The Basics of Aggregates Used in Construction

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December 10, 2013

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Outline

1.) Introduction to aggregates

2.) Aggregate properties
- a.) physical
- b.) chemical
- c.) Durable
- D.) Mechanical

3.) Exploration

4.) Exacting
- a.) Sand & Gravel
- b.) Crushed stone
- C.) Clay Brick
- D.) light weight aggregate

5.) Quarry production
- a.) crushing
- b.) screening and Gradation
- C.) stock piling and segregation prevention

6.) Construction Uses & Specifications
- a.) dirt work
- b.) Asphalt
- C.) Concrete

Q: As engineers why do we need to know about materials?

A: How the materials of a structure are made, constructed, and function in an environment, all effect the performance of the structure throughout its service life. It is also important to understand and even write aggregate specifications.

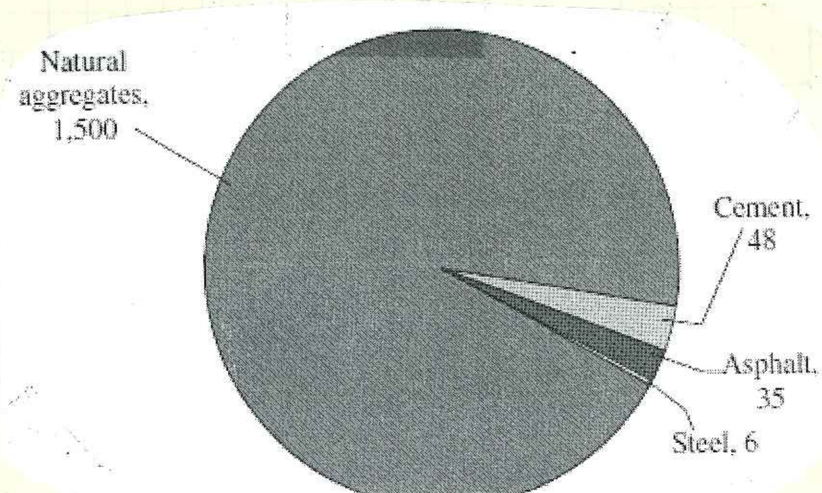
Aggregate

- a general term for crushed stone, sand, and gravel

Why are aggregates important?

- It's used widely in many application: concrete, asphalt, concrete masonry units, clay brick, aggregate base, drainage, and filtration in water treatment plants.
- on average to build:
  - a.) house takes 400 tons of aggregates
  - b.) 4-Lane highway takes 38,000 tons of aggregates
  - c.) 100,000 SF office build will use 5,000 tons of aggregate

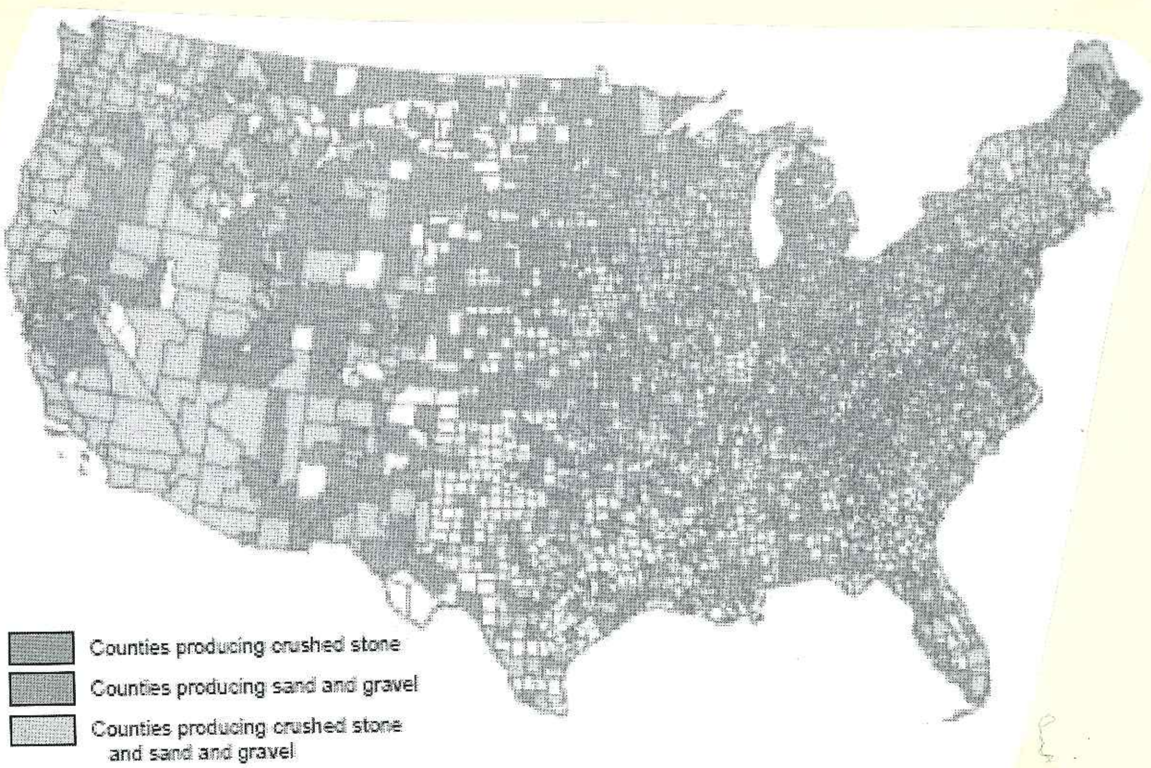
*Estimated amount used in 2006 for National Highway system.



*Note: Data is in million metric tons

Aggregate Industry Statistics (in US)

- about 3 billion tons of aggregate are produced annually
- 40% of the market is sand and gravel
- 60% of the market is crushed stone.
- all 50 states have an aggregate industry that exceeds a combined annual sales of $21 billion
- crushed stone production leaders – Texas, Pennsylvania, Missouri, Florida, and illinois
- sand and gravel production leaders – Texas, California, arizona, Michigan, and washington.
- over 10,000 quarry and sand sources are in U.S.



U.S. counties producing natural aggregates.

The Aggregate Industry effects on U.S.

- For every dollar outputted by the aggregate industry, an additional $1.58 is generated in the national economy.
- 3.3 million pounds of minerals, metals, and fuel will be used on average for each U.S. citizen.

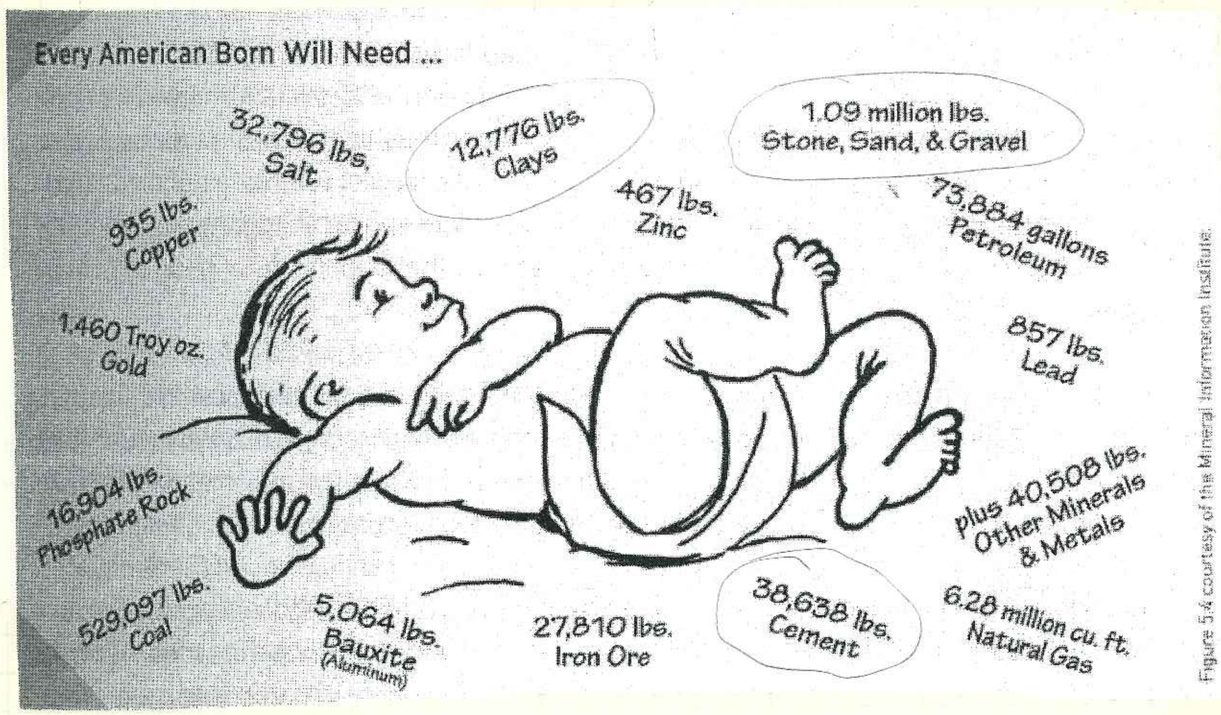


Figure 5.4 courtesy of the Mineral Information Institute.

From the Aggregate hand Book

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Basic Terminology of Aggregates

Crushed stone - composed of Limestone, granite, Traprock, or any other hard, sound rock that is crushed to meet certian industry specifications.

gravel - a coarse rock found typically in a body of water such as a river.

natural sand - a small gradular sized material typically found in water.

coarse aggregate - a general name for stone and gravel. Usually 1.5" - #4

fine aggregate - a material passing the 3/8" sieve size,

manufactured sand - a by-product of the crushed stone process.
- this product passes the 3/8" sieve size

gradation - the description of the size distribution for an aggregate

Quarry - area in which the extracting operations of crushed stone takes place.

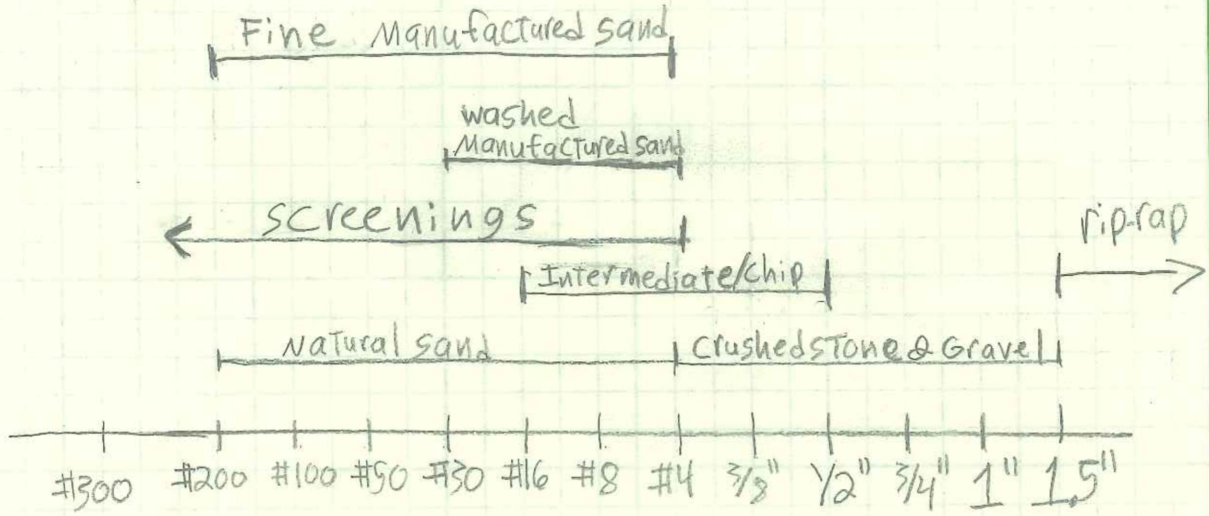
pit - area in which the sand or gravel is extracted.

