1. Introduction:
Aggregates occupy 65 to 80% of the total volume of concrete and affect the fresh and hardened properties of concrete. In this document, the focus will be placed on the characteristics of the fine aggregate. Out of the total composition of aggregate, the fine aggregate consumes around 20 to 30% percent of the volume (1,2). The shortage of the resources of natural sand, has opened the possibility for the use of manufactured sands. Manufactured sands, in contrast with the natural sand, come from the mechanical crushing of virgin rock, which many times is also used for aggregates of larger size and whose mineralogical composition is well known. In the use of limestone, if the composition of the material is known some deleterious reactions, such as alkali silica reactions, can be avoided or minimized by selecting the appropriate materials.

In the following sections, several different physical characteristics and properties that give a general description and evaluation of typical natural sands (ns) and manufactured sands (ms) will be discussed. Finally, a comparison between manufactured and the natural sands will help out to draw a piece of advice for whenever one of these two materials is to be used.

2. Tests
In order to be able to develop the standard procedures for the evaluation of both sands, the samples were reduced to a representative size as described by ASTM C-702.

2.1. Gradation and Sieve analysis.
The aggregate gradation plays an important role on the fresh concrete properties. The sieve analysis of an aggregate gives a percentage of the material passing through an opening of a certain size. A representative sample tested will give the characteristics of the total amount of the aggregate to be used. There are two types of aggregates, coarse and fine. The fine aggregates will be described as those passing the #4 mesh using ASTM C-136.
From the sieve analysis of the fine aggregate a characteristic curve for the material and a number, known as the fineness modulus, will be obtained as described by ASTM C-33. The gradation curve will show the tendency of the material to be fine, coarse or deficient in a certain particle sizes (1). The fineness modulus is a number represented by the sum of the cumulative percentages retained on the ASTM standard sieves number 4,8,16,30,50 and 100. It is important to mention that the fineness modulus is not unique to a single gradation curve, i.e., the same fineness modulus could be obtained from different gradations. The fineness modulus by itself does not represent a gradation but its value can be used for the concrete mix design as stated in the ACI procedure.

In the following graph, Figure 1, the gradations of the natural sand (NS) and manufactured sand (MS) are shown.

![Gradation According to ASTM C-33](image)

**Figure 1. Gradations of ns and ms according to ASTM C-33**

The particle size distribution of the selected natural sand tends to be in the middle of the fine and coarse limits established by ASTM. The natural sand moves towards the finer limit after the sieve number 50. The manufactured sand remains close to the coarse limit established by ASTM, however, after the #50 sieve the curve is shifted towards the fine...
limit. The amount of fines, percentage passing the #200 sieve, for the manufactured sand is 4.2 percent. ASTM recommends the amount passing the #200 sieve for a concrete pavement application should be between 1 and 3% as long as the material does not contain organic or deleterious impurities. Concrete mixes containing greater than 3% passing the #200 have exhibited diminished wearing resistance (reference??). In the case of manufactured sands, washing the material can reduce the amount of fines. The amount of material passing the 200 sieve has also shown to be inversely proportional to bleeding (3). It is important to mention that ASTM only gives recommendations and the gradations should fit the purpose of the project for which they will be used.

2.2 Aggregate moisture condition
The moisture condition of the fine aggregates change depending on the environment (temperature and humidity) where they are stored. To achieve uniform concrete placement, a stable aggregate moisture content is desired. The oven dry condition, figure 2, is easily obtained by placing the aggregate in an oven, but this is impractical to maintain the material in this condition.

Figure 2 graphically shows the moisture conditions in which an aggregate can be in. To perform the standard test is convenient to bring the material to a saturated surface dry, SSD, condition. To achieve the SSD condition of a fine aggregate, figure 2, the following procedure described in detail in ASTM C-128 should be followed. The material has to be placed in a cone of given dimension and then tamped 25 times. If the shape of the material keeps the shape of the cone than the material still contains surface moisture. If the material shears off slightly than the material has reached an SSD condition. There are two other moisture conditions in which an aggregate can be: air dry and wet. In the air dry condition, the aggregate’s moisture is between the oven dry and SSD condition. In the wet condition, the aggregate’s moisture is beyond the SSD condition.

