Specifications allowing high fines content

In the first four articles in this series, Barry Hudson looked at some of the properties of manufactured sands for concrete. Overwhelming test data and performance records from around the world suggest that manufactured sands can not only be an alternative to natural sands, but they can actually out perform natural sands in terms of the quality of the finished concrete, and, as well, lower the total cost of the raw materials.

This article deals with the specifications that will allow higher percentages of fines in a manufactured sand, as well as investigating the ASTM C1252 test for uncompacted fine aggregate. We will look at this test and try to decipher its accuracy in determining particle shape and surface texture of fine aggregates.

One of the problems in dealing with manufactured sands is the lack of a set of tests that fully characterise the three main properties of the individual particles. The properties that we should be trying to characterise are:

1. Particle shape
2. Particle size
3. Particle surface texture

Not only do we need to know these individual properties of the aggregates, we need to know how these properties influence the concrete in both its hardened and plastic states. It is also desirable to understand how the properties of each of the aggregate sizes, or material types, impacts on the entire aggregate blend.

The interaction of the particles with each other is an issue that is not adequately addressed by the concrete standards of today. Logic should dictate that for specifications of particle size distribution we should be looking at the entire gradation, ie. the sand and aggregate fractions together - so that we can with more certainty have a commonsense overall gradation in the concrete mix.

High Fines

An example of what is meant by this is illustrated by changing sand percentages in an aggregate blend. Obviously when we add higher percentages of sand into the total aggregate blend, the gradation of the aggregate becomes finer. So, if for example, we had a property of the coarse aggregate that was undesirable, say very flaky, we would be in effect helping to mask that particular problem by adding more sand.

Likewise, if you had sand that was of a poor quality, you would try to minimise its use so that the concrete was workable at an acceptable total cost. In either case, the change to the total aggregate gradation is likely to be significant as compared to the "normal". However, as long as the concrete performs in its plastic and hardened states to the prescribed level of quality, and the concrete is produced at an acceptable total cost, there should be no problem and the materials should be used.

So, if we look at the total concept of gradation in coarse and fine aggregates, what are we trying to get these materials to achieve in concrete? The number one criteria for a concrete mix is that it has to meet the specifications for workability when it is plastic, and strength, durability etc. when it is hardened. The concrete producer wants to achieve all of this at the lowest possible cost.

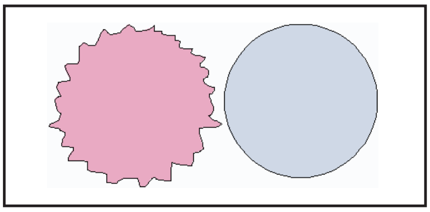


Figure 1. Particles can have similar shapes and volumes, but differing surface textures.

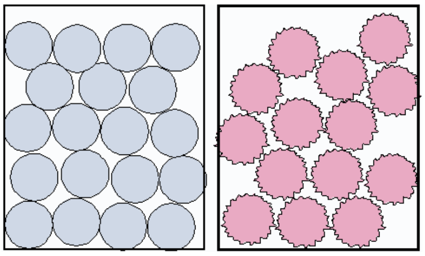


Figure 2. The roughness or coarse surface texture of one particle, when compared to a particle of relatively smooth surface texture, will influence that particles packing efficiency. Note the higher voids content in the rougher surface textured material. (Less material in the container).

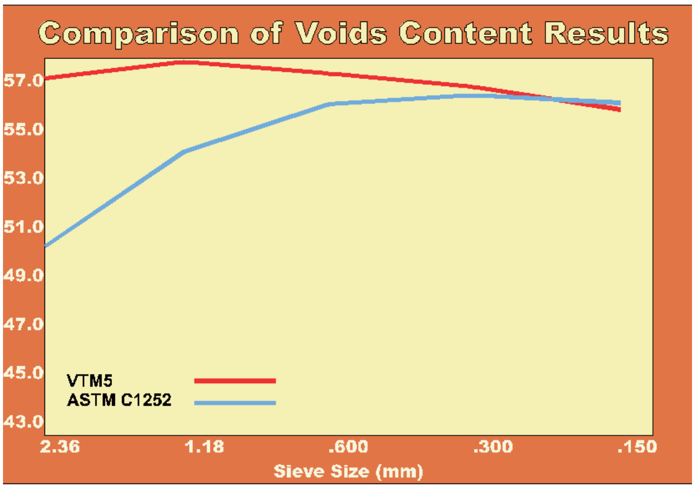
And, as far as the aggregate industry is concerned, we want the concrete to have as much rock in it as possible. We can only achieve this by supplying the best quality aggregates and manufactured sands. This will obviously benefit the concrete producer by lowering the cement requirements for a given grade of concrete, and produce a very durable product that meets the quality standards of strength etc.