screening - The left over by-product from the crushed stone process. This isn't washed sieved, or crushed into a product. Used in fine-grading of dirtwork

ASTM - American Society for Testing and Materials.
- More of an acedmic developed specifications and Testing

AASHTO - American Association of State Highway and Transportation Officials
- highway and Transportation Departments develope specifications and Test methods.
- AASHTO standards are many Times adopted by The ASTM

Aggregate Range Sieve size (Typical)



Common name	Description	retained Sieve Range
rip-rap	- large cobble stones used in drainage	≈6" – 36"
crushed stone	- Quarry produced coarse aggregate	2" – #4
crushed gravel	- Found in nature but ran through a crusher	2" – #4
Intermediate	- Quarry produced aggregate - commonly referred to as a chip	1/2" – #16
Natural sand	- small gradular-sized material found in a body of water	#4 – #200
screenings	- The by-product leftover from the crushing process. - commonly called manufactured sand	#4 – dust
Washed Manufactured sand	- washed screenings that typically is a coarser gradation	#4 – #50
Fine Manufactured sand	- washed and recrushed screenings that creates a finer gradation	#4 – #200

Basic Chemical Make-up

3 Classifications of Aggregate

a.) Metamorphic - created from pre-existing rock using Temperature and pressure

Examples: Quartzite, Marble, slate, phyllite, Gneiss, Hornfels

b.) igneous - formed from hardened magma
- has crystalline structure

Example: Granite, Basalt, Rhyolite, Andesite, Pumice, Felsite

c.) sedimentary - formed from physical or chemical degradation of other rocks

Example: Limestone, Dolomite, sandstone, shale, Argillite, chert

*Most gravels and sands are sedimentary

Construction Aggregates

- crushed stone
- river gravel
- river sand
- manufactured sand
- light-weight aggregate

I.) Crushed Stone - rock crushed to meet industry specifications

Most often used in U.S.

- Limestone & Dolomite 69.3%
- Granite 13.6%
- Sandstone & Quartzite 2.9%
- miscellaneous - 14.2%

Stone Type	Geology	Chemical composition
Limestone	sedimentary	calcium carbonate
Dolomite	sedimentary	calcium magnesium carbonate
Granite	Igneous	quartz & alkali feldspars
Quartzite	Metamorphic	Quartz
Sandstone	Sedimentary	Quartz, feldspars, & opal

II.) Manufactured sand - a by-product of the crushed stone industry
- composed of same chemical makeup as stone
- This aggregate has problems finding uses because it is angular and coarse in gradation

III.) light-weight aggregate - a manufactured aggregate
- typically made from shale, slate, clay, perlite, or vermiculite
- largely used in concrete

IV & V). Natural sand & River Gravel - found in water usually
- composed of mainly silica
- River Gravel can be used in decorative concrete
- Natural sand is used in most applications

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Common Minerals in Aggregates

a.) Silica based (SiO_2)

i.) Quartz - very hard, glassy, & colorless silica
- abundant in sand, gravel, & sandstone

ii.) Opal - hydrated silica ($SiO_2 \cdot H_2O$)
- highly Alkali-Reactive

iii.) Chalcedony, Tridymite, & Cristobalite
- Usually Alkali-Reactive

b.) Feldspars
- Alumino-silicate Al_2SiO_5
- most abundant rock forming minerals
- different types: Potassium, sodium, calcium

c.) clays
- silicate material
- large amounts create soft, highly absorptive, and even unstable aggregate

i.) Kaolinites, illites, chlorites
- stable but highly absorptive

ii.) Smectites and montmorillonites
- highly unstable
- Changes volume due to wetting and drying

D.) Carbonate (CO_3)
- Limestone - calcium carbonate
- Dolomite - calcium magnesium carbonate

E.) Sulphate (SO_4) -
- Gypsum ($CaSO_4 \cdot 2(H_2O)$) - used to control flash set
- sodium & magnesium - effects concrete

Petrology

- The study of the origin, composition, distribution, and structure of aggregate

Petrography

- a branch of petrology that focuses on the detailed description of aggregates

Petrographer

- Someone who studies petrography
- Petrographers look at any dealing with aggregates from minerology to aggregate characteristics
- Many different tools and techniques are used to examine aggregates.
- This is a very important profession in the aggregate industry and surrounding industries
- Also, this is a high demand job that causes high salaries
- most petrographers are self-taught
- For more information, "The Petrographer's Handbook"

- ASTM C856 - "Standard Practice for Petrographic Examination of Hardened Concrete"
- FHWA-HRT-04-150 "Petrographic Methods of Examing hardened concrete: A Petrographic Manual."

Introduction of Material Properties

4 types of Material Properties

- **Physical property of a material** is a characteristic that can be physically measured.
- **Chemical property of a material** is a characteristic created through a chemical process.
- **Mechanical property of a material** is a characteristic behavior of a physical property when load is applied.
- **Durability property of a material** is a characteristic of the physical, chemical, and/or mechanical properties being affected by the environment.

Definitions of General Properties

Absorption is the ability of a material to soak-up a liquid.

Specific Gravity is the ratio of the mass of a given volume of aggregates to the mass of an equal volume of water.

Abrasion resistance is the ability of a material to resist being worn away by rubbing and friction.

Porosity is the amount of voids in a material.

Permeability is the ability for a fluid to move within a porous body.

Thermal Volume Change is the change in volume of a material from varying temperatures.

Thermal Conductivity is the ability of a material to transmit heat.

Resistance to Wetting/Drying is the ability of a material to resist wetting and drying cycles.

Freeze/thaw durability is the ability of a material to resist deterioration due to freezing and thawing cycles.

Electrical resistance is the movement of ions inside a material under a fixed current.

Physical Properties of Aggregates

- Properties physically measureable

Transportation of Moisture

absorption – the ability of a material to soak-up a liquid

- when aggregate absorps water, the weight of the aggregate will increase. This effects the batch weight of concrete especially.
  - a) Concrete mix designs assumes the aggregate is at SSD.
  - b.) Asphalt uses the effective SG to account for ABS.

- Coarse – ASTM C127
- Fine – ASTM C128

$$ABS.(\%) = \frac{\text{SSD Wet Wt} - \text{Oven Dry Wt}}{\text{Oven Dry Wt}}$$

- This is dependent of the porosity and permeability of the aggregate.

porosity – the amount of void in the aggregate

permeability – interconnectivity of a pore structure

* For concrete, high absorption aggregate can effect the freeze/thaw durability and a high measurement of air volume.

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Density Properties

unit weight - mass of aggregate per a certain volume
- Typically in lbs/cF or CF/ton

$$\gamma\,(\text{lb/cF}) = \frac{\text{material weight}}{\text{volume occupied by material}}$$

- This can varry due to packing and water content.

Table 3.7 Typical Unit Weights of Sand and Gravel

Aggregates	Pounds per Cubic Foot
Sand and Gravel	
Dry	108
Wet	125
Compacted (with clay)	140 to 150
In situ (dry)	117 to 135
Sand	
Loose dry	100
Slightly damp	120
Wet	130
Wet packed	130

NSSGA's Aggregates Handbook

Stone type	Typical Range (lbs/cF)
Limestone	117-175
Granite	162-172
Quartzite	165-170
Sandstone	119-168
light weight Aggregate	40-70

Specific Gravity (SG) - Ratio comparison of the weight of a material to the weight of water in a volume

- SSD Specific Gravity = $\frac{\text{SSD Wt}}{\text{SSD Wt} - \text{SSD Wt in water}}$

- Bulk Dry Specific Gravity = $\frac{\text{Oven Dry Wt}}{\text{SSD Wt} - \text{SSD Wt in water}}$

- Apparent Specific Gravity = $\frac{\text{Oven Dry Wt}}{\text{Oven Dry Wt} - \text{SSD Wt in water}}$

- Coarse aggregate - AASHTO T85 or ASTM C127
- Fine aggregate - AASHTO T84 or ASTM C128

Source Type	SG
Limestone	1.88 - 2.81
Granite	2.60 - 2.76
Quartzite	2.65 - 2.73
Sandstone	2.44 - 2.61
natural sand	≈ 2.60
river Gravel	≈ 2.60

Manufactured sand close to SG of quarry's stone

lightweight aggregate ≈ 1.25 - 1.55

* Concrete uses SSD specific gravity to design batch weights. Ideally, the aggregate is going to be at SSD condition when making concrete.

* Asphalt uses Bulk dry SG to convert dry weights to to volume occupied in a mixture.

* Apparent SG is used to determine unit weight of stone blocks.

Thermal Properties

Thermal conductivity – ability of a material to transmit heat

Specific heat – the amount of heat per unit mass to raise the temperature by 1°C.

Table 1.5 Thermal Conductivity and Specific Heat for Certain Aggregates[a] in Concrete

Material	70°F C	70°F H	90°F C	90°F H	110°F C	110°F H	130°F C	130°F H
Quartz sand	1.784	0.167	1.779	0.178	1.772	0.190	1.769	0.207
Basalt gravel	1.103	0.183	1.100	0.181	1.099	0.187	1.096	0.200
Dolomite gravel	2.490	0.192	2.446	0.196	2.407	0.204	2.298	0.212
Granite gravel	1.684	0.171	1.678	0.169	1.674	0.175	1.664	0.185
Limestone gravel	2.329	0.179	2.275	0.181	2.231	0.187	2.189	0.196
Quartzite gravel	2.711	0.165	2.689	0.173	2.667	0.181	2.641	0.189
Rhyolite gravel	1.085	0.183	1.092	0.185	1.100	0.191	1.104	0.193

[a] Conductivity (*C*) and specific heat (*H*) are for the mean temperature indicated. Conductivity is in Btu/(ft hr °F). Data are from Final Report, Boulder Canyon Project, Part VII, *Cement and Concrete Investigations*, Bulletin 1: "Thermal Properties of Concrete," Bureau of Reclamation, Denver, Colorado, 1940.

TC Power's properties of fresh concrete

Coefficient of thermal Expansion – the expansion of an aggregate particle due to heat.

Table 1.4 Thermal Coefficients of Expansion of Various Rocks[a] in Concrete

Name of Rock	Number of Specimens	Average Linear Expansion (millionths) per °F	per °C
Granites and rhyolites	27	1.0 to 6.6	1.8 to 11.9
Diorites and andesites	17	2.3 to 5.7	4.1 to 10.3
Gabbros, basalts, diabases	15	2.0 to 5.4	3.6 to 9.7
Sandstones	24	2.4 to 7.7	4.3 to 13.9
Quartzites	20	3.9 to 7.3	7.0 to 13.1
Dolomites	7	3.7 to 4.8	6.7 to 8.6
Limestones	65	0.5 to 6.8	0.9 to 12.2
Siliceous limestones	6	2.0 to 5.5	3.6 to 9.9
Cherts	49	4.1 to 7.3	7.4 to 13.1
Marbles	29	0.6 to 8.9	1.1 to 16.0
Slates and argillites	5	4.5 to 4.8	8.1 to 8.6

[a] Data are from Rhodes and Meilenz, *Proc. ACI*, **42**, 590, 1946. Reproduced by permission American Concrete Institute.

