THE IMPACT OF AGGREGATE QUALITY ON CONCRETE PERFORMANCE

WITH REFERENCE TO TEST SHORTCOMINGS

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ABSTRACT

The aggregate industry does little to differentiate its core product – the aggregate itself, from one source to the next. Different properties of aggregates influence different aspects of concrete and asphalt. These impacts may be small or large, physical performance-orientated or economical. Whatever the differences, the industry as a whole, needs to understand and measure them to ensure quality, economic end products

INTRODUCTION

Numerous tests have been developed to empirically characterize aggregates without, necessarily, a strong relationship with the performance of the final products incorporating these aggregates.

Typically, aggregate specifications are drafted using a prescriptive technique whereby an aggregate is tested and as long as the test result for that given aggregate sample falls within a given range, that aggregate is deemed acceptable for use in that product. Obviously there are some critical factors for both the aggregates and the specifications when taking this form of approach to designing asphalts and concretes.

The first consideration has to be, what is the test we are applying to the aggregate telling us? Then, once we have arrived at that answer, what is the allowable range away from the target value. On the surface, this would appear to be a reasonable way of ensuring that the end product of asphalt or concrete will perform as desired. After all, approximately 80% of concrete volume is aggregate, and even more so (95%) in asphalt.

So why then, are there so much conjecture and apparent problems in the performance of products such as SuperPave and concretes?

First we must look at what characteristics of aggregates are important, which characteristics we want to measure, and then how we measure these characteristics. Assuming that the aggregates are free of deleterious materials, and are inert, and then the basic properties of the aggregates that will impact asphalt or concrete products will be their shape, size and surface texture.

Other properties that will determine an aggregates' suitability for a given application are toughness and abrasion resistance. These tests also need to be accompanied by tests to ensure aggregate processing is not adversely impacting aggregate quality; so measures to determine cleanliness and the presence of deleterious materials are also required.

In summary then, the tests that should be used to ascertain an aggregates' suitability for asphalt or concrete production should adequately characterize particle size, shape and texture, ensure the aggregate is sound enough for the end use product, and verify that the aggregate has been processed to ensure there is an acceptable level of deleterious contaminants in the product.

L.A. ABRASION

In the USA, the predominant test to determine abrasion resistance of an aggregate is the L.A. Abrasion test. Transportation agency specifications reveal a number of available test methods, but only a few that are widely used. The survey of specifications indicated that 94% of the states use the Los Angeles abrasion test or some variation. Only two states have a degradation requirement from some other type tests.

Aggregates must be tough and abrasion resistant to prevent crushing, degradation, and disintegration when stockpiled. In asphalt, aggregate toughness and abrasion resistance is required to limit the above as the aggregates are fed through an asphalt plant, placed with a paver, compacted with rollers, and subjected to traffic loadings.

The properties of toughness and abrasion resistance are especially critical for open or gap graded asphalt concrete mixtures (such as open-graded friction courses and stone matrix asphalt), which do not benefit from the cushioning effect of the fine aggregate and where coarse particles are subjected to high contact stresses

Aggregates which lack adequate toughness and abrasion resistance may cause construction and performance problems. Degradation occurring during production can affect the overall gradation and, thus, widen the gap between properties of the laboratory designed mix and field produced mix. (1)

The L.A. Abrasion test has, in numerous studies, shown that there is very little if any correlation to this characteristic in the performance of either concrete or asphalt. The test result, which should be a function of the parent rock itself, can be skewed in either direction by the way in which the aggregate is manufactured.

The change in the L.A. Abrasion value can be brought about by changing the specific surface of the aggregate sample, i.e., the more equidimensional or cubical the aggregate sample is to start off with, the more abrasion resistant the aggregate will seem, according to the test.

It is a relatively simple process to correct an out of specification aggregate (Most states have an aggregate L.A. requirement in the 40 – 45 range) by altering the aggregate production process. In changing the process, and taking a failing aggregate and making it pass this test, are we enhancing the performance of the asphalt or concrete product? Short answer, probably not. Is the specification or test actually giving us information on the likely performance of that aggregate, and then the likely performance of the product it makes up? Probably not. Why specify this test then? And if it is specified, how do you set pass or fail criteria?

Thankfully, there appears to be a move towards another test method for assessing an aggregate's abrasion resistance, the Micro Deval test. Research projects are showing promise in this test method and it's ability to better characterize abrasion properties of aggregates.

SIEVE ANALYSIS

The sieve analysis is a test that is probably the most widely used test to assess an aggregate's suitability for asphalt or concrete production. It is also a critical test to determine mix designs or aggregate proportions for road bases, asphalt mixtures and concretes etc.

So, as a test that determines both acceptance and rejection of an aggregate, and then, that test result determines how the aggregate will be used in the end product, as an industry (aggregate), we had best be sure that the test is adequately characterizing our product.