As a general rule, aggregates, both coarse and fine, will occupy approximately 80 percent of the concrete volume. Cement will account for approximately 60 percent of the cost of the raw materials. As far as concrete quality is concerned, the golden rule for better quality is to have as low a water cement ratio as possible. This does not necessarily mean to have higher quality concrete you need to put more cement into the concrete. In a lot of cases, the opposite is actually correct.

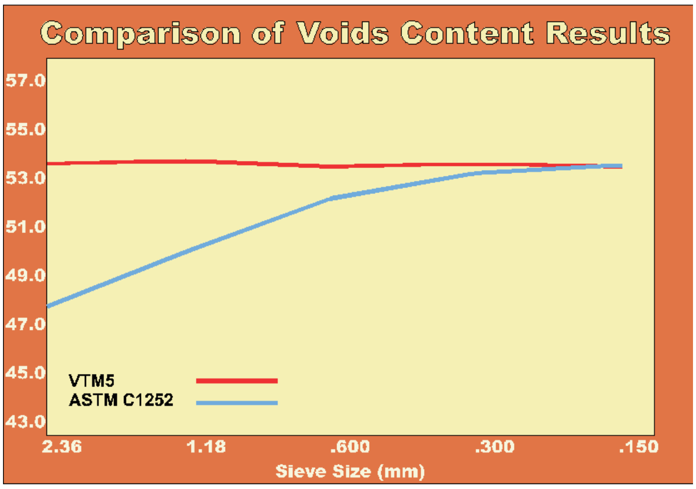
The trend in specifications today is to have minimum and maximum cement contents. The maximum limit on cement content is to limit the heat of hydration (the heat given off during the exothermic reaction that occurs when cement and water are added together), so that detrimental properties of concrete such as shrinkage etc. are given the minimum opportunity to yield problems.

Obviously it makes sense to limit cement content in this fashion. For cement content specifications therefore, we should set a maximum cement content, a nomination of the type of cement to be used, and a range of water/cement ratios. Performance tests for permeability and durability etc. would also become an integral part of the concrete specification.

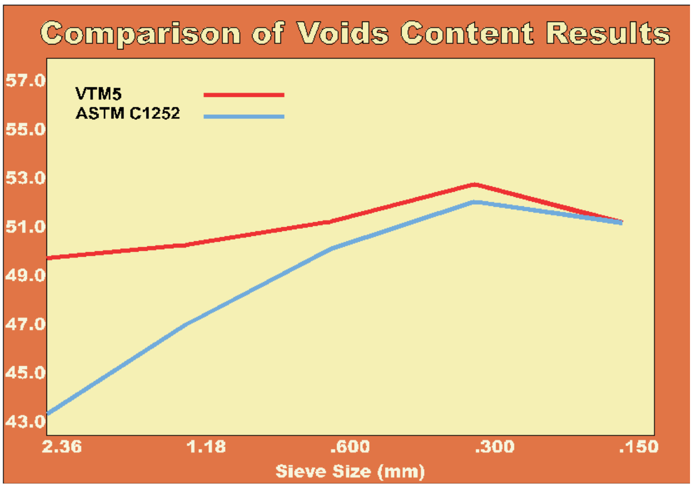
What should we be looking for in a specification for manufactured sands? As discussed in the earlier articles in this series, we should be trying, (with the sands and the coarse aggregates) to minimise the void space between the aggregate and sand particles. This is important as the volume of cement and water paste required to make a



Graph 1. You will note that there is a large variation between the voids results, especially at the coarser end of the sand fraction between these two test methods. VTM5 indicates a slight improvement in shape from the 1.18 mm fraction down, whereas the ASTM C 1252 method indicates a deteriorating particle shape/surface texture as the particle size decreases.