TC Power's properties of fresh concrete

Particle Angularity

- description of the jaggedness of the aggregates surface.
- Typically, this is measured visually.
- Krumbein Scale

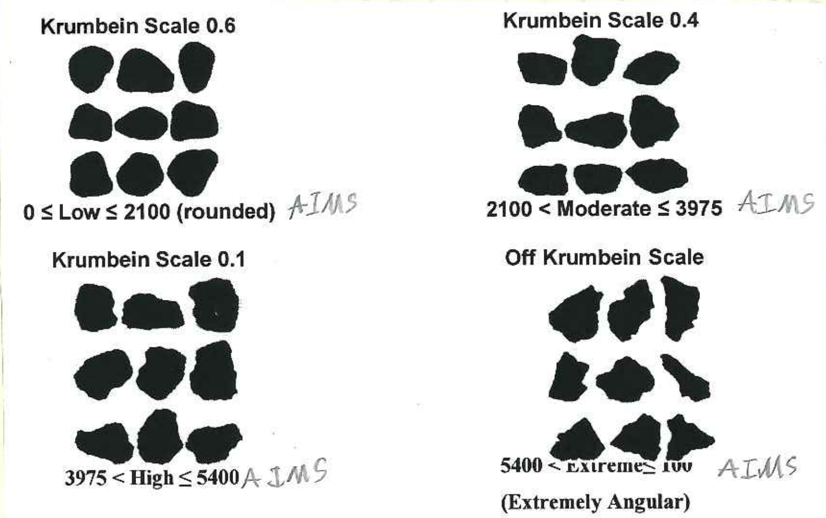


Figure19 - Fine and Coarse Aggregate Angularity Ranges

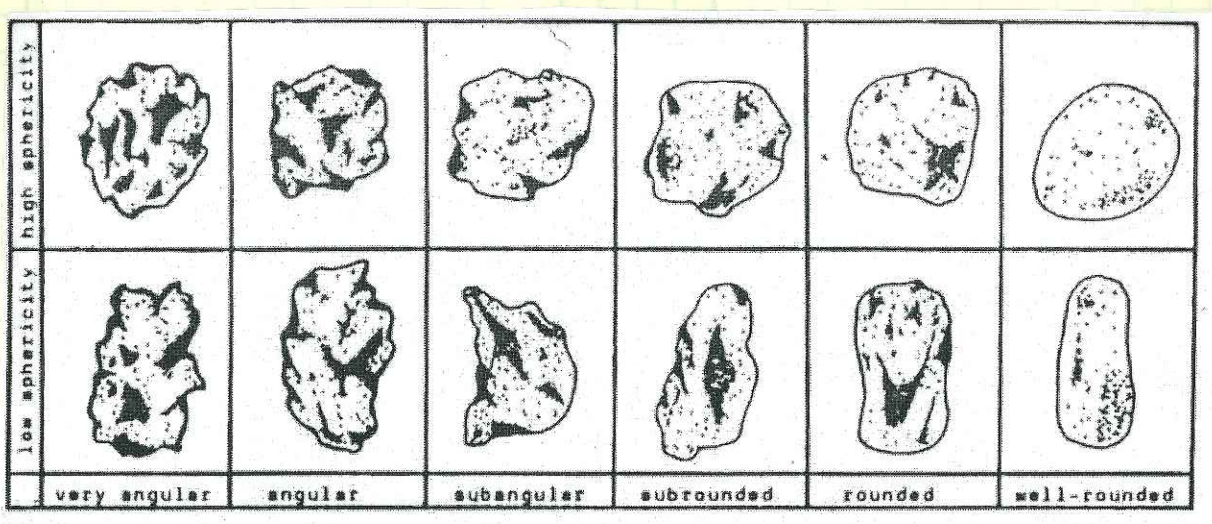


FIG. 9.5(a). Degree of particle roundness for sediment grains with each category showing low and high sphericity (after Tucker 1982).

Fractured Faces in Coarse Aggregate

- After a muckpile is crushed, the amount of fractured faces on a particle can be determined.
- The amount of faces are associated with the aggregate interlock and also angularity.
- Measured by ASTM D5821 or AASHTO TP61

Before Crushing, 0 Faces

After Crushing, 1 Faces

$$P = \frac{\text{amount of fractured Particles}}{\text{Total amount of Particles}} \times 100$$

* amount can be measured in mass or number count of particles.

* P is precent of particles with a certain number of fractured faces. (Round to nearest 1%)

- The Asphalt industry requires the coarse aggregate to have a certain percentage of crushed faces to have aggregate interlock.

Particle Texture

- description of the Aggregates surface roughness.
- This is not the same as angularity
- Also, this is an important measurement for the surface wear of an asphalt surface, since Asphalt doesn't have a surface finish like concrete, the texture of the aggregate becomes very important in the skid resistances of a pavement
- For concrete, an aggregate with low texture can create poor bonding between aggregate and the paste on the surface of the concrete

Texture Roughness Scale

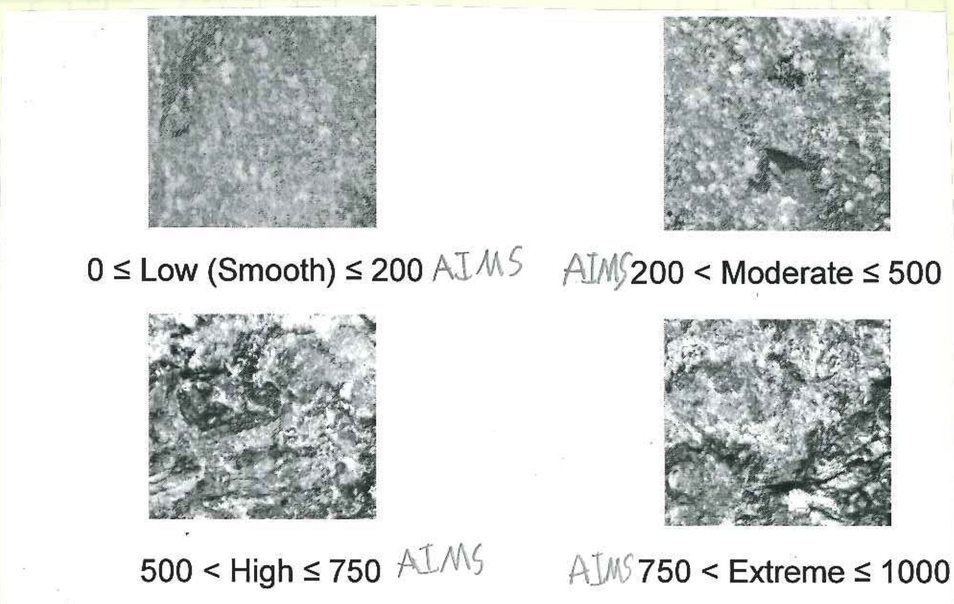


Figure 20 - Coarse Aggregate Texture Range of AIMS II

Particle Shape

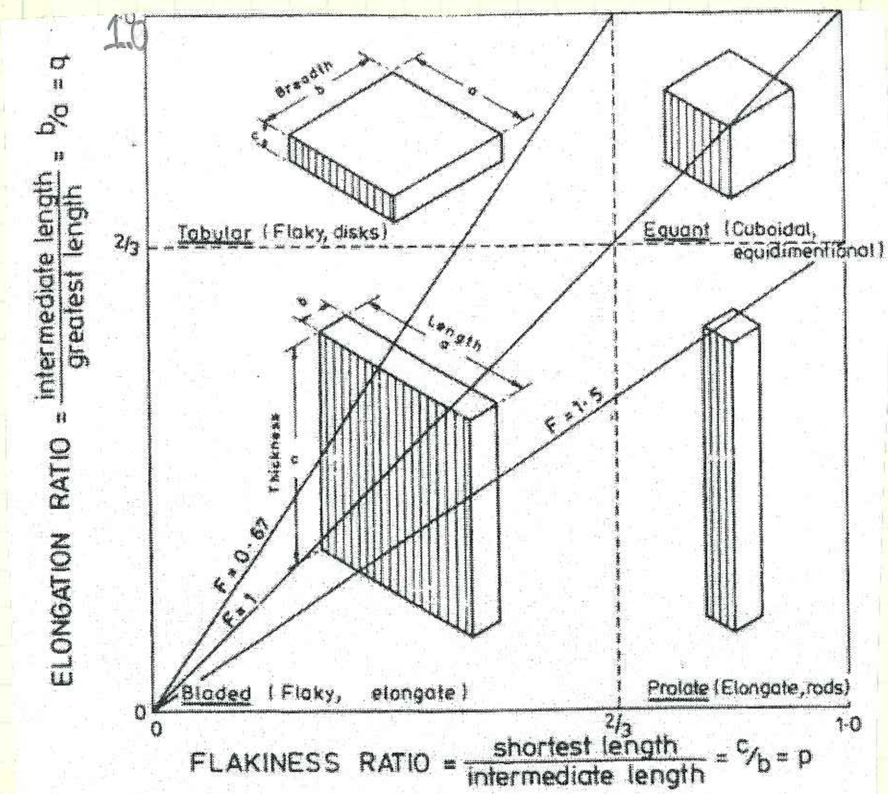
- Describes the deminisons and overall shape of particle
- Can have large impacts on gradation charts, particle packing, aggregate interlock, workability of fresh concrete, and placement of asphalt.
- shape can be described as flat (aka flaky), elongated, flat and elongated, cubical, or spherical.

$$\text{Flatness ratio} = \frac{\text{shortest Length}}{\text{intermediate Length}}$$

$$\text{Elongation ratio} = \frac{\text{intermediate Length}}{\text{longest Length}}$$

$$\text{Flat \& Elongation ratio} = \frac{\text{Shortest Length}}{\text{longest Length}}$$

$$\text{Shape Factor} = \frac{\text{longest Length} \times \text{shortest Length}}{(\text{Intermediate Length})^2}$$



All shapes are prismatic (after Zingg)

Flat, Elongated or Flat and Elongated Particles: Particle flatness and elongation is determined by ASTM Test Method D4791. This method provides three definitions for particle shape as follows:

1. Flat: Particles having a width to thickness ratio greater than a certain value
2. Elongated: Particles having a length to width ratio greater than a certain value
3. Flat and Elongated: Particles having a length to thickness ratio greater than a certain value

The definition of flatness and elongation that is used varies with the application. In most hot mix asphalt applications, only the third definition for flat and elongated particles is used. Other applications, such as railroad ballast, may refer to the total percentage of flat particles and elongated particles as shown in the first and second definitions. Individuals responsible for writing specifications should make it clear which definition should be used.

The test measures individual coarse particles using the proportional caliper shown in Figure 2.4. The proportional caliper is set to the ratio as defined by the specifications, typically 5:1 or 3:1. Depending on what is being measured, flatness, elongation, or flat and elongated, the maximum dimension can be quickly compared to the minimum dimension. Particles that are deemed to be flat, elongated or flat and elongated are separated and either weighed or counted. The percentage of particles determined to be flat, elongated or flat and elongated is expressed as a percentage of total mass or total particle count.

