

# **CEEN 3320 - Laboratory 4 Aggregates for Base Layers, Portland Cement Concrete & Hot Mix Asphalt**

## **INTRODUCTION**

Civil Engineering projects utilize aggregates for a variety of purposes, including unbound base or foundation layers beneath pavements and buildings, and as component materials for Portland cement concrete (PCC) and hot mix asphalt (HMA). *Natural* aggregates are considered as individual granular materials primarily obtained from natural deposits, i.e., gravel pits, river run deposits or rock quarries. *Manufactured* aggregates generally include individual granular materials derived from the secondary processing of waste materials, i.e. ground granulated slag from steel mills.

Natural aggregates result from the breakdown of igneous, sedimentary or metamorphic rock masses, either by the process of erosion or by physical processes such as mechanical crushing. Aggregates are typically selected for use based on their ability to meet specific project requirements, which may include considerations for size and shape, stability and durability. In some instances, the mineralogy and geologic history of the aggregate may be considered to minimize/eliminate potential problems associated with material compatibilities and/or environmental exposure.

Aggregate properties of interest may include particle shape and texture; soundness and durability; toughness, hardness and abrasion resistance; absorption; specific gravity; bulk unit weight; strength and modulus; gradation and maximum size; alkali-aggregate reactivity; and affinity for asphalt.

## **PARTICLE SHAPE & TEXTURE**

The shape and texture of individual aggregate particles affects their compactability and stability. Rough and angular particles are more difficult to compact than rounded and smooth particles but typically yield an aggregate layer with higher stability. Freshly weathered rock pieces are typically large, rough and angular. As these particles are further weathered, the size decreases and the shape tends toward rounded and smooth. Crushing rock by mechanical means typically produces rough, angular aggregate particles of varying sizes. The shape and surface texture of coarse aggregates particles greater than 4 mm in size can easily be determined by means of visual inspection. The angularity and surface texture of fine aggregates (sand-sized particles) is indirectly measured using the uncompacted voids test (ASTM C1252).

## **SOUNDNESS & DURABILITY**

Soundness and durability refer to the aggregate's ability to withstand weathering in severe exposure conditions. For most applications, the aggregate's ability to withstand wet freezing and thawing without breakdown is of paramount concern. Soundness and durability are commonly measured using alternating soaking and drying cycles with a sodium/magnesium sulfate solution (ASTM C88) or by alternating freeze-thaw cycles with varying solutions (ASTM T103, D4792, C666, C671, C682).

## **TOUGHNESS, HARDNESS & ABRASION RESISTANCE**

Aggregate particles must be tough and hard to resist breakdown when stockpiled, mixed, transported, placed, compacted and/or subjected to loadings. The Los Angeles abrasion test (ASTM C131, C535) is commonly used to evaluate the toughness and abrasion resistance of an aggregate.

## **ABSORPTION**

Most aggregates contain permeable surface pores which may draw in moisture or asphalt binder made available during mixing processes of PCC and HMA, respectively. This absorbed moisture/binder must be accounted for during mix design to ensure adequate moisture/binder remains available for cement hydration (PCC) or for mix stability (HMA). The volume of the permeable surface pores is of interest but the direct measurement of this volume is not practical. Instead, this volume is computed based on the quantity of water necessary to completely fill these voids. Four moisture states are recognized for coarse and fine aggregates: completely dry, saturated – surface dry, moist, and wet. For reporting purposes, these moisture states are represented as moisture contents (MC), computed as the ratio of water weight ( $W_W$ ) to oven dried aggregate weight ( $W_{OD}$ ) and expressed as a percentage value;  $MC = (W_W / W_{OD}) \times 100\%$ .

The completely dried or oven-dried (OD) state is obtained by placing an aggregate sample in a drying oven for a specified period of time, which drives off all free moisture from the aggregate (MC = 0%). The saturated-surface dry (SSD) state is obtained by first soaking the aggregate sample to full saturation and then quickly drying only the free moisture on the surface of the aggregate. When properly done, the aggregate surface will be dry and the permeable pores will be completely saturated. The moisture content of the aggregate in this SSD condition is termed the absorption capacity:

$$MC = AC\% = (W_{SSD} - W_{OD}) / W_{OD} \times 100\%$$

The completely dry and saturated-surface dry states are considered as reference values because these states can be easily repeated in the lab with high repeatability.

