecting aggregates to produce pavements of adequate quality. Thus, the quantification of the angularity, shape, and surface texture is important as high-quality pavements are needed to meet increases in traffic volume and load (Kuo and Freeman, 2000).

The weight and volume of mineral aggregates used in asphalt mixtures are respectively, at the rate of 90–95 % of mixture weight, 75–85 % of mixture volume (Topal and Sengoz, 2005). Since the percentage of volume of aggregate in a mixture is a function of gradation, D_{max}, the shape and surface texture of aggregate, it influences "packing" and load transfer through the mixture, which eventually affects the performance.

The Superpave Hot Mix Asphalt Design method currently specifies the use of ASTM C1252 to determine the angularity of the fine aggregate portion in the total aggregate blend. This was based on research studies prior to the development of Superpave that had demonstrated the stability of HMA increased with the increase of crushed particles. To measure angularity of the fine aggregate fraction, ASTM C1252 assumes that a higher degree of fractured faces will result in a higher void content in the uncompacted sample. Superpave currently specifies an uncompacted void content value, also called fine aggregate angularity (FAA), of 45 to ensure HMA stability.

However, there have been occasions when the FAA value determined using the uncompacted void content was not always able to separate good and poor performing fine aggregates. Cubical shaped particles, for example, even with 100% percent fractured faces, have been found not to be able to meet the FAA requirement for heavy volume traffic even though good field performance has been observed Additional field studies have also shown that even when the fine aggregates met the minimum FAA values, poor field performance had occurred (White et al., 1998; Lee at al., 1999; Fernandes et al., 2000;). Therefore, further work may be needed to validate and/or possibly refine the use of the FAA test as a means of screening different fine aggregates for their use in hot mix asphalt and/or provide a surrogate test method to screen fine aggregates for use in hot mix asphalt.

Since the Superpave (Superior performing asphalt pavements) FAA test (ASTM C1252) rejects many 100 % crushed limestone aggregates that are known to perform well, the CAR test was proposed as an alternative method for measuring fine aggregate properties with respect to their contribution to producing rut resistant asphalt mixtures (Jahn, 2003). The CAR test is believed to better predict performance, properly evaluate carbonates, and permit the evaluation of blended natural and manufactured sands which would certainly have been rejected by the FAA test. The Superpave mixtures expert task group has recently expressed interest in the CAR test as a potential replacement for the FAA test (Zaniewski and Rafferty, 2004).

The primary objective of this paper is to determine if a correlation exists between the CAR test and the ASTM C1252 results.

2. EXPERIMENTAL

Fine-grained aggregate samples were collected from fourteen different quarries and natural deposits from different locations in Turkey. During the collection of samples the ASTM D75 specification procedure was followed. The crusher and the aggregate type, the quarry, the specific gravities, and the percentage absorption values corresponding to each aggregate sample are presented in Table 1.

Following the determination of the properties of the aggregates, the ASTM C1252 and the CAR test were conducted on each of the samples.

Table 1. Aggregate Samples.

No	Crusher type	Source	Quarry/Region	No.5-No.200 Spec. Gr. (Pr)	No.10-No.200 Spec. Gr. (Pr)
R1	Natural	River sand	Odemis/Izmir	2.626	2.628
S1		Sediment S.	Ege B./Turgutlu	2.571	2.573
S2	Roll	Sediment S.	Ege B./Turgutllu	2.565	2.565
A1	Jaw	Andesite	Balikesir	2.287	2.278
M1	Conical	Marble	Akhisar/Denizli	2.633	2.597
L1		Limestone	Alacatli/Ankara	2.660	2.624
L2		Limestone	Cimbeton/Urla	2.457	2.625
L3		Limestone	Y.Hereke/Gebze	2.700	2.720
L4		Limestone	Ozture/Torbalı	2.679	2.645
L5		Limestone	Belkahve/Izmir	2.636	2.639
L6	Vertical Shaft Impactor	Limestone	Batibeton/Izmir	2.632	2.576
L7		Limestone	Agregasa/Gebze	2.700	2.707
L8		Limestone	Dere Mad./Izmir	2.687	2.689
S3		Sediment S.	Ege B./Turgutlu	2.566	2.565

2. 1. ASTM C 1252 Method

The ASTM C1252 “Uncompacted Void Content of Fine Aggregate” is used to determine the loose, uncompacted void content of the fine aggregates. This method estimates the angularity, sphericity and surface texture of the aggregate having a given grading (Anon., 1993).