Graph 2. You will note in this test comparison that using the VTM5 apparatus, the particle shape appears to remain constant over the entire size range, whereas the ASTM C 1252 method indicates a deteriorating particle shape/surface texture as the particle size decreases.



Graph 3. In this example, the VTM5 device has detected a deterioration in particle shape across the size range (with the exception of the 150 micron (100 mesh) size), The same trends as usual are evident with the ASTM C 1252 apparatus.

solid volume of concrete is directly proportional to the void spaces around the sand and aggregates.

We know that the volume of cement and water paste required to make a solid volume of concrete will equal the volume of void around the aggregates. We need approximately 3 to 4 percent (of the total volume of concrete) extra paste as well as the volume of the voids in the aggregates to make the concrete plastic and workable.

Our research to date is indicating strongly that there is an optimum volume of minus 75 micron (200 mesh) crushed rock fines in concrete. Early indications are that optimum fines' volume is approximately five to seven percent of the total volume of aggregates. Manufactured sands with higher than traditional fine fractions present are being used in concrete in many places around the world. However, the percentage of sand that is used in a concrete mix is usually dictated to a large extent by the quality of the coarse aggregate. Because this is the case, we will find that the poorer quality aggregates (by poorer quality aggregates I refer to flaky or elongated particles compared to cubical or equidimensional particles) require higher percentages of sand to make the concrete workable. Obviously, if we are using high fines manufactured sands, and also using coarse aggregates of poor quality, the volume of the minus 75 micron (200 mesh) material will rise.

We have experienced concrete manufactured with minus 75 micron (200 mesh) material in excess of eight percent of the total volume of the aggregates and observed a drop off in concrete quality due to an increase in the water demand of the mix.

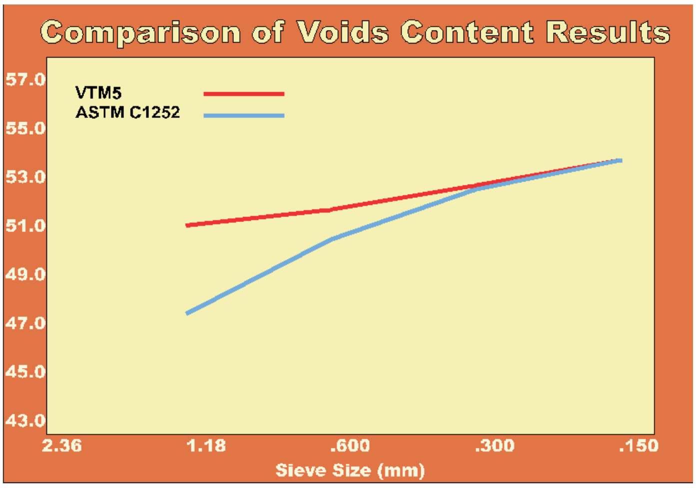
Therefore, using these new manufactured sands in concrete requires us to take a more practical approach to the question of particle size distribution or gradation. If we were to say that the gradation limit on the minus 75 micron (200 mesh) material was to be a function of the entire aggregate gradation, we would put a limit on this material of say, seven percent. By doing this, we allow a new flexibility into what materials we can use in a concrete mix.

For example, assume our coarse aggregate has a high fines content (minus 75 micron material present 2.0 percent), and this aggregate occupied 60 percent of the total sand and aggregate volume. The specification states that the total volume of minus 75 micron material allowed in the concrete aggregates has a ceiling of seven percent. In the coarse aggregate, we have 60 percent of the aggregate fraction having 2.0 percent passing 75 micron. This yields a total volume of minus 75 micron material of 1.2 percent. The remaining 40.0 percent of the aggregate, in this case, the sand, could have a percentage of material passing the 75 micron sieve of: 7.0 percent minus 1.2 percent = 5.8 percent.