Aggregate samples are considered moist when there is some free moisture, but not enough to reach the SSD condition (MC < AC%). Aggregate samples are considered wet when the free moisture content exceeds that necessary to reach SSD conditions (MC > AC%). Depending on the environment (wet, dry, sunny, windy) and storage conditions (covered, open), the moisture content of aggregate stockpiles typically ranges between moist and wet.

## **SPECIFIC GRAVITY**

The weight-volume characteristics are typically not of particular interest for determining aggregate quality unless certain extremes are desired (i.e., light-weight or heavy-weight aggregates). However, during the mix design process it is often necessary to determine the volume of the aggregates based on a known weight. In general terms, the specific gravity (SG) of any material represents that ratio of that material's unit weight ( $\gamma = W/V$ ) to that of water ( $\gamma_w$ ), or  $SG = \gamma / \gamma_w$ . For practical considerations, the unit weight of water ( $\gamma_w$ ) is commonly assumed to be equal to  $62.4 \text{ lb/ft}^3 = 1 \text{ g/cc} = 1000 \text{ kg/m}^3$ .

Because aggregates contain permeable surface pores, three distinct specific gravity values are widely accepted for use in mix design calculations: Bulk, Bulk SSD, and Apparent. The bulk specific gravity ( $SG_{\text{BULK}}$ ) incorporates the aggregate's unit weight computed with the oven-dried aggregate weight ( $W_{\text{OD}}$ ) and the total aggregate volume ( $V_{\text{BULK}}$ ), which includes the combined volume of aggregate solids, surface-permeable pores and internal impermeable pores ( $\gamma_{\text{BULK}} = W_{\text{OD}} / V_{\text{BULK}}$ ;  $GS_{\text{BULK}} = \gamma_{\text{BULK}} / \gamma_w$ ).

The bulk saturated-surface dry specific gravity ( $SG_{\text{BULK-SSD}}$ ) incorporates the aggregate's unit weight calculated with the saturated-surface dry aggregate weight ( $W_{\text{SSD}}$ ) and the total aggregate volume ( $V_{\text{BULK}}$ ). ( $\gamma_{\text{SSD}} = W_{\text{SSD}} / V_{\text{BULK}}$ ;  $GS_{\text{BULK-SSD}} = \gamma_{\text{SSD}} / \gamma_w$ ).

The apparent specific gravity ( $SG_{\text{APP}}$ ) incorporates the aggregate's unit weight using the oven-dried aggregate weight ( $W_{\text{OD}}$ ) and the apparent aggregate volume ( $V_{\text{APP}}$ ), which includes the volume of aggregate solids and internal impermeable pores and excludes the volume of surface-permeable pores. ( $\gamma_{\text{APP}} = W_{\text{OD}} / V_{\text{APP}}$ ;  $GS_{\text{APP}} = \gamma_{\text{APP}} / \gamma_w$ ).

### **BULK UNIT WEIGHT**

The bulk unit weight ( $\gamma_b$ ) is commonly used for PCC mix proportioning and represents the dry weight of compacted coarse aggregate ( $W_{\text{CA}}$ ) occupying a specific bulk volume, which is commonly the internal volume of a cylindrical steel mold ( $V_{\text{MOLD}}$ ). In practice, the dry coarse aggregates are added in layers into the steel mold and compacted by rodding, jiggling or shoveling. Once the mold is completely filled, the weight of dry coarse aggregate is determined and the bulk unit weight is computed as  $\gamma_b = W_{\text{OD}} / V_{\text{MOLD}}$ .

### **STRENGTH & MODULUS**

The strength of an unbound aggregate is commonly determined using repeated triaxial testing and is reported as the resilient modulus,  $M_R$ . The resilient modulus is computed as the ratio of deviatoric stress,  $\sigma_D$ , to recoverable strain,  $\epsilon_r$ . Experience has shown that the computed resilient modulus is dependent on the confining stress,  $\sigma_3$ , used during triaxial testing. In general, as the confining stress increases, the computed  $M_R$  value increases (stress-stiffening material). The resilient modulus test (ASTM T292) utilizes a range of confining and deviatoric stresses to establish the specific trend of strength versus stress for an aggregate, which can be represented as  $M_R = k \theta^n$ . In this expression,  $\theta$  represents the bulk stress state under loading and is computed as  $\theta = \sigma_D + 3\sigma_3$ . As an aggregate's angularity and/or roughness increases, its  $M_R$  value will also increase.