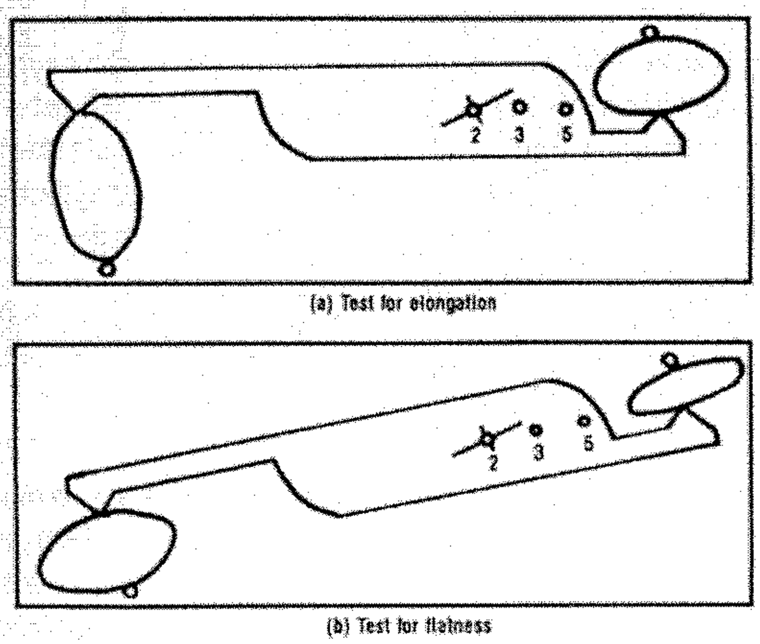


Figure 2.4 Flatness-elongation test caliper

Note: The caliper shown in this figure currently is set for a 2:1 ratio.

Computer Analyzing Systems (CAS)

- many aggregate characteristics can be measured visually using multiple scales and ASTMs.

- To speed up the process and reduce variability, computers have been utilized.

- AIMS II has been a popular CAS.
    - From research conducted at Oklahoma State University, we have found:
        i.) Does a fairly good job at analyzing aggregate characteristics including texture & angularity

        ii.) However, shape measurements of AIMSII doesn't compare well to ASTM4791 for F&E and also visual measurements

Maximum Sieve size Required

- In any application, aggregate can only be so large before the size of the aggregate starts creating problems typically with the transportation, handling, construction process, and/or deminisons of a certain application.

- Maximum size is the smallest sieve size before aggregate becomes retain.
- Nominal maximum size is one sieve size larger than the first sieve to retain more than 10%.
- Nominal - is an engineering term for close-to a certain value.
- Different organizations use the term Nominal maximum size to mean slightly different definitions.

Gradation

- Gradation describes the distribution of aggregate particles
- Almost all aggregate specifications require some type of gradation Limits
- some gradation Limits are very tight while others are extremely broad.
- To measure gradation, a sieve analysis is completed.
- for coarse and fine aggregate, ASTM C136 or AASHTO T27
- for soils (passing #200 sieve size), ASTM D422 or AASHTO T88

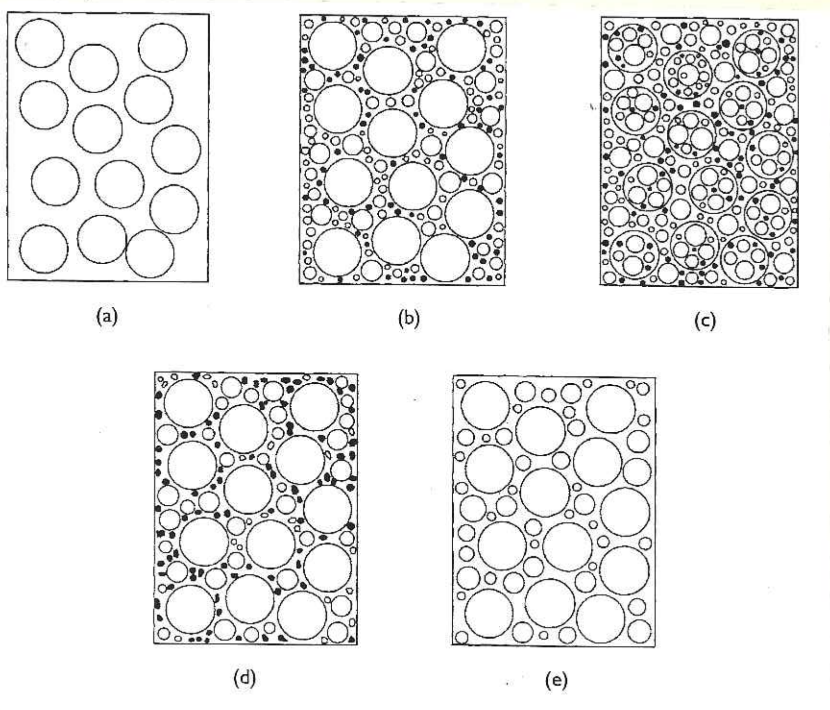


Figure 3.9 Schematic representations of aggregate gradations in an assembly of aggregate particles: (a) uniform size; (b) continuous grading; (c) replacement of small sizes by large sizes; (d) gap-graded aggregate; (e) no-fines grading (from Mindess *et al.*, 2003).

Table 2.3 Selected U.S. Standard Sieve Sizes (Adapted from ASTM E 11)

Sieve Designation		Nominal Sieve
Standard	Alternative	Opening, in.
75 mm	3 in	3
63 mm	2 ½	2.5
50 mm	2	2
37.5 mm	1 ½	1.5
25.0 mm	1	1
19.0 mm	¾	0.75
16.0 mm	⅝	0.625
12.5 mm	½	0.500
9.5 mm	⅜	0.375
6.3 mm	¼	0.250
4.75 mm	No. 4	0.187
3.35 mm	No. 6	0.132
2.36 mm	No. 8	0.0937
2.00 mm	No. 10	0.0787
1.70 mm	No. 12	0.0661
1.18 mm	No. 16	0.0469
850 µm	No. 20	0.0331
600 µm	No. 30	0.0234
425 µm	No. 40	0.0165
300 µm	No. 50	0.0117
250 µm	No. 60	0.0098
212 µm	No. 70	0.0083
150 µm	No. 100	0.0059
125 µm	No. 120	0.0049
106 µm	No. 140	0.0041
75 µm	No. 200	0.0029
53 µm	No. 270	0.0021
45 µm	No. 325	0.0017
38 µm	No. 400	0.0015

Gradation Basics Evaluation Ideas

- People tend to classify gradation into:

  a.) well-graded - a gradation that is distributed widely through many sieve sizes

  b.) gap-graded - a gradation that is distributed with lacking amounts on mid-range of sieve sizes

  c.) open-graded - a gradation containing only a few sieve sizes

  D.) Uniformly-graded - a gradation that mainly contains a single sieve size

  * These 4 terms for classifying gradations are broad and really just describe the overall distribution of the entire gradation

- Individual sieve sizes can be described as retaining small, mid, and large amounts. However, This is also a broad statement that really can only be determined by the application

- Also, people tend to classify a combined gradation into groups. This can be as broad as coarse aggregate (#4 & up) and fine aggregate (below #4). It can also be classified according to the behave of sieve size groups such as Fine, Intermidate, and coarse.

  * Again, this is a broad classifications. More research needs to be conducted and futher detailed terminology

Gradation Techniques

- Many design techniques have been developed over the years to assist in perdicting the performance of the aggregate gradation for a certain application.

- Graphically, a gradation can be displayed in the cumulative percent passing, cumulative percent retained, and individual percent retained charts.

- Understanding the distribution of a gradation for a certain application is extremely important. It can quickly point out possible issues. However, this is many times an art that comes with lots of experience.

- Gradation can be either a single stockpile of aggregate or a combined gradation of multiple stockpiles blended together such as a concrete or asphalt mixture

- One of the very first methods for proportioning gradation was developed by thompson and Fuller in 1907. They claimed using their graphical method created the optimal gradation for concrete. However, this can be too harsh for a concrete mixture but much more applicable for Asphalt.

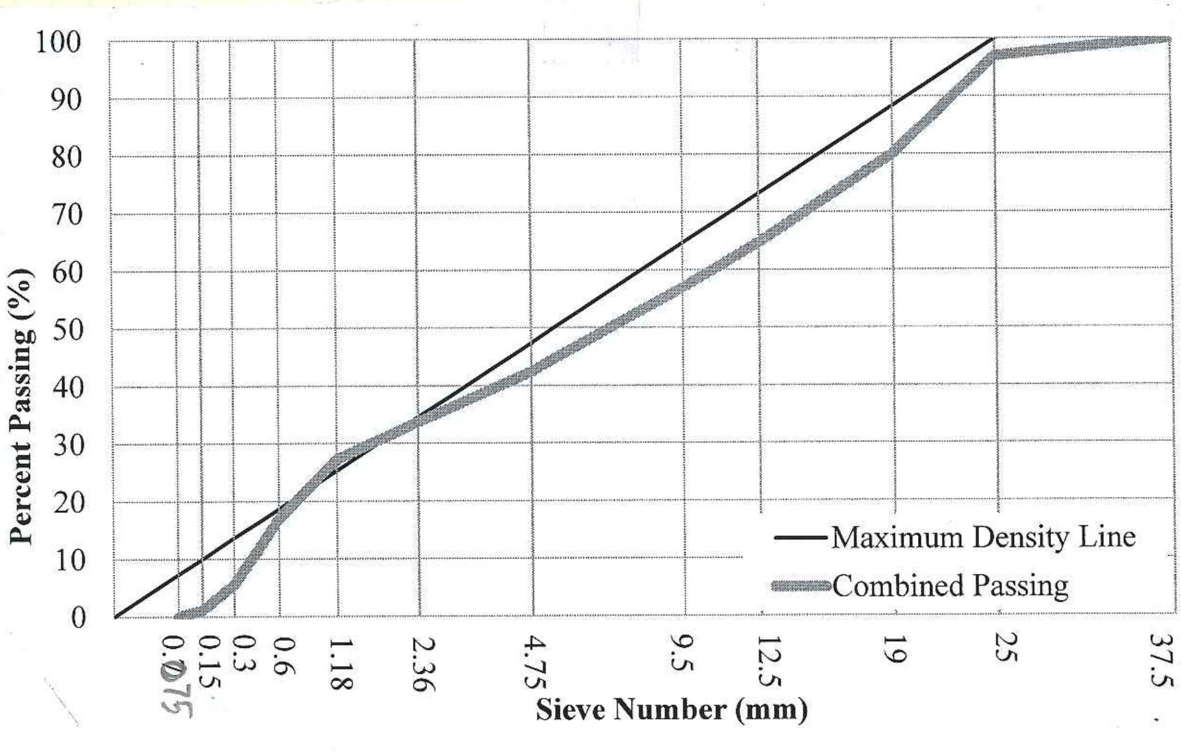
- Another gradation technique is the individual percent retained chart. This method quickly points out high and low sieve sizes