The apparatus used in this test is shown in Figure 1. A sample of dry fine aggregate is placed into the apparatus, and falls through the cone into a calibrated cylinder. The orifice in the cone is 12.5 mm (0.5 inch). The height from the orifice of the cone and the rim of the cylinder is 114 mm (4.5 inch). The theory behind this test is that the higher the uncompacted void content, the more freshly fractured faces and highly textured particle faces.

Figure 1. Uncompacted void content apparatus.

The uncompacted void content is determined as:

$$U = \frac{\left(V - \dfrac{F}{G_{sb}}\right)}{V} x100 \qquad (1)$$

U = Uncompacted voids in the fine aggregate, %
V = Volume of calibrated cylinder, ml
F = Mass of fine aggregate in the cylinder, g
Gsb = Bulk dry specific gravity of fine aggregate.

There are three methods for running this test; Method A specifies the use of a predetermined aggregate gradation ranging from No.8 to No.100 sieve, which usually does not represent the natural gradation of the aggregate material. Method B specifies that the uncompacted void content be conducted on three individual aggregate size ranges, (B1, B2, B3); No.8 to No.16, No.16 to No.30 and No.30 to No.50 and the final reported FAA value being the average of the three ranges. Method C specifies that the uncompacted void content be determined for the fine aggregate’s natural (as received) gradation. For each test method, testing was conducted in triplicate and averaged to determine the final FAA value. Method A was also conducted on the fine aggregate portion (minus No.8 sieve) of the different HMA total

aggregate blends. The mass of the sample for all three methods is fixed at 190 gr. Superpave requires that an FAA value of 45 must be achieved for the total fine aggregate fraction in the HMA mix, but not for individual aggregate sources.

2. 2. The Compacted Aggregate Resistance (CAR) Test Mmethod

The compacted aggregate resistance test (CAR) was proposed by David Jahn as an alternative method for measuring fine aggregate properties with respect to their contribution to producing rut resistant mixes (Jahn, 2003). The CAR test is basically a "punch shear" that measures the shear resistance of compacted fine aggregates which is an indirect measure of the shape and angularity of fine aggregates. Conceptually, the CAR test which is similar to the California Bearing Ratio (CBR) test is in the developing process of replacing the current Superpave standard for FAA (Zaniewski and Rafferty, 2004). And like the CBR test, the results of the CAR test are dependent on the shear strength properties of the aggregate.

The CAR test uses standard Marshall equipment along with a simple loading head (Figure 2), for evaluating the shear resistance of fine aggregates.

Figure 2. CAR test apparatus.

The CAR test shows potential for evaluating fine aggregates with respect to their contribution to the rutting potential of HMA. The test procedure is summarized as:

- The aggregates are dried then brought to the required moisture content (3.5 %).
- The aggregates are placed in a 4 inch (100 mm.) Marshall mold and rodded to provide initial compaction.
- The sample is compacted using a standard Marshall hammer and drop height; 50 blows are applied to one face of the sample.
- The sample is placed in a Marshall stabilometer configured with a punch loading head as shown in Figure 2.
- The load is applied at a rate of 2 inch (50mm) inches per minute and the force and deformation are recorded.
- The CAR result is the peak force measured during the test, or the force (kgf) at a deformation of 0.25 inch (6.35 mm) if the strength of the material exceeds the maximum load capacity of the machine.
- The CAR test was conducted three times for each test sample. Testing was carried out on the individual aggregates sources, as well as the fine aggregate portion (minus No. 8 sieve) of the different mixtures.

This test was conducted on the fourteen aggregate samples as well as on the aggregate blends (M0, M25, M50, M75, M100) to evaluate the effect of angularity of crushed fine aggregate. Samples were prepared to the gradations used for the Marshall mix designs using only the material passing the No.8 sieve. In order to evaluate the gradation changes on the test procedure, the test was also performed on the specimens prepared with as received gradation material passing No. 8 sieve.