### **GRADATION AND MAXIMUM SIZE**

Mechanical sieve analyses are commonly used to determine the relative size distribution of coarse and fine aggregate particles greater than 0.075 mm (No. 200 sieve). A well graded aggregate, which contains a wide range of particle sizes, generally produces a compacted layer with high unit weight (low voids), good stability, and low permeability. In contrast, a poorly graded aggregate, which contains a limited range of particle sizes, generally produces a compacted layer with low unit weight (high voids), poor stability, and high permeability. Depending on the application, either gradation extreme (or some intermediate value) may be desirable.

The gradation of an aggregate is commonly determined by a dry sieve analysis, which is accomplished using a stack of sieves, one on top of the other, sometimes referred to as a nest of sieves. The sieves are arranged with the sieve having the largest opening (smallest sieve number) on top progressing to the smallest opening size (largest sieve number) on the bottom. Specific sieves used to complete the nest are selected based on the aggregate type being analyzed (i.e., coarse or fine aggregate). Oftentimes a U.S. standard sieve series is used, which indicates that each sieve in the stack has openings approximately 1/2 as large as the sieve immediately above in the stack. A lid is usually placed on top of the sieve stack to prevent spillage and a pan is placed below the bottom sieve to catch any soil particles that pass through the smallest sieve used.

The maximum size of aggregates suitable for use in construction can be related to many factors, such as thickness of constructed layer, distance between forms, clear space between reinforcing steel, etc. Using results of the gradation analysis, the largest aggregate size is generally reported as either the *maximum aggregate size* or the *nominal maximum aggregate size*, depending on the prevailing industry standard. The maximum aggregate size typically is reported as the smallest sieve size for which 100% of the aggregate particles pass. The nominal maximum aggregate size is typically reported as the largest sieve size that retains any of the aggregate particles pass, but generally not more than 10%.

### **ALKALI-AGGREGATE REACTIVITY**

Certain aggregates chemically react with Portland cement, producing expansive reaction products which can cause excessive cracking and/or popouts in the concrete. Aggregates can be screened prior to construction to identify/exclude sources that may be problematic (ASTM C227, C289, C586). When potentially reactive aggregates must be used, low alkali cements and/or other additives (fly ash, silica fume, etc.) may be used to improve performance.

### **AFFINITY FOR ASPHALT**

Aggregates can be classified as hydrophilic (water loving) or hydrophobic (water repelling) based on their pH and net surface charge. Hydrophilic aggregates typically are acidic in nature (low pH) and have a net negative surface charge. These aggregates are prone to stripping, which results in a separation between the aggregate and asphalt coating, reducing the durability of the HMA. Screening tests may be conducted on the HMA to identify/eliminate aggregates that may be prone to stripping and/or to ensure that HMA additives are effective in reducing/eliminating the stripping potential (ASTM D1664, D3625, D1075).

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**OBJECTIVE:** To determine the grain size distribution and weight/volume properties of aggregates used in the making of Portland cement concrete (PCC) and hot mix asphalt (HMA).

**EQUIPMENT:** A set of sieves (1", 3/4", 1/2", 3/8", Nos. 4, 8, 16, 30 50, 100 & 200, and pan), brushes for cleaning sieves, balance, large pans, sieve shaker, mold, glass plate, volumetric flask, tampers and drying fans and ovens.