Cumulative Percent Passing

- This is the traditional graphical method for displaying a gradation

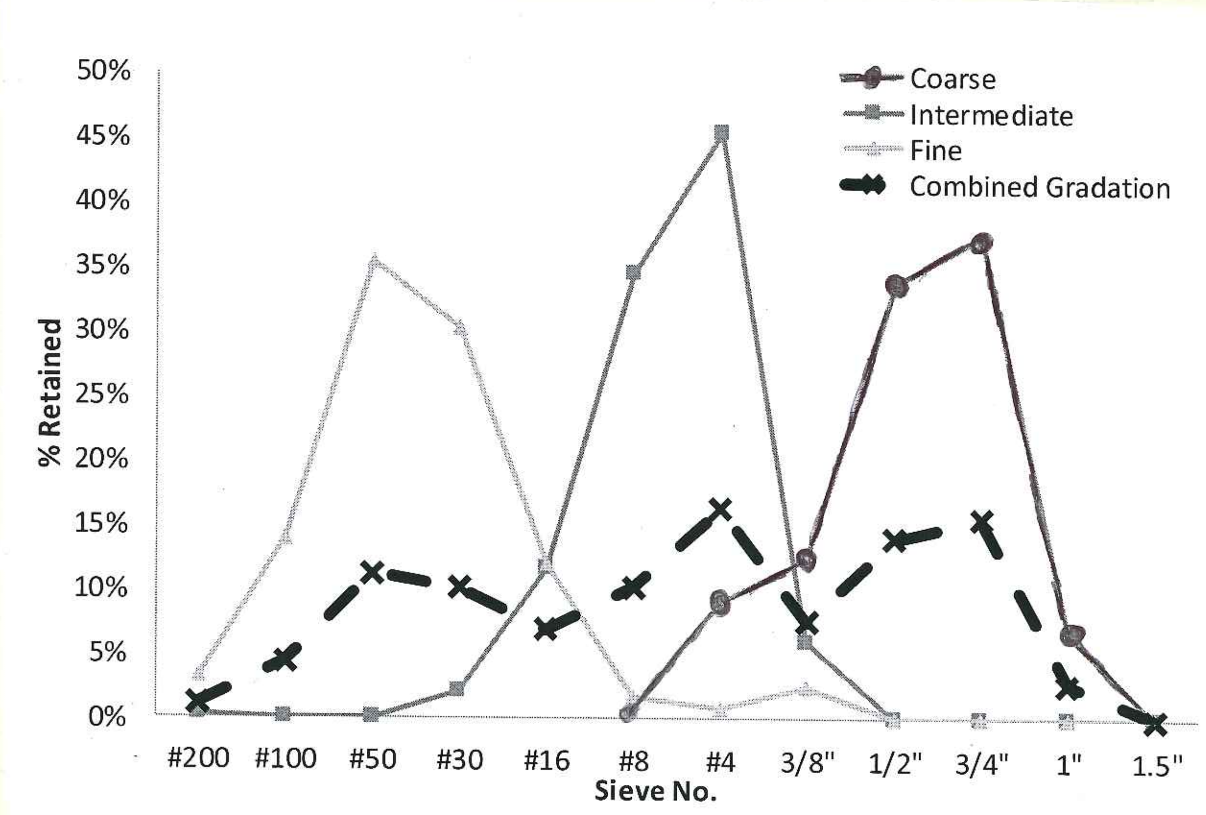
- The basic concept behind this is to understand the "flow" of the gradation as a whole,
- However, determining a lacking or excessive amount on a sieve size can be somewhat difficult.

- The traditional Cumulative Percent Passing is typically plotted with each sieve size raised to the power 45. This allows a gradation to follow more of a straight line. Different details have been drawn to help evaluate the gradation.
  1.) Maximum density line - From the orgin to the Nominal maximum sieve size
  2.) Boundary Lines - From orgin to the sieve size adjacent to the NM size.
  3.) Control Points - various sieve sizes are allowed a certain range.

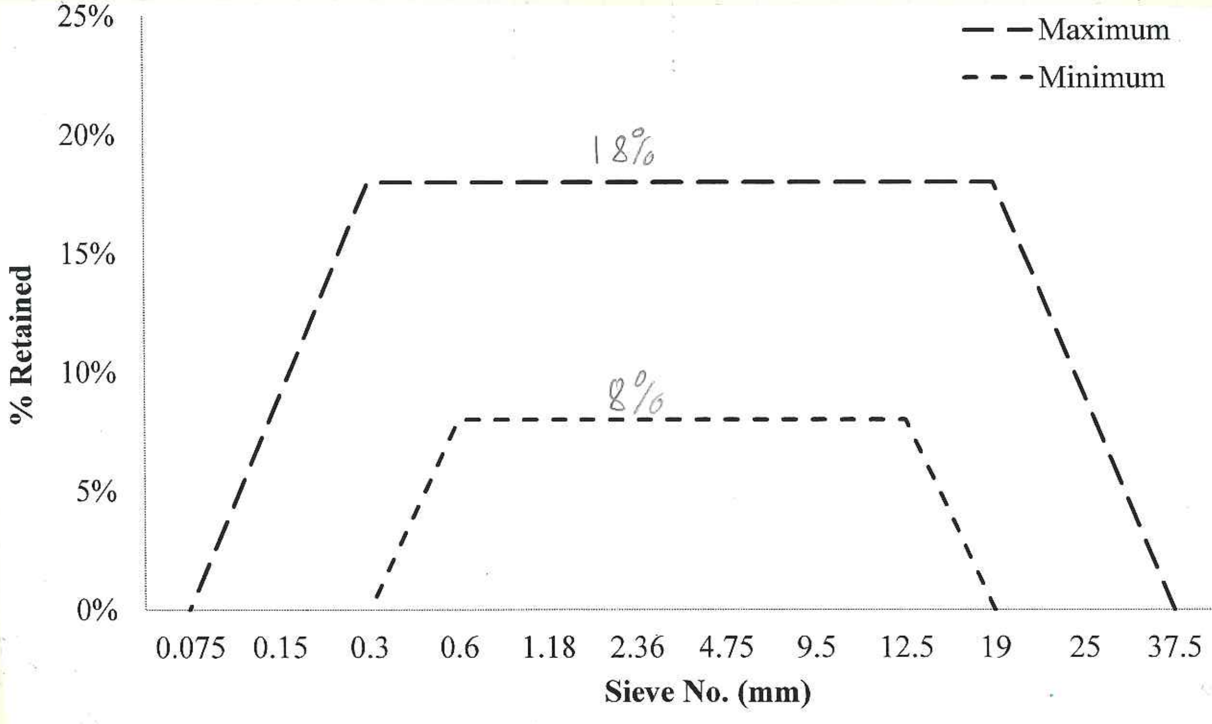


Individual Percent Retained

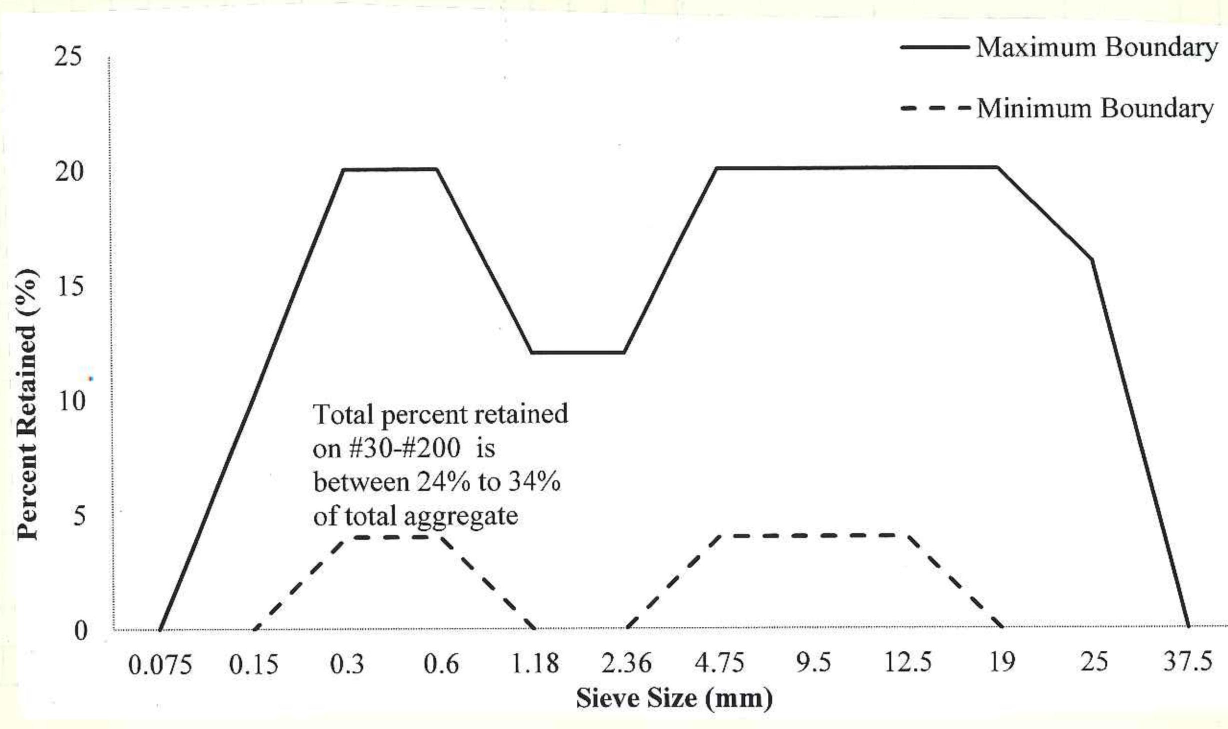
- This is a very basic tool used to evaluate excessive or lacking amounts on sieve sizes
- The concrete industry in recent years has started using this graph to determine potential problematic areas
- Also, the chart can quickly show the gradation as well, gap, open, or uniformly-graded.
- This graphical Method displays shows the combined gradation out of 100%, or in other calculus words the area under the curve is 100%.
- The graph below shows a coarse, intermedate and fine gradation being combined into a single combined gradation.



- Below is the boundary limits for Traditional Individual Percent Retained chart



- Others have suggested different Limits such as 22% maximum and 5% minimum.
- At Oklahoma State, we are developing limits for different application of concrete. Below is limits for Concrete pavements for slip formed pavers.



Effects of Shape on a Sieve Analysis

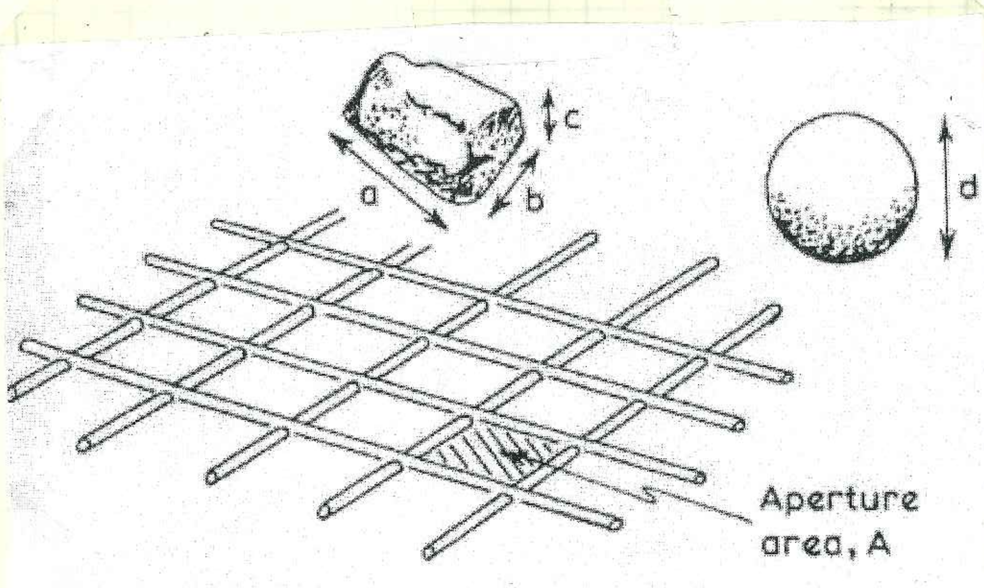
- Many different techniques have been developed for determining performance of a gradation for specific applications

- However, a sieve analysis doesn't take into account irregular shapes.

- ASTM D4791 can evalute flat and elongated shapes.

- Futhermore, many do not understand the impacts of shape on the gradation.

- A common shape specification is the Coarse aggregate shall be limited to 10% of flat and/or elongation particles on the 1:5 ratio according to ASTM D 4791.
  * This is actually very broad specification that allows extremely flat and/or elongated shapes to be produced.