Does it?
The sieve analysis test takes a sample of aggregates, and passes that sample through a nest of sieves with square apertures. These apertures are typically half the nominal size of the sieve above. When an aggregate passes through an aperture, and is retained on the next aperture; the retained aperture size becomes the designated size for that aggregate particle, or group of particles. The total mass of aggregates on each sieve is recorded, and the percentage is either expressed as a cumulative percentage passing, or individual percentage retained on a given sieve.

As stated earlier, the size, or nominal size of an aggregate sample is important to determine the suitability of that material for its intended use. The governing dimension of the aggregate particle when it comes to size when passed through an aperture is the median dimension. Not the greatest or longest dimension, nor the least.

Size is a critical property for an aggregate. Therefore, it should be measured correctly. Aggregates, because they are of irregular shape - - typically angular and non symmetrical - - are relatively difficult to measure en mass any other way than the pass/retained method described. However, using the conventional square apertures in most cases introduces a significant error to the actual size of the median dimension of the aggregate particle.

SQUARE VS ROUND

The differences between a square and a circle are rather obvious. The total area covered by a square of a nominal size, is larger than that of the corresponding circle of the same nominal size. Also, the nominal dimension of the square is only nominal when measured along one of the sides. When measuring the diagonal dimension of the square aperture, the available opening for an aggregate particle to pass is significantly greater than that of the nominal dimension. This is not the case with a circular opening.

What can happen, therefore, is that with a square aperture, a particle with a larger median dimension than that of the nominal sieve aperture can actually pass through that aperture on the diagonal. As a particle gets further away from being equidimensional or cubical, the likelihood of this increases. If the aperture has the same nominal dimension as with a circle, this cannot happen.

Is this important? Yes. Why? Well, what the sieve analysis is measuring when using square apertures is particle size which is influenced by particle shape. Therefore, the worse shape a particle is, i.e. if it is flat or elongated the square apertures will indicate the nominal size of the particle is less than it truly is.

SAND SIZE FRACTIONS

In sand size fractions, the problems can be exacerbated by the use of wire woven sieves. Not only is the diagonal dimension greater than the nominal, the distortion of the wire as it moves up and down in the weave at the cross over points adds even more potential error. So, as aggregate particles decrease in size, the chance that they will be poorly characterized by sieves increases.

Another problem with the sieve analysis test that can influence a true particle size distribution result is that of differing specific gravities. This can also be an issue with coarse aggregates. As aggregate particles are reduced in the crushing and screening process, the chance of liberating particles of a different specific gravity than that of the "all in" parent rock sample increases. As the test specification calls for the particle size distribution by weight, any alteration in particle density will impact on the particle size distribution by volume. An important point, especially when specifications tend to inhibit the use of the finer size fractions in both concrete and asphalt. A problem type material would be micaceous granite, for example.

Also, when performing a sieve analysis test, research has shown that especially for fine aggregates, it is best to perform a wet sieve analysis. Most specifications call for rigid tolerances on the finest size fractions. If these size fractions are indeed important, the wet sieve analysis better shows the true amount of this material in the sample.

So, with the sieve analysis test as it is, and the methods of reporting the results, it can clearly be seen that this test is open for providing misleading information. It is very unfortunate when you consider that the particle size distribution (grading) is the cornerstone of so m any specifications, and, a "variable" that is controlled during research projects.

CONCRETE AND ASPHALT

The vast majority of mix designs for asphalt and concrete are based around the sieve analysis test. For concrete, there are graphs that purport to give maximum density gradings. For SuperPave, the 45 power curve is used, based around a maximum density gleaned from gradation data, and then proceeds to go further by introducing the "restricted zone", for which the combined gradings are plotted, and this magical no-go area is determined. If the restricted zone has any validity at all, and it is based on the particle size distribution around the 45 power curve, how can it be determined by a test that is heavily influenced by things other than what it is measuring?

The same can be said for the latest fad in concrete mix design. There is a groundswell of support for concrete aggregates to conform to a prescriptive grading that is determined by looking at the individual sizes retained on a given sieve throughout the particle size distribution of the combined aggregates. Often this is referred to as 8 to 18, or the "Shilstone" method. This method is supposed to somehow produce a dense packed aggregate grading which will positively influence all of the plastic and hardened concrete properties.

Whether you are expressing the particle size distribution as acumulative percentage passing, or an individual percent retained, the problem relating to the test not accurately measuring the median size fraction remains. However, when, as is the case with the 8 – 18 size requirements in the marketplace today, you combine two or more aggregates with different specific gravities, there would need to be an adjustment to compensate for the differing volumes of each sample for a given mass. This can be significant, if you are using a diabase coarse aggregate (specific gravity of around 3.0) and combining it with natural sand (specific gravity of around 2.6) the resulting gradings will skew the result by some 15 or so percent.