**PROCEDURES:**

**Part A - Specific Gravity & Absorption of Aggregate**

1. Determine and record the mass of a clean moisture pan. Obtain a 500 gram sample of soaked coarse aggregate and quickly roll it in a large absorbent cloth to remove all visible films of water such that the aggregate is in the SSD condition. Take care to avoid removal of water from surface permeable pores during this operation. Place the SSD coarse aggregate into the pan and record the mass of pan + SSD aggregate to the nearest 0.1g. Immediately after weighing in air, place the SSD sample in the specific gravity sample basket and determine its weight submerged in water. Return the aggregate sample to the moisture pan and place in a drying oven at 110 +/- 5 °C. Remove the moisture pan + aggregate from the oven periodically and check its weight to the nearest 0.1 g. Continue drying and weighing until the aggregate has reached a constant weight, signified by two consecutive weight readings, separated by at least 10 minutes, giving identical weights.
2. Partially fill the specific gravity vessel with D. I. water and record the mass to the nearest 0.1 g on the data sheet in the space provided. Take care to remove any water that may have splashed onto the outside of the vessel before weighing. Determine the mass of a clean moisture pan to the nearest 0.1 g. and record on the data sheet. Remove the fine aggregate test sample from the water and spread it out on a flat, nonabsorbent material. Dry the sample with a gently moving current of warm air until the sample approaches a free-flowing condition. Continue drying and test at frequent intervals with the Cone Test until the sample has reached a saturated surface dry condition.
3. Place approximately 100g of the SSD fine aggregate into the partially filled specific gravity vessel and record the mass of the vessel + aggregate to the nearest 0.1g. Place approx. 50g. of SSD fine aggregate into the moisture pan and record the mass of the pan + aggregate to the nearest 0.1g. Place the moisture pan + sample in a drying oven at 110 +/- 5 °C. Remove the moisture pan from the oven periodically and check its weight to the nearest 0.1 g. Continue drying and weighing until the pan + aggregate has reached a constant weight, signified by two consecutive weight readings, separated by at least 10 minutes, giving identical weights.
5. Fill the specific gravity vessel + SSD fine aggregate to approx. 1/2" from the top and place in the vacuum tank. Apply a vacuum to the sample for approx. 5 minutes to de-air the sample. Attach the conical top to the specific gravity vessel and fill until a meniscus forms at the tip of the conical top. Dry the outside of the vessel completely taking care not to disturb the meniscus. Weigh to the nearest 0.1g and record the mass of the filled vessel + aggregate. Determine and record the water temperature to the nearest 0.1 degree C.

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**Part B - Sieve Analysis of Aggregates**

1. Weigh to the nearest 0.1 g each sieve to be used and record on data sheet. Make sure each sieve is cleaned of loose particles prior to weighing. Note: Never force particles forward through openings in sieves. If particles are imbedded, try to remove them with gentle pressure in a backwards direction.
2. Obtain a representative sample of aggregate and separate the aggregate through a nest of sieves using the mechanical shaker. At least 5 minutes of mechanical shaking is desirable.
4. Weigh each sieve with the aggregate retained to the nearest 0.1 g.

**Part C - Unit Weight of Coarse Aggregate**

1. Weight the empty mold to the nearest 0.1 lb. Fill the mold loosely with coarse aggregate and determine the weight of the mold filled with loose aggregate to the nearest 0.1 lb.
2. Empty the mold and re-fill with coarse aggregate to one-third full and level the surface with your fingers. Rod the layer with 25 strokes of the tamping rod evenly distributed over the surface, but do not allow the rod to strike the bottom of the mold forcibly. Fill the mold two-thirds full and again level and rod as above, but use no more force than is necessary to penetrate the previous layer of aggregate. Finally, fill the mold to overflowing and rod again in the same manner. Level the surface of the mold with your fingers or a steel straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the mold. Determine the weight of the mold filled with dry-rodded aggregate to the nearest 0.1 lb.

**Part D – Coarse Aggregate Angularity, Shape and Texture**

1. Obtain a 500 g sample of coarse aggregate. Examine each piece of aggregate to determine its overall shape, noting if it is rounded, angular or elongated. Separate the aggregates based on shape and determine the percentage of aggregate particles within each category, by number.
2. Re-examine the aggregate particles to see if they contain one or more fractured faces. Separate the aggregates based the following categories: No fractured faces, one fractured face, two more fractured faces. Determine the percentage of aggregate particles within each category, by number.
3. Re-examine the aggregate particle surfaces to see if they are generally smooth or rough in texture. Separate the aggregates based on surface texture and determine the percentage of aggregate particles within each category, by number.