Aggregate Blending To Meet a Gradation

- Multiple stockpiles are blended together into a single combine gradation.
- This is very common for Asphalt and concrete.
- A single sand pile and a single rock pile are the minimum stockpiles used.
- Sand may be very fine-graded and require a coarser sand such as a manufactured sand to meet the requirements.
- Rock tends to segregate in stockpiles with a large distribution of sieve sizes. To meet a required gradation with a large sieve size distribution, two or more stockpiles can be blended together.
- Normally, the blending process happens in the mixing stage when all asphalt or concrete ingredients are mixed together

Basic Equation for a given sieve size

$$P = A \cdot a + B \cdot b + C \cdot c + D \cdot d \ldots$$

P = Percentage of the combined aggregate in a given sieve size

A, B, C, D,... = Percentage of a sieve size in stockpile A, B, C...

a, b, c, d,... = Proportion ratio of stockpile A, B, C,... to the combined gradation of 100.

$* \; a + b + c + \ldots = 1$

* This can be calculated for individual retained or percent passing

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

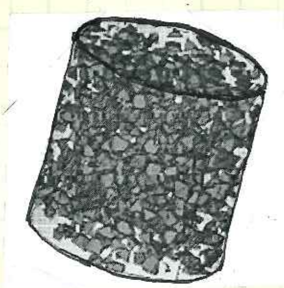
Packing of Aggregates

- The basic concept behind packing is measuring the combined aggregate gradation to fill a volume

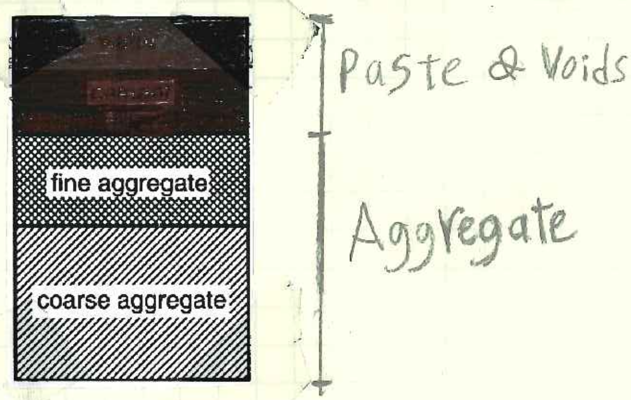
- Typically, packing models are very complex and difficult to apply.

- Most packing models measure the ability of aggregate to take up space by the amount of voids.

- People have used the voids to proportion the aggregate.



Specimen



Volume

- The voids can be measured by dry-rodded unit weight. ASTM C29 or AASHTO T119

- Factors impacting the packing:
  - Shape
  - Size (aka gradation)

- However, a very limited amount of knowledge has been presented on the void content and performance in an application.

Aggregate Packing Methods

- ACI 211 Method for concrete and the Bailey Method for asphalt, each use dry-rodded unit weights to proportion aggregate.
    - i.) Both methods don't always work well
    - ii.) This creates an iterative process for porportioning initially
    - iii.) Many still only use gradation techniques for determining fresh property preformance

Aggregate Packing Models

- Again, these are complex models that are not used largely in the field.
- Some of the more popular methods were derived from TC Power's Book, "The Properperties of fresh concrete."
    - a.) Toufar - use mono size particles to determine void content.
        - This is used by European Mixture Design method for concrete
    - b.) Dewar - uses particle interference of different sizes to model voids
        - For more information, read Dewar's Book.
    - c.) Larrard - Multiple variations of this model have formed.
        - It is derrivated from Deword and T.C. Powers.
        - looks at the wall effects of the container and vibration impacts

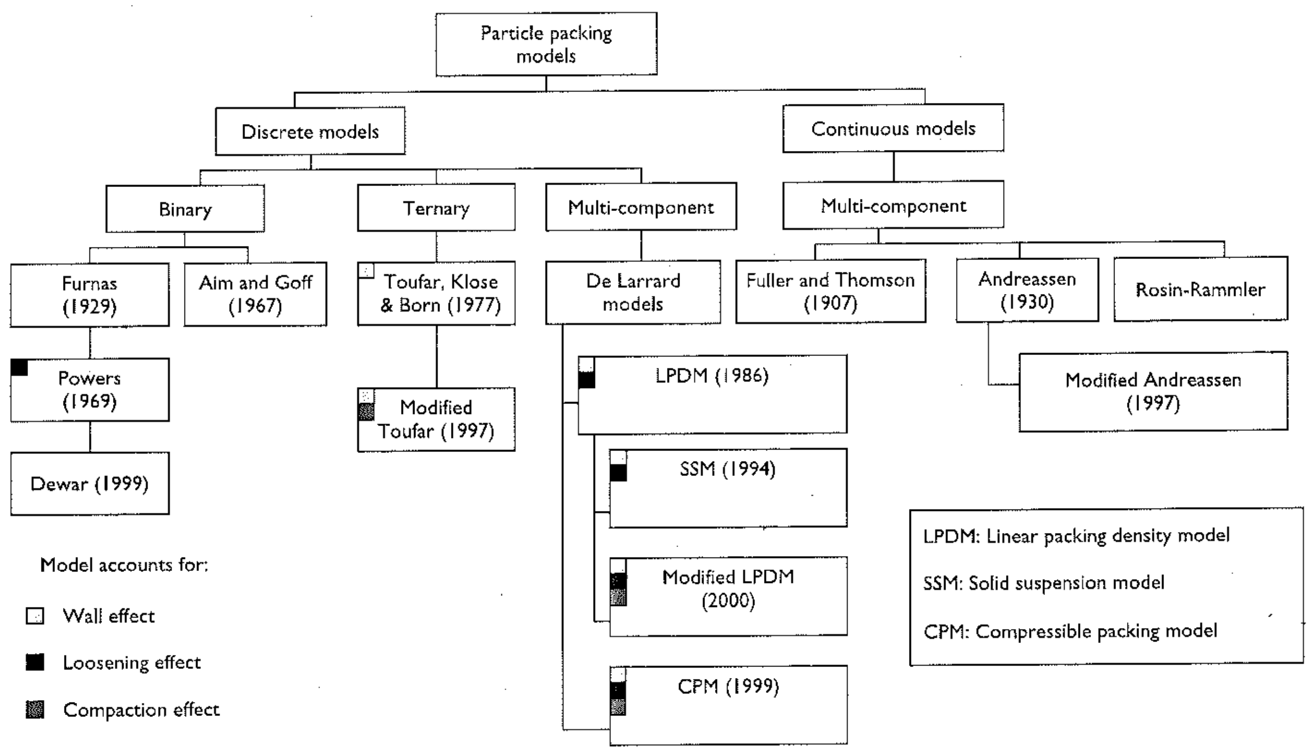


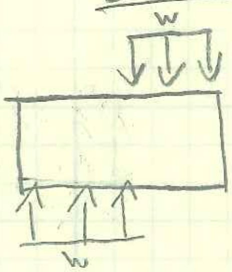
Figure 3.16 Particle packing models (adapted from Kumar V and Santhanam, 2003).

Mechanical Properties of Aggregates

- characteristic behavior when various loads are applied

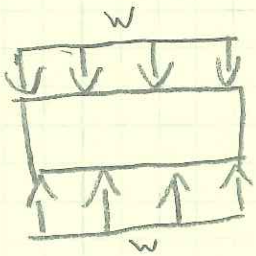
Particle strength

Shear - Ability of a material to resist sliding



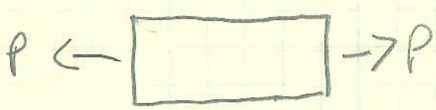
- Typical values
  - Limestone & Sandstone 0.3-3.8 ksi
  - Granite 3.7-4.8 ksi

compression - ability of a material to resist pushing



- Typical values
  - Limestone 2.6-28 ksi
  - Quartzite 16-45 ksi
  - Granite 5-67 ksi
  - Sandstone 5-20 ksi

tensile - ability of a material to resist pulling

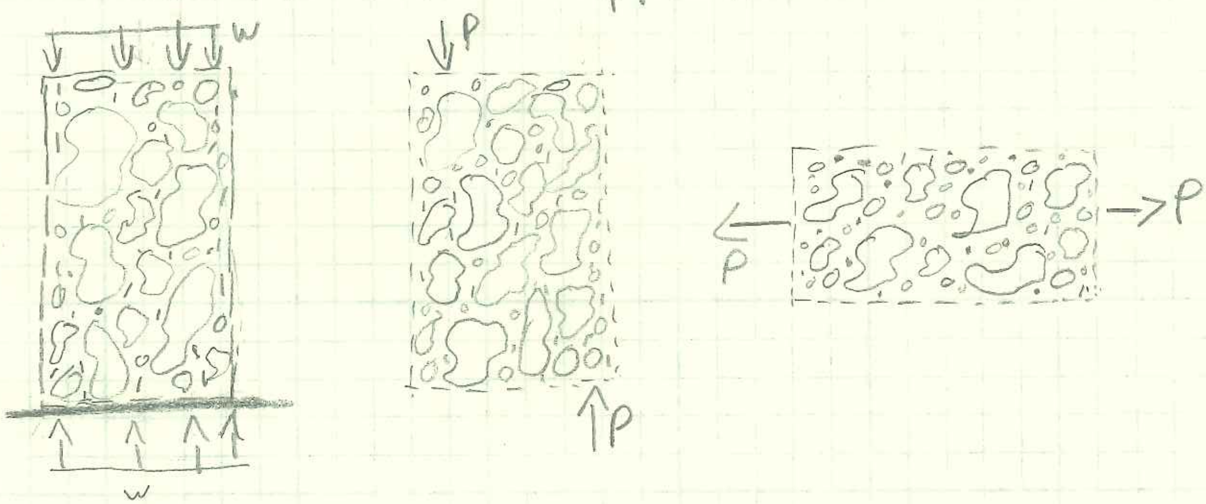


- Typical values
  - Limestone & Granite 427-850 psi
  - Sandstone 140-430 psi

Aggregate Interaction

- Particles of aggregate interact with each other to produce overall strengths and friction angle of the overall aggregate.

- This applies to aggregate base, asphalt and most concrete applications.



Compression   Shear   Tension

- The tension of the system is weak

- the compression of the system is highly dependent on the compressive strength of the aggregate

- The shear strength is highly dependent on the friction angle.

California Bearing Ratio (CBR)

- Empirical test developed by Califorina DOT to evaluate the aggregate base, subgrade, & soil.
- Test indicates the punching shear strength
- A low CBR value means a weak aggregate base
- AASHTO T-193 or ASTM D 1883

Steps

1.) sample is compacted into a 6" dia X 4.6" tall mold and soaked for 96 hrs
2.) Specimen is penetrated at loading rate of 0.05 inches per minutes.
3.) calculate CBR value

$$CBR = \frac{\text{piston pressure}}{\text{standard reference value}} \times 100$$

- Many base coarse aggregates specification require atleast 80%.

- Factors Influencing CBR
  a.) maximum size
  b.) well-distributed gradation
  c.) well-shaped aggregate
  D.) Plastic Index.