3. TEST RESULTS AND DISCUSSION

3. 1. FAA and CAR Test Results

The uncompacted void content of fine aggregates including method A, B, C is presented in Figure 3.

Among the three methods, the method B yields the highest uncompacted void (U) content (which is an indicator of the highest angularity); where as the method C yields the lowest U value, as indicated in Figure 1. Among the three individual sampling related to the method B, the samples prepared with B3 give the highest U value. This result demonstrates the effect of gradation on the U values of the samples because as the percentage of finer fraction of aggregate increases, the U values increase as well due to the internal friction between the aggregate particles. Figure 3 also shows that a relation exists between the method B and method C.

Figure 4 presents the CAR test results of the fourteen aggregate samples prepared with standard and as received gradation.

Although the aggregate samples prepared with standard gradation have higher shear resistance compared with aggregates prepared with as received gradation, the difference in gradations is relatively minor, as presented in Figure 4. This result demonstrates that the test can be performed on as received gradation samples eliminating the need for preparation of gradation regulation. Also, crushed limestone aggregates have high shear resistance than the other types of aggregates. Among the aggregate samples which contain the same mineralogical type of aggregate (S1, S2 and S3) but crushed with different type of crushers (natural, roll crusher and vertical shaft impactor), crushed aggregates have higher shear resistance compared with natural aggregate samples. Also the sample crushed with the vertical shaft impactor has higher shear resistance.

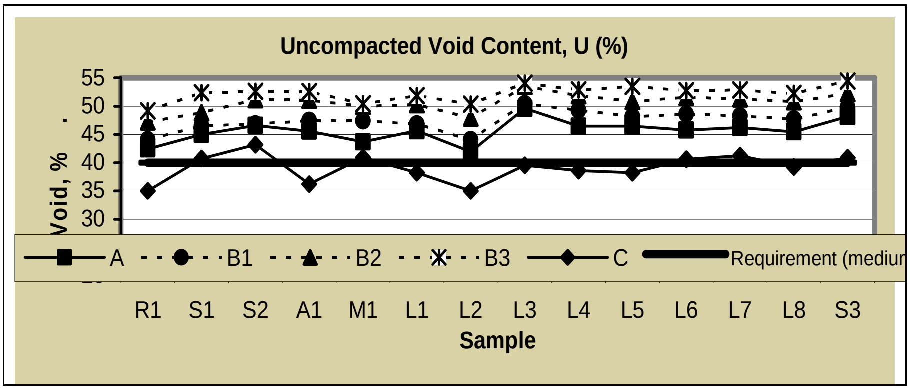

Figure 3. Uncompacted void content of fine aggregates (ASTM C 1252).

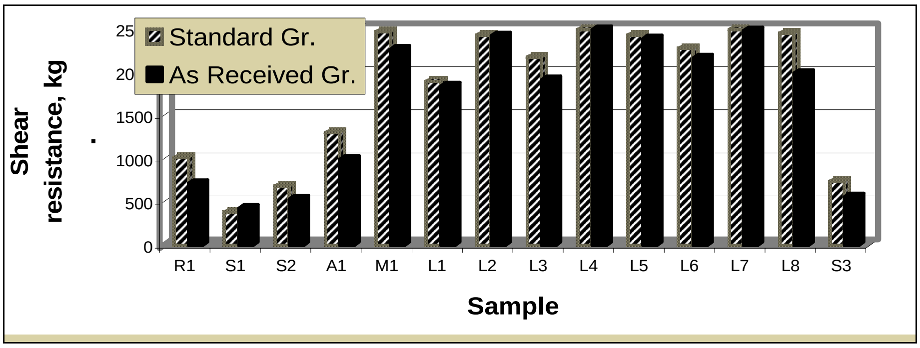

Figure 4. CAR test results of fine aggregates.