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**Part E – Fine Aggregate Uncompacted Void Content**

1. Thoroughly clean and dry the cylindrical measure and obtain its mass to the nearest 0.1g.
2. Prepare a 190 g standard graded sample of the natural sand based on the following size fractions:  $P_8 - R_{16}$ : 44g;  $P_{16} - R_{30}$ : 57g;  $P_{30} - R_{50}$ : 72 g;  $P_{50} - R_{100}$ : 17g.
3. Thoroughly mix the sample and place in the sample jar positioned above the cylindrical measure, using your finger to block the opening of the funnel. Level the material in the funnel and remove your finger to allow the sample to fall freely into the cylindrical measure.
4. Strike off the excess heaped sand, taking care to avoid vibrations or any disturbance that could cause compaction of the aggregate. After strike-off, the cylinder may be tapped lightly to compact the sample, making it easier to transfer the measure to the balance.
5. Brush adhering grains from the outside of the measure and determine the mass of the cylinder and aggregate to the nearest 0.1g.
6. Recombine the sample and repeat steps 3 - 5 one additional time. Obtain the average result of these two tests.
7. Repeat steps 1 - 6 for the manufactured sand.
8. Repeat steps 1 - 6 for a 35:65 blend of natural and manufactured sand.
9. Repeat steps 1 - 6 for a 65:35 blend of natural and manufactured sand.

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**Report**

**Part A - Specific Gravity & Absorption of Coarse Aggregates**

1. Determine the absorption capacity (AC%) for each aggregate.
2. Determine the Bulk, Bulk SSD, and Apparent specific gravity for each aggregate.
3. Comment on the values obtained above as compared to typical values presented in class.

**Part B - Sieve Analysis of Aggregate**

1. For each aggregate, compute the %Passing each sieve and plot the grain size distribution of the aggregates.
2. Determine the closest size number of the coarse aggregate(s) using Table 5.5 in your textbook. Comment on variances from ASTM C-33 tolerances (if any).

**Part C - Bulk Unit Weight of Coarse Aggregate**

1. Determine the loose and dry rodded unit weights for the coarse aggregates tested.
2. Using the results from Part A, determine the bulk porosity of the coarse aggregate in the dry rodded state of compaction.

**Part D – Coarse Aggregate Angularity, Shape and Texture**

1. Prepare a table summarizing the results for each coarse aggregate and comment of the quality of each coarse aggregate for use in PCC and HMA.

**Part E - Uncompacted Void Content**

1. Determine the loose unit weight for each aggregate sample tested.
2. Determine the uncompacted void content (bulk porosity) of each aggregate tested.
3. Prepare a plot of the uncompacted void content vs % manufactured sand.



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**PART A - SPECIFIC GRAVITY AND ABSORPTION DATA SHEET**

<b>Aggregate Type</b>	<b>Coarse</b>	<b>Fine</b>
Weight of Moisture Pan, g		
Weight of Pan + SSD Coarse Agg in air, g		
Weight of SSD Coarse Agg Submerged, g		
Weight of Pan + SSD Fine Agg, g		
Weight of Partially Filled Vessel, g		
Weight of Partially Filled Vessel + SSD Agg, g		
Weight of Filled Vessel + SSD Agg, g		
Water Temp, C		

**PART C – UNIT WEIGHT OF COARSE AGGREGATE DATA SHEET**

<b>Aggregate Type</b>		
Weight of Mold, lb		
Volume of Mold, ft <sup>3</sup>	0.1	
Mold + Loose Aggregate, lb		
Mold + Dry-Rodded Aggregate, lb		

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**PART D - COARSE AGGRAGATE ANGULARITY, SHAPE & TEXTURE DATA SHEET**

<b>Aggregate Type</b>		
No. of Rounded Particles		
No. of Angular Particles		
No. of Elongated Particles		
No. of Particles with 0 Fractured Faces		
No. of Particles with 1 Fractured Face		
No. of Particles with 2+ Fractured Faces		
No. of Particles with Smooth Surface Texture		
No. of Particles with Rough Surface Texture		

**PART E - UNCOMPACTED VOID CONTENT DATA SHEET**

**Bulk Specific Gravity (Gsb) of Manufactured Sand \_\_\_\_\_**

Aggregate Type	Trial No.	Volume of Measure, cc	Mass of Measure, g	Mass of Measure + Sand, g
Natural Sand	1	100		
	2			
Manufactured Sand	1	100		
	2			
35:65 Blend (Nat:Man)	1	100		
	2			
65:35 Blend (Nat:Man)	1	100		
	2			