![Oven dry, Air dry, Saturated Surface dry, Wet](Figure 2. Moisture conditions of an aggregate)

2.3. Bulk specific gravity and absorption capacity.
The bulk specific gravity (BSG) of the NS and the MS was obtained based on the ASTM C-128. The principle by which this parameter is determined is the following. The material is placed in an oven for 24 hours at 100°C to drive off all absorbed moisture and then cooled to room temperature. The material is then submerged in water for 24 hours and then taken to a SSD condition. At this point the weight of a picnometer filled with water should be known and a known weight of the material in SSD condition should then be placed in the picnometer. The weight of the picnometer with the material and the
water should be recorded in order to obtain the value of the volume of water displaced by the material. The weight of the material in SSD condition divided by the volume of water that the material displaces is the BSG in the SSD basis.

The absorption capacity of the material is also obtained from a sample in SSD condition. When the material is in SSD condition a known weight of the sample is placed in the oven for 24 hours at 100°C. The weight difference as a percentage of the dry material is called the absorption capacity and it represents the amount of water required to bring the aggregate from an oven dry state to an SSD condition. The absorption capacity is used to make moisture corrections in order to maintain a consistent water/cement ratio between concrete mixes.

Table 1, shows the values of BSG and absorption capacity of the NS and the MS.

<table>
<thead>
<tr>
<th>Material</th>
<th>BSG (SSD)</th>
<th>BSG (dry)</th>
<th>AC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufactured sand</td>
<td>2.7</td>
<td>2.63</td>
<td>2.59</td>
</tr>
<tr>
<td>Natural sand</td>
<td>2.43</td>
<td>2.38</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Table 1. BSG and absorption capacity according to ASTM C-128

2.3. Bulk density, percentage of voids and particle shape.

The bulk density of the material can be described as the amount of material required to fill a given volume (ASTM C-29). The test is performed in a container of known volume. The container is filled with oven-dried aggregates, in three layers of equal volume. Each layer is rodded 25 times and the top layer is then leveled off. The weight of the dry material divided by the volume of the container is known as the bulk density on a dry basis. The bulk density on a SSD basis is calculated taking into account the absorption capacity of the material as described by ASTM C-128. Table 2 shows the results obtained from the testing of bulk density, in SSD and dry, and the percent of voids.

<table>
<thead>
<tr>
<th>Material</th>
<th>Bulk density dry (kg/m3)</th>
<th>Bulk density SSD (kg/m3)</th>
<th>% Voids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufactured sand</td>
<td>1628</td>
<td>1670</td>
<td>38.1</td>
</tr>
<tr>
<td>Natural sand</td>
<td>1703</td>
<td>1740</td>
<td>28.3</td>
</tr>
</tbody>
</table>

Table 2. Bulk density, dry and SSD, and percentage of voids according to ASTM C-29

The percentage of voids represents the amount volume of unfilled material. If the rock increases in angularity, the void content will also increase (4). In order to prove this point, photographs of different sizes of NS and MS aggregates were taken to analyze their shape in a qualitative way. Figure 3 shows the MS particles retained on the #8 sieve
and figure 4 shows the particles of the natural sand retained on the same sieve number. Figures 5 and 6 show photographs of MS and NS, respectively, retained on the #50 sieve.

![Figure 3. MS retained in sieve #8](image1)
![Figure 4. NS retained in sieve #8](image2)

![Figure 5. MS retained in sieve #50](image3)
![Figure 6. NS retained in sieve #50](image4)

There is a noticeable difference between the particle shape and the surface characteristics of the NS and MS. The NS particles are more rounded and smooth which is why the void content was measured lower than the MS. The MS has a more angular shape and micro-roughness is revealed on the surface of the particles at higher camera resolutions (Figure 5). Another interesting observation was the particles retained on the #50 sieve have greater amounts of dust adhering to their surface. This observation reinforces the findings from the gradation of MS which had greater amounts of fines than the NS.

The increased angularity, fines, and void content will also increase the water demand for a mix to obtain the same slump, but the mechanical properties of the material do not seem to be affected (3).

3. Comments and observations
It is important to consider the gradations recommended by ASTM for fine aggregates. The BSG and absorption capacity are physical properties that are required to make the calculation of a mixture design and can also be used to evaluate the consistency of a
source of materials. The high amount of fines, angular particle shape, and higher void content of the MS will likely result in concrete with higher water demand for the same slump relative to a NS. Since the void content is higher there is a need for more paste to fill the voids. The fresh properties of concrete are certainly affected by the use of a manufactured sand, the hardened properties as mentioned in reference 3, such as flexural and compressive strength do not seem to be greatly affected by the gradation. The effect on the use of MS or NS on early age and long-term volumetric properties, such as shrinkage and creep respectively, are not available and should be studied.

4. References

ASTM Standards:
  C-33, “Standard Specification for Concrete Aggregates”.
  C-702,”Standard Practice for Reducing Samples of Aggregates to a Testing Size”.