3. 2. Comparison of ASTM C1252 and CAR Test Results

In order to compare the ASTM C1252 and the CAR test, natural sedimentary deposit fine aggregate (S1) is blended with different proportions (0 % to 100 %) of crushed fine aggregate (L6). Figure 5 shows the effect of natural fine aggregate on the CAR force for each of the blends. In the figure, the ratio of limestone to natural fine aggregate is based on the material that is finer than the 2.36 sieve (No. 8). M0, M25, M50, M75 and M100 indicate the percentage of crushed fine aggregate (L6) in the blend.

When the natural fine aggregate percentages were above % 50, the CAR force reached to the peak values. When the percentage of crushed limestone was 50 % of the mix and greater a peak force was not identified so the readings were taken at 0.25 inches of penetration. As expected, the greater the crushed limestone in the mix, the greater the CAR force. Similar results were obtained by Zaniewski and Rafferty (2004).

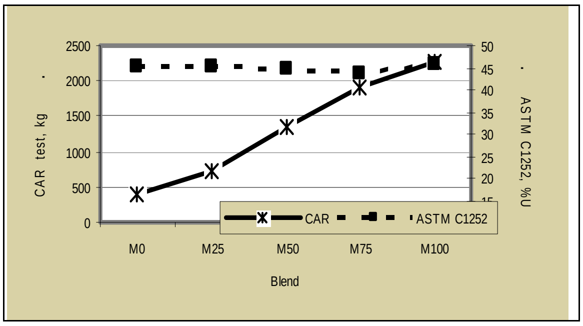

Figure 5. Comparison of FAA tests and CAR test.

The shear resistance (which is an indicator of resistance to deformation of mixtures) increases with the crushed fine aggregate (L6) content. Figure 5 demonstrates an increase in the resistance to deformation as the percent of limestone fine aggregate increases. Moreover, no relationship between the uncompacted void contents and crushed fine aggregate content was established. This result demonstrates the significant weakness of the ASTM C1252 in determining the angularity of different kind of aggregates either crushed or natural.

4. CONCLUSION

The primary aim of this study is to investigate the angularity of fine aggregates produced in Turkey and to draw the attention of design engineers to this subject. As mentioned previously, aggregate particle shape, size and gradation have an impact on the performance of asphalt concrete. In asphalt concrete, the shape of aggregate particles is related to permanent deformation, fatigue resistance and the skid resistance of pavements. Fine aggregate is a primary constituent of asphalt mixtures and the amount and angularity of fine aggregate are important factors affecting the performance of asphalt concrete.

Indirect measures of shape and texture are based either on measuring the shear resistance of the aggregate or on the ability of the aggregate to flow and pack into a cylinder. The results of the ASTM C1252, both the method A and B are correlated well, with method B producing larger uncompacted void contents because the method B specifies the test be run on the individual size fraction. On the other hand, as the method C is affected by the fine aggregate gradation, it yields the lowest uncompacted void content and is therefore not recommended for comparing particle shape and texture. As the Superpave researchers choose the method A, the test itself is incapable of evaluating the effect of gradation. In order to evaluate this effect, tests using alternative gradations other than the method A should be used. Nevertheless applications of these methods are time consuming.

The CAR test distinguishes the two aggregate blends which are crushed and natural. Among the two tests, the effect of crushed fine aggregate content is far more noticeable in CAR test. This is an advantage over the ASTM C1252 which uses a defined gradation and requires specific gravity to determine the results. The CAR test eliminates the need for specific gravity computation and uses the "as received" gradations because the difference in the shear strength is relatively minor compared with standard gradation. This is an advantage over the fine aggregate angularity procedure which uses a defined gradation during the test and is therefore incapable of evaluating the effect of gradation. These results conclude that the CAR test can be a useful tool for determining the shape and angularity of fine aggregates.

It can also be concluded that the ASTM C1252 test is not capable of distinguishing the effect of angularity on the internal friction produced between the fine aggregates compared with the CAR test.

The CAR test method is still under development and has not been adopted by any highway agencies in Turkey. However, more research has to be undertaken in order to determine a relationship with the permanent deformation characteristics of the asphalt concrete mixtures.

Due to the size of fine aggregates, it is not feasible to manually evaluate their shape and texture as is done for coarse aggregates. With the advent of digital images and computer analysis, several methods have recently been developed to measure shape and texture directly. However, the state of the art has not developed to the point where these methods can be recommended for implementation.

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