Variations of the 8 – 18 concept is creeping into the specification arena, these include a "6 –16", "2 – 22" and others we are sure we have not heard of. Apart from having a range of particle sizes available to pack and reduce voids, there appears to be little if any technical reasoning behind applying the sieve analysis this way.

The same can be said for the 45 power curve. We have never seen an aggregate that has its maxim um density or packing potential along this line. Not only have we not seen an aggregate on this particular line, we have never experienced an aggregate having the same particle shape or packing characteristics at consecutive size fractions. This may be a function of the fact that as particle size changes, typically so does particle shape. Add to this the fact that as particle shape changes, so too will the ability of the sieve analysis test to express the particle size in relative terms, even within a given sample.

The errors in the test and the misapplication of the values can inhibit the introduction of new technologies. It is impossible to use the sieve analysis test to predict the performance of an aggregate, so, when a contractor is trying to duplicate a product from one location to another, they often are left scratching their head as to why a product that appears to be the same as per the sieve analysis is not performing the way a seemingly identical material is elsewhere. A product that immediately comes to mind is Self Compacting Concrete (SCC).

MAXIMUM PACKING

We think the ability to predict the maximum packing grading of an aggregate is important. However, one must use correct data to try and achieve this. In our opinion, for the reasons above, the sieve analysis test and the subsequent application of the results as it sits today does not have this ability.

When looking at the theoretical maximum packing curves for aggregates, and comparing these with the actual test specifications, an interesting deviation from actual appears. Looking at the three leading maximum density packing curves, we note that the theoretical maximum density lines of Fuller, 45 power, and Talbot all follow a similar pattern. The reverse dish shape of the curve does not follow the actual test envelope of, say, the ASTM C 33 specification. You will note that the grading envelope for concrete sand under this and most specifications has a distinctive "S" shape to it. This goes against the desire to produce sand with minimum voids or maximum packing density.

The "S" shape that is prescribed by ASTM and other specifications is more likely a result of historical data from natural sands that have performed satisfactorily in concrete, rather than a specification for sands that will deliver what a producer really desires. The historical data includes the "S" shape at the top of the grading curve not as a performance enhancing trait, but more likely because of inefficient screening in the earlier years that the specifications were drawn up in. The insufficient screening would not generate a clean "cut" at the top size of the grading curve, and hence the inversion compared to the desired maximum density curves.

FINENESS MODULUS

From a specification and a concrete or asphalt design standpoint, using the fineness modulus (F.M.) of an aggregate can be very misleading. The fineness modulus is a single value that represents the particle size distribution. As a value, it is commonly used to assess the suitability of sand for a given purpose. It is one of the criteria used in ACI concrete mix design to determine material proportions for example.

If the sieve analysis test is misleading, then any consolidation of the test and its values will be even more misleading. This is definitely the case, as per the example below of two totally different sands in both grading and shape/texture yielding the same FM value. Mix design proportioning procedures that use FM as a value, will treat these materials in the same way. Obviously, the resulting concretes will behave in a different manner. The lack of correlation between concrete performance and fineness modulus is highlighted in the ICAR 102 research project, where fineness modulus of the sands showed no correlation to concrete performance whatsoever.

ENHANCEMENTS

There is obviously a lot of room for improvement when it comes to measuring particle size. The existing method of measuring particle size through square apertures is flawed. One change would be to perform the test with screens having circular apertures. Obviously, all tables, charts and the likes would need to be altered as the actual sizes of most aggregates tested would alter, with the circular sieves yielding sizes that are larger than those of square.

New technologies on the market to measure size and shape, namely the video, digital and laser type technologies, have the ability to make accurate measurements of a particle at many different size fractions. However, what is the point of making a test result from this or any other technology try to mimic the square sieve result, when the square sieve result in itself is in error?

Changing the test or the use of the sieve analysis test would be a massive task. It is certainly the cornerstone of m any specifications. The advent of performance based specifications and contracting may short circuit the reliance of producers on this test, as innovative technologies are employed to produce asphalts and concretes of high quality and alternative methods of mix proportioning and non-traditional material types are employed in the end products.

Some State DOT’s are doing away with the prescriptive particle size requirements. After all, isn’t the important thing to consider the end product or end use of that product? For example, if you are designing a road, aren’t the properties of the finished road more important than the properties of the materials in that road?

The above two tests are not the only two tests that can be misleading, or overstated as to their significance in either quality or economic performance. Other tests are the Particle Size,

Shape and Texture as measured in ASTM C 1252, Specific Gravity and Absorption tests, especially for fine aggregates, Flat and Elongated tests for coarse aggregates, Hydrometer and Sand Equivalent tests for minus 200 mesh materials.

If you would like to join in on further discussion and remedies for aggregates, concrete and asphalt specifications, log onto our website at www.aggregateresearch.com and join the appropriate forum.

REFERENCE

1. (NCAT Report # 98-4)