- If a subgrade has a low CBR value the soil can be removed and replaced with a higher CBR valued coarse aggregate base

CBR Field Test

- Most suitable for evaluating subgrade
- ASTM D4429 outlines the test
- 3 criteria for CBR Field Test
    1) 80% or greater saturation of soil
    2.) Material is coarse grained and cohesionless
    3.) soil has not been modified in 2 yrs
- Typical Performance Range of CBR Test

CBR Value	Performance
+15	Excellent
10-14	good
6-9	fair
5-0	Poor

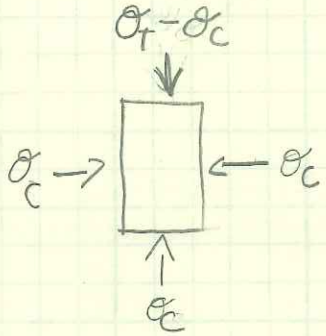
Resistane R-value – measures resistance to deformation

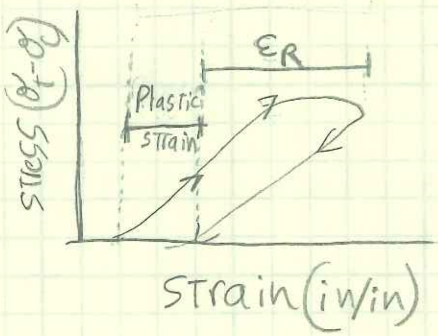
- Another test developed by Califoring DOT is the Hveem Stabilometer test AASHTO T-190 and ASTM D-2844. This test calculates the R-value.
- R-values range from 0 (for water) to 100 (for rigid material)
- Typical R-values for aggregate range from:
    a.) 50-60 for more gap-graded and high fines.
    b.) 80-90 for densely well-graded crushed stone
- Western part of U.S. DOTS use this.

Resilient Modulus (M_R)

- measurement of stiffness and elastic response of loading
- important especially for Asphalt pavement design.

$$M_R = \frac{\text{Applied dynamic deviator stress}}{\text{resilient (recoverable) strain}} = \frac{\sigma_T - \sigma_C}{\varepsilon_R}$$





σ_T = Total stress
σ_C = confine stress
ε_R = resilient strain

- AASHTO T-307 Standard test Method for M_R,
  - However, this is not preformed very often due to the complexness of the test
- A second way to find M_r is by equations using CBR or R-value.

$M_r = 2555\ CBR^{0.64}$, CBr = California Bearing ratio (%)

or

$M_r = 1155 + 555R$, R = R-value from AASHTO T190

- A third way to find M_r is to estimate it through AASHTO and unified soil Classification systems.

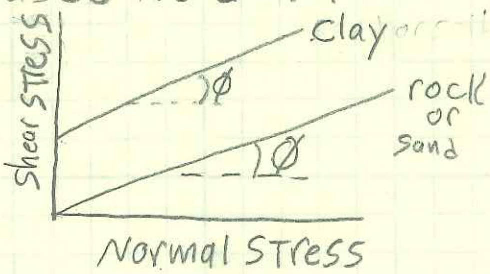
table 13.5

Friction Angle (ø)

- used to measure the shear strength of aggregate for backfill of retaining walls
- This is determined on soils or sand usually using either direct shear test (ASTM D3080 or AASHTO T236) or Triaxial shear test.

- The strength of a granular material depends on its compaction, stress-state, surface texture and angularity of particles, and gradation.

- Typically, the Mohr-Coulomb failure equation is used to determine the friction angle



- If a friction angle value can not be attained for a cohesionless material such as crushed stone, many will use a friction angle of 30°

- A Typical Range of ø is 20 – 45.
  - * above 35 is more of compacted aggregate
  - * below 25 is a loose clay or sand

ABRASION

- Resistance to wear: ability of aggregate surface to resist polishing due to rubbing and friction producing forces of live loads such as wheels of car, foot traffic, or even particle collision.

- Measured by L.A Degradation Test. ASTM C131 or AASHTO T-96 (for 1.5" or larger, ASTM C535)

Basic Steps

1.) wash, oven dry, and sieve aggregate into sizes
2.) Using the specified gradation limits in this standard test, aggregate is blended together
3.) Aggregate blend and steel balls are placed into container
4.) Contents are rotated in machine for 500 revolutions and then sieved over #12 sieve.
5.) calculate:

$$LOSS = \left(\frac{Mass_{orginal} - Mass_{final}}{Mass_{orginal}} \right) \times 100$$

Values:

- No set value range for preformance.
- Most state DOTs specify 25 to 55%
- Max. of ≈40% is typical
- Higher the % loss, the softer the rock is

Rock Type	LA % Loss by Wt
Limestone	19-30%
Dolomite	18-30%
Quartzite	20-35%
Granite	27-49%
Sandstone	≈60%

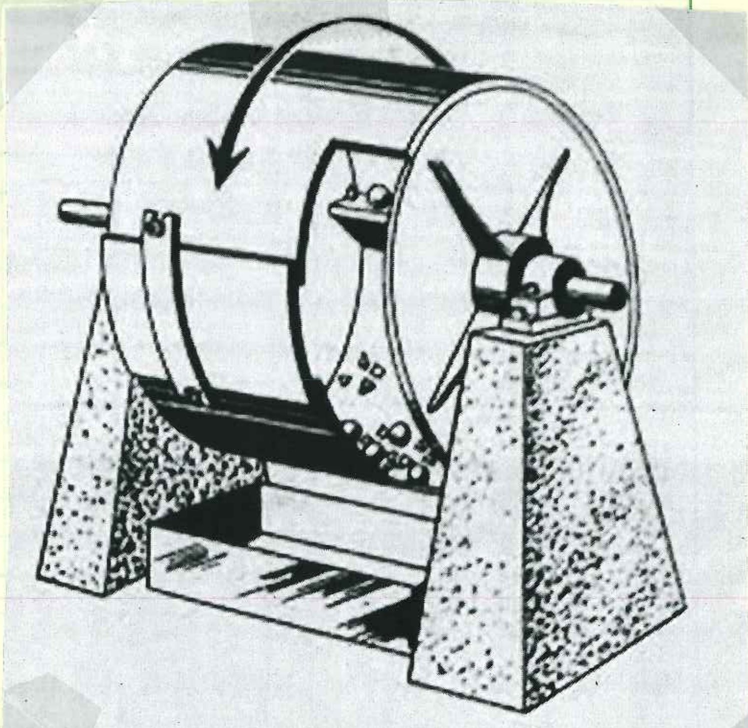


Figure 2.3 Los Angeles Degradation test machine.[7]

Other ABRASION Tests

- Micro-Deval Test
  - has been show to correlate well with aggregate performance in asphalt, concrete, and aggregate base.
  - ASTM D6928 or AASHTO T327 for coarse aggregate
  - ASTM D7428 for fine aggregate
  - This test is very repeatable, but most state DOTs do not use this.
  - Preformed similary to LA Abrasion test but aggregate is soaked, equiptment is minorly changed, and revolutions are different.

- Mill Abrasion Test
  - used in railroad ballast
  - however, this isn't a standardized test
  - Similary to LA abrasion Test, but a mill pot is used with 10,000 revolution in 5 hrs

- Abrasion number
  - used in railroad ballast design for evaluting the abrasion of an aggregate

$$AN = \text{LA Loss\%} + (5 \times \text{Mill Abrasion value})$$

SUMMARY TABLE

Typical physical and mechanical properties of commom aggregates used

Property	Granite	Limestone	Quartzite	Sandstone
1. Unit Weight (pcf)	162-172	117-175	165-170	119-168
2. Compressive Strength (x 10^3 psi)	5-67	2.6-28	16-45	5-20
3. Tensile Strength (psi)	427-711	427-853	NA*	142-427
4. Shear Strength (x 10^3 psi)	3.7-4.8	0.8-3.6	NA*	0.3-3.0
5. Modulus of Rupture (psi)	1380-5550	500-2000	NA*	700-2300
6. Modulus of Elasticity (x 10^6 psi)	4.5-8.7	4.3-8.7	NA*	2.3-10.8
7. Water Absorption (% by wt)	0.07-0.30	0.50-24.0	0.10-2.0	2.0-12.0
8. Avg. Porosity (%)	0.4-3.8	1.1-31.0	1.5-1.9	1.9-27.3
9. Linear Expansion (x 10^{-6} in./in./°C)	1.8-11.9	0.9-12.2	7.0-13.1	4.3-13.9
10. Specific Gravity	2.60-2.76	1.88-2.81	2.65-2.73	2.44-2.61

NA = Data not available*

Chemical properties

Aggregate & Water

a) hydrophilic aggregate

- Surface of aggregate is attracted to water
- Quartz minerals are typically hydrophilic
  - granite, gravel, and other siliceous aggregate

b) hydrophobic aggregate

- surface charge of aggregate repels water
- Carbonate aggregates can be more hydrophobic
- Usually aggregates are more acidic by nature

Solubility - Tendency of a material to be dissolved by a liquid

- Construction aggregate should not be highly dissolvable in water

Chemical Reactive - surface of aggregate chemically reacts with a substance such as alkalies to change the aggregate structure

Chemical Impurities

- Chloride – aggregates with high concentrations of chlorides can create corrosion issues for concrete reinforcement.

- Sulfates – cause concrete to have excessive expansion from sulfate attack

- Clays – increase water demand due to high absorption in concrete
  - can reduce the affects of Asphalt bonding to the aggregate

- Chert – Light weight material that can cause pop outs on the surface of the concrete

- Sulfide Ions – causes corrosion in many metals such as steel and cooper

Durability Properties

- the physical, chemical, and mechanical effects of a material due to the environment

Effect of Moisture

- Stripping - seperation of the asphalt from the aggregates surface due to moisture
    - This is thought to be the result of the surface charge wanting to bond to water rather than Asphalt.
    - ASTM D 4867 or AASHTO T-283

- Freeze/Thaw - in concrete, water can be absorbed into the pores of the aggregate and freeze. This can build up pressure and over multiple freezing and thawing cycles it can cause the aggregate to break down.
    - ASTM C 666 - 300 cycles
    - AASHTO T-161 - 350 cycles
    - From the test, a durability factor is reported.
    - For an aggregate to be sound in F/T durability according to the test, an agency will require a certain durability factor.
    - Typically, DF = 70% or up after the completion of required number of cycles is considered to be passing

$$\text{Durability Factor (DF)} = \left(\frac{\text{Final Dynamic Modulous}}{\text{Initial Dynamic Modulous}}\right)^2 \times 100$$

Alkali Aggregate Reactivity

- In concrete, aggregates can react to the alkalies in portland cement creating cracks.

1.) Alkali silica Reaction (ASR)
   - Silica in aggregate can react with the Alkalies
   - Multiple test have been developed.
   - Common tests
     - ASTM C1293 - 1 year
     - ASTM C1260 - 14 days

2.) Alkali Carbonate Reaction (ACR)
   - Carbonate in aggregate can reat with the Alkalies
   - ASTM C586 - the rock cylinder test
   - ASTM C295 - Petrographic examination
   - ASTM C1105 - concrete prism test

* Manufactured sand and smaller crushed stone have more surface area and thus are more prone to AAR

ASR

Table 14.12 Test Methods for Potential ~~Alkali-Aggregates Reactivity~~ (Excerpted from Table 5-5, FHWA Publication No. HIF-07-004)

Test Method I.D.	Test Method Title	Test Duration	Comments	Criteria
ASTM C 227	Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method)	Usually at least 1 year	Long test. Expansions may not be Alkdai-Aggregate Reactivity	ASTM C 33 6 Month Expansion • 0.10% - excessive
ASTM C 289	Potential Reactivity of Aggregates (Chemical Method)	24 hours	Quick results. Not reliable.	Result plotted on graph. Areas of demarcation: • potentially deleterious • deleterious
ASTM C 295	Petrographic Examination of Aggregates for Concrete	Short duration - visual examination	Optical microscopy, potentially other tests.	
ASTM C 1260 AASHTO T 303	Potential Alkali Reactivity of Aggregates (Mortar Bar Method)	16 days	Fast alternative to C 227. Useful for slowly reacting aggregates	14 Day Expansion: • 0.10% - further testing needed • 0.20% - potentially deleterious
ASTM C 1293	Determination of Length Change of Concrete Due to Alkali-Silica Reaction (Concrete Prism Test)	Usually 1 year or longer when SCMs are used	Long test. Use as a supplement to C 227, C 289, C 295, and C 1260.	1 Year Expansion: • 0.04% - potentially deleterious
Modified ASTM C 1293	Accelerated Concrete Prism Test	91 days	Fast alternative to C 227. Good correlation to C 227 for carbonate and sedimentary rocks	91 Day Expansion: • 0.04% - potentially deleterious
ASTM C 1567	Potential Alkali-Silica Reactivity of Combination of Cementitious Materials and Aggregate (Accelerated Mortar Bar Method)	16 days	Fast alternative to C 1293. Useful for assessing effects of supplementary cementitious materials	14 Day Expansion: • 0.10% - potentially deleterious, confirm with C 1293

Listing of Available AASHTO and ASTM Test Procedures from Aggregates Handbook 2nd Ed.