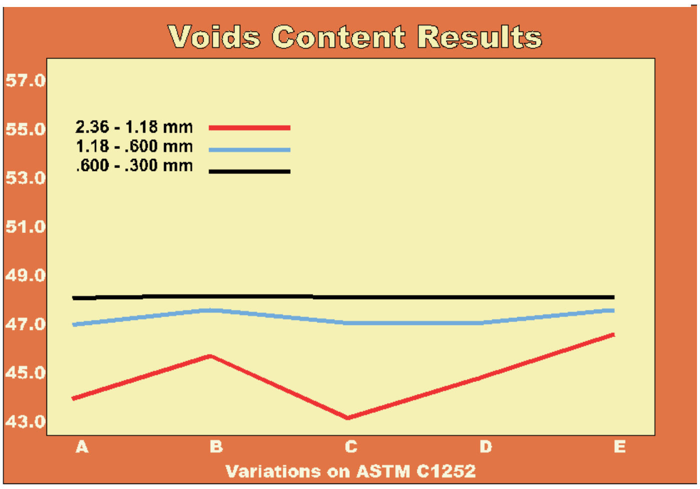
However, this is 5.8 percent of the total aggregate fraction, and the remainder of the material (the sand) occupies only 40 percent of this volume. In this example, the maximum percentage of material passing 75 micron in the sand therefore would be 14.5 percent. (5.8 percent divided by 0.40 = 14.5)

If the coarse aggregate had been washed, the percentage of minus 75 micron material allowable in the sand would be closer to 17.5 percent. (7.0 divided by 0.40 = 17.5 percent)

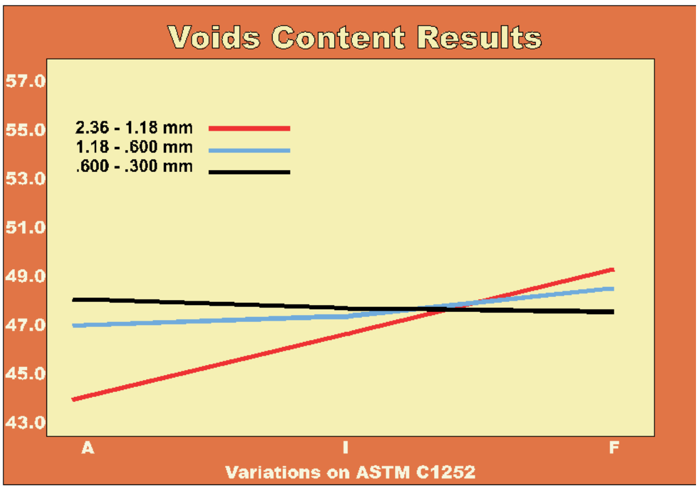
Once again, we are talking in terms of the entire aggregate fraction and the percentage of minus 75 micron material allowable in the combined materials. The sand in the above example may be divided into two materials. For the ease of calculation, we will say



Graph 4. Similar trends as per the sample in graph 3. An interesting point in the 4 graphs is however that the two apparatus yield the same results at the finer end of the particle size distribution.



Graph 5. Illustrated here are the different voids values obtained from exactly the same sample run through the ASTM C 1252 test apparatus with the variations as listed in Table 1. You will note the higher voids contents as the particles get smaller, as well as a dampening of the impact that the modifications to the test method have as the particles approach the 600 micron (30 mesh) size fraction. The height of the drop into the container has an obvious bearing on the test result, as does the larger receiving container.



Graph 6. In this example, the only variable in the test was the orifice size from the flow cone. It is very evident that the size of the discharge orifice of the cone in relation to the particle size passing through it impacts heavily on the test result obtained. (A being the smallest, F being the largest orifice tested.)

50 percent each. If we were using a natural sand with no minus 75 micron material present, this would allow the sand that occupies the remaining 20 percent of the total volume of aggregates to have a minus 75 micron percentage of 29 percent, and so on. But, because we are dealing with the total gradation, rather than an individual material, we get the same net result.

This is a sensible approach to the question of aggregate gradation. Logic will tell you that you can put a small quantity of sand into a batch of concrete that is a long way outside of the current ASTM C-33 sand gradation limits, and it will have very little impact on the quality of the concrete in its plastic or hardened states.

Particle Shape of Fine Aggregate

The importance of particle shape increases as particles get smaller. As you halve the size of a given particle shape, you double the specific surface. (Specific surface is the surface area to volume ratio of a particle).

One way of measuring the specific surface of a sample of aggregate particles is to perform a test to determine the voids content of a sample. The voids test as outlined in ASTM C 1252, is a loose pour test whereby a set mass of material is poured into a receiving container of known volume, and the percentage of air around the sample in the container is calculated.

The test method is broken into three sections. The first, test method A, uses a prescribed gradation so that any material can be compared to another. Hence the adoption of the "45 percent" value in the Superpave specification.

The second section of the specification (Method B) tests single size fractions to look at any shape change between size fractions. This is of particular importance when referring the data back to Murdock's Surface Index (In a previous article in this series). Murdock's Surface index shows the most important size fractions to have good particle shape as being in the 2.36 mm to 600 micron (8 mesh to 30 mesh) range. This part of the specification tests these size fractions.

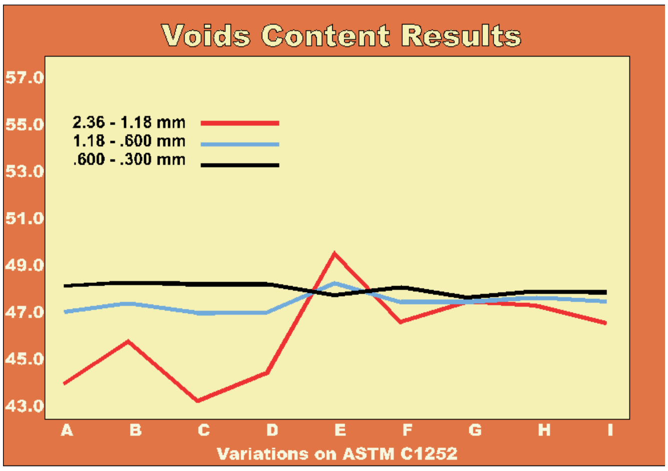
Test method C relates to the materials "as-is", or "in-situ". Little or no shape information can be determined from this method as the reduction in voids content that would be attributed to improved particle shape cannot be separated due to the influence of the sample gradation. For example, a sample with higher fines will typically have a low voids content because of the voids-filling abilities of the fine materials.

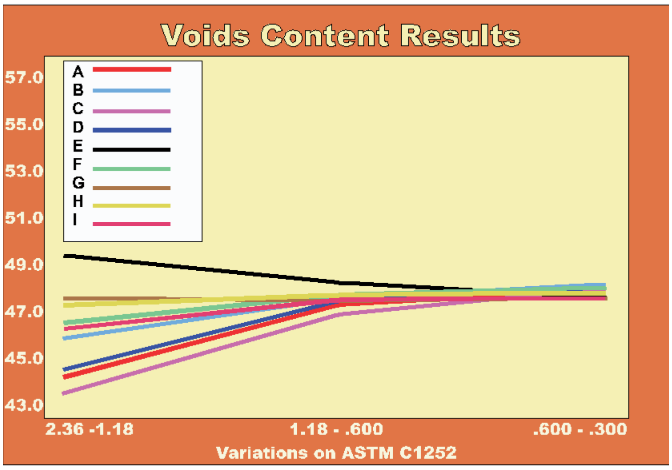
ASTM C 1252, in the Specification title introduces the test as a test for determining the particle shape and surface texture of fine aggregates. The problem with this type of volumetric test is that the test will not distinguish between the two separate characteristics. Obviously, particles can have similar shapes, but differing surface textures. See Figure 1

The particles will have the same or similar volumes, but because one particle has a rougher surface texture, it will not pack so efficiently as the other during the ASTM C 1252 voids test. See Figure 2.

This could explain why some materials that fail the current Superpave ASTM C 1252 45 percent specification perform well in asphalt, and some materials that "pass" the 45 percent do not perform well. The test does not, and cannot, differentiate between shape and surface texture. The question being, what characteristic, or what combination of characteristics, contribute to a materials ability to perform in the field, and is there a correlation to the way those particles yield a voids result in this particular test?

What properties of the fine aggregate, the angularity or the surface texture, have the greatest impact on rutting in asphalt for example, and at what size fraction? Perhaps there is no correlation to these





Graph 7 & 8. In these graphs, it is very plain to see that with all of the configurations that we used to influence the test result, the changes ceased to have an impact at the 600 to 300 micron size fraction. However, at the 2.36 to 1.18 mm size range, every alteration gave us a change in the result. The impact was significantly less for the 1.18 mm to 600 micron fraction. The interesting thing to note with this particular sample is that, even though we have not used another shape measurement test, the particle shapes as observed under a microscope appear to be very similar at the different size fractions.

properties and this test method as these functions of the particle characteristics may change with particle volume and specific surface? We desperately need to be able to split out further the characteristics of surface texture, particle size distribution (perhaps expressed volumetrically), and particle shape/specific surface.

Surface texture plays a more important role in aggregate performance as the particles get smaller. This is simply because, the smaller a particle, the more specific surface (surface area) it has. The higher the surface area, the more surface texture available to influence concrete or asphalt bond or internal friction.

The inability of this test method to split out these two different properties in a fine aggregate is obviously of concern. As part of the ICAR Manufactured Sand Research Project we are investigating test methods that will distinguish between these characteristics and will hopefully lead to some specifications that are based on the measurement of individual properties of the aggregates.

As part of the investigations into manufactured sands, we have been relying on the information that has been forthcoming from the ASTM C 1252 test specification. As time progressed, we became aware of some disturbing trends in the test results obtained.

Of particular concern was the information coming from test method B (Single Size Fraction). A disturbing trend on the materials that we were testing using this test method was that, as the particle became smaller in size, the voids content was always increasing. This was telling us that as the particles in a given sample got smaller, their particle shape got worse, or, their surface texture was becoming rougher. This trend emerged in a very large number of samples, so, in conjunction with US companies, Vulcan Materials Company and Luck Stone Corporation, Svedala Barmac undertook a series of tests to determine the accuracy of the ASTM C 1252 apparatus and test Specification.

Luck Stone Corporation and Vulcan Materials Company tested various samples to try to ascertain the critical parameters for this type of test method. Luck Stone tested the materials with the Virginia Department of Transportation's VTM5 test apparatus and compared results with the same materials through the ASTM C 1252 test apparatus.

Vulcan Materials Company and Svedala Barmac duplicated the test series using the ASTM C 1252 apparatus, with several modifications, as well as the 1960's test method from New Zealand, again modifying the apparatus.

The theory of the test is based on very sound principles. However, as the following data will illustrate the test apparatus, especially ASTM C 1252 needs to be refined.

We decided to look into the test apparatus to try to uncover what was difference in the two test devices, and which device was giving us the best answers. We were assessing the actual particle shapes by examination under a microscope. The VTM5 appeared to be giving a more accurate assessment of particle shape.

We isolated the areas of sample size, sample drop height, orifice size and container size and ran some variations to the test methods. See Table 1.

From the test run (graphs 7 & 8), it was very obvious that relationship between particle size and the 1. drop height of the sample, 2. Size of the receiving container and 3. The orifice size in relation to the particle size being discharged, has to be studied to determine the critical dimensions.

Vulcan Materials and Svedala Barmac are currently working on a new test method to more accurately assess particle shape and surface texture. As part of this study, we are calibrating existing devices and our newly developed apparatus with differing diameters of shot, as well as glass beads.

The next two graphs follow the previous graphs, but instead of using sands, round shot has been substituted. The reason for this is that the shot has a very uniform, spherical shape, has little or no surface texture to speak of, and is singularly sized. Table 2. Describes the various alterations made to the test devices and we can see the influences that these changes make on the test results.

Conclusions on Voids Tests

I am firmly in favour of using a voids test to help determine fine aggregate characteristics of particle shape and surface texture. ASTM C 1252 as it sits today, does not have the ability to yield an answer that can be considered meaningful. Areas of concern for this test are that the discharge orifice is not large enough to take the size of material through it that is allowed under the current specification. The receiving container is also too small and ensures differing degrees of error dependent on the particle size. A single value cannot distinguish between surface texture and particle shape, especially the smaller the particles become.

We have proven that voids type tests, or volumetric tests such as unit weight etc. tell us much about the characteristics of a material. We do need to be able to characterise the properties of shape, texture and size of a particle to be able to accurately design a product that will perform to a given specification.

The information that is derived from this type of test (ASTM C 1252), needs to be analysed in conjunction with another set of tests that would isolate surface texture. Hopefully, with the work that we are undertaking, along with the other research projects currently underway around the world, we will be able to better understand the materials we work with and have more meaningful specifications for both concrete and asphalt. ■