The following AASHTO and ASTM standard test methods are listed by title to serve as an aid in helping to locate appropriate test methods. A large number of standards have been developed over the years by the two major organizations involved. Other organizations which have standard test methods include the state transportation agencies, federal government agencies and various related industries. A complete listing of all such standards is beyond the scope of this Handbook.

1. General Testing:
   - AASHTO M-92 (ASTM E 11) Wire Cloth Sieves for Testing Purposes
   - AASHTO M-231 Weights and Balances Used in Testing
   - ASTM Manual of Aggregates and Concrete Testing (found in ASTM Volume 04.02 in the back of the gray pages)
   - AASHTO R 18 Establishing and Implementing a System for Construction Materials Testing Laboratories
   - ASTM D 3666 Evaluation of Inspecting and Testing Agencies for Bituminous Paving Materials
   - ASTM C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates

2. Sampling and Sample Preparation:
   - AASHTO T-2 (ASTM D 75) Sampling Aggregates
   - AASHTO T-248 (ASTM C 702) Reducing Field Samples of Aggregates to Testing Size
   - AASHTO T-87 (ASTM D 421) Dry Preparation of Disturbed Soil and Soil Aggregates Samples for Tests
   - AASHTO T-146 Wet Preparation of Disturbed Soil Samples for Tests

3. Particle Size Analysis of Aggregates:
   - AASHTO T-27 (ASTM C 136) Sieve Analysis of Fine and Coarse Aggregates
   - AASHTO T-11 (ASTM C 117) Amount of Material Finer Than the No. 200 Sieve
   - AASHTO T-30 (ASTM D 5444) Mechanical Analysis of Extracted Aggregates
   - AASHTO T-88 (ASTM D 422) Particle Size Analysis of Soils
   - AASHTO T-37 (ASTM D 546) Sieve Analysis of Mineral Filler

4. Properties of Fines in Aggregates:
   - AASHTO T-176 (ASTM D 2419) Sand Equivalent Test for Plastic Fines in Graded Aggregates and Soils
   - ASTM D 4318 (Combines AASHTO T-89 and T-90) Liquid Limit, Plastic Limit and Plasticity Index of Soils
   - AASHTO T-210 (ASTM D 3744) Aggregates Durability Index
   - AASHTO T 330 Standard Method of Test for The Qualitative Detection of Harmful Clays of the Smectite Group in Aggregates Using Methylene Blue

5. Tests to Evaluate General Quality of Aggregates (unconfined or in concrete):
   - AASHTO T-104 (ASTM C 88) Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
   - AASHTO T-103 Soundness of Aggregates by Freezing and Thawing
   - ASTM D 4792 Potential Expansion of Aggregates from Hydration Reactions
   - AASHTO T-161 (ASTM C 666) Resistance of Concrete to Rapid Freezing and Thawing
   - AASHTO T-96 (ASTM C 131 or C 535) Resistance to Abrasion (Degradation by Abrasion and Impact) of Small or Large Size Coarse Aggregates by Use of the Los Angeles Machine
   - ASTM D 6928 (AASHTO T 327) Resistance of Coarse Aggregates to Degradation by Abrasion in the Micro-Deval Apparatus
   - ASTM D 7428 Standard Test Method for Resistance of Fine Aggregates to Degradation by Abrasion in the Micro-Deval Apparatus
   - ASTM D 4791 Flat or Elongated Particles in Coarse Aggregates

6. Deleterious Materials in Aggregates:
   - AASHTO T-21 (ASTM C 40) Organic Impurities in Sands for Concrete
   - AASHTO T-71 (ASTM C 87) Effect of Organic Impurities in Fine Aggregates on Strength of Mortar
   - AASHTO T-112 (ASTM C 142) Clay Lumps and Friable Particles in Aggregates
   - AASHTO T-113 (ASTM C 123) Lightweight Pieces in Aggregates
   - ASTM C 294 Nomenclature of Constituents of Natural Mineral Aggregates
   - ASTM C 295 Practice for Petrographic Examination of Aggregates for Concrete

7. Test to Evaluate Potential Alkali-Aggregates Reactivity
   - ASTM C 227 Alkali Reactivity Potential of Cement-Aggregates Combinations
   - ASTM C 289 Potential Reactivity of Aggregates (chemical method)
   - ASTM C 586 Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (rock cylinder method)
   - ASTM C 441 Mineral Admixture Effectiveness in Preventing Excessive Expansion Due to Alkali Aggregates Reaction
   - ASTM C 1260 Potential Alkali Reactivity in Aggregates (Mortar Bar Method)
   - ASTM C 1293 Determination of Length Change of Concrete Due to Alkali-Silica Reaction
   - ASTM C 1105 Length Change of Concrete Due to Alkali-Carbonate Reaction
   - ASTM C 1567 Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregates

8. Testing Aggregates in Bituminous Applications:
   - AASHTO T-165 (ASTM D 1075) Effect of Water on Cohesion of Compacted Bituminous Mixtures
   - AASHTO T-182 Coating and Stripping of Bitumen-Aggregates Mixtures
   - AASHTO T-195 (ASTM D 2489) Determining Degree of Particle Coating of Bituminous Aggregates Mixtures
   - AASHTO T-283 (ASTM D 4867) Resistance of Compacted Bituminous Mixture to Moisture Induced Damage
   - ASTM D 4469 Calculating Percent Absorption by the Aggregates in an Asphalt Pavement Mixture
   - ASTM D 6927 Resistance to Plastic Flow-Marshall Apparatus
   - ASTM D 1560 Deformation and Cohesion-Hveem Apparatus

9. Aggregates Base Moisture-Density-Permeability Relationships:
   - AASHTO T-99 (ASTM D 698) Moisture-Density Relationship Using a 5.5 Pound Rammer and a 12 Inch Drop
   - AASHTO T-180 (ASTM D 1557) Moisture-Density Relationship Using a 10 Pound Rammer and an 18 Inch Drop
   - AASHTO T-215 (ASTM D 2434) Permeability of Granular Soils (Constant Head)
   - AASHTO T-224 (ASTM D 4718) Correction for Coarse Particles in Soil Compaction Tests
   - ASTM D 2922 Density of Soil and Soil Aggregates In-Place by Nuclear Methods (shallow depth, both backscatter and direct transmission methods)
   - ASTM D 3017 Moisture Content of Soil and Soil Aggregates In Place by Nuclear Methods (shallow depth, back-scatter method only)
   - ASTM D 4253 Index Density of Soils Using a Vibratory Table (applicable to cohesionless, free-draining soils or soil aggregates)
   - ASTM D 4254 Minimum Index Density and Unit Weight of Soils
   - ASTM D 6938 (AASHTO T 310) Density and Water Content of Soil and Soil Aggregates by Nuclear Method (Shallow Depth)
   - AASHTO T-191 (ASTM D 1556) Density of Soil In-Place by the Sand Cone Method
   - ASTM D 2167 Density of Soil In-Place by the Rubber Balloon Method

10. Strength Parameters of Aggregates Base:
    - AASHTO T-190 (ASTM D 2844) Resistance R-Value and Expansion Pressure of Compacted Soils
    - AASHTO T-193 (ASTM D 1883) The California Bearing Ratio
    - AASHTO T 296 (ASTM D 2850) Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
    - AASHTO T-212 (ASTM D 3397) Triaxial Classification of Base Materials, Soils and Soil Mixtures (Texas method, static loading, discontinued as a standard 1989)
    - AASHTO T 236 (ASTM D 3080) Direct Shear of Soils Under Consolidated-Undrained Conditions
    - AASHTO T 297 (ASTM D 4767) Consolidated-Undrained Triaxial Compression Test on Cohesive Soils
    - AASHTO T 307 Resilient Modulus of Soils and Aggregates Materials
    - ASTM D 6758 Stiffness of Soil and Soil-Aggregates by the Soil Stiffness Gauge

11. Specific Gravity, Absorption and Unit Weight of Aggregates:
    - AASHTO T-84 (ASTM C 128) Specific Gravity and Absorption of Fine Aggregates
    - AASHTO T-85 (ASTM C 127) Specific Gravity and Absorption of Coarse Aggregates
    - AASHTO T-19 (ASTM C 29) Unit Weight and Voids in Aggregates
    - ASTM D 7172 Relative Density (Specific Gravity) and Absorption of Fine Aggregates Using Infrared

12. Frictional Properties of Aggregates and Pavements:
    - AASHTO T-242 (ASTM E 274) Frictional Properties of Paved Surfaces Using a Full-Scale Tire (skid trailers)
    - AASHTO T-279 (ASTM D 3319) Accelerated Polishing of Aggregates Using the British Wheel
    - AASHTO T-278 (ASTM E 303) Measuring Surface Frictional Properties Using the British Pendulum Tester (BPT)
    - ASTM D 3042 Insoluble Residue in Carbonate Aggregates
    - ASTM E 707 Skid Resistance of Paved Surfaces Using the NC State Variable-Speed Friction Tester
    - ASTM E 660 Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel Circular Polishing Machine

13. Measurements and Indices of Particle Shape and Texture:
    - ASTM D 1252 (AASHTO T 304) Uncompacted Void Content of Fine Aggregates
    - ASTM D 4791 Flat or Elongated Particles in Coarse Aggregates
    - ASTM D 3398 Index of Aggregates Particle Shape and Texture
    - ASTM D 5821 (AASHTO TP 61) Fractured Particles in Coarse Aggregates

SUMMary of Tests for Aggregates

Table 8.2 Synoptic table of test methods for aggregates from Aggregates in Concrete Book

Test methods	*USA (ASTM)*	*UK (BS)*	*Canada (CSA)*	*SA (SANS)* South Africa
AAR/ASR – Potential expansivity of aggregates (procedure for length change in concrete prisms)		812-123: 1999	A23.2-14A	
Abrasion resistance by LA machine	C13 C535		A23.2-16A; A23.2-17A	5846
Absorption of water	C127 C128		A23.2-6A; A23.2-12A	5843
Acid insolubility				6242
Acid-soluble material in fine aggregate		812-119: 1985		
Acid-soluble sulphates of fines		812-118: 1988		5850
Aggregate abrasion value		812-113: 1990		
Aggregate impact value (AIV)		812-112: 1990		6239
Alkali–aggregate reactivity methods: Rock cylinder method, chemical method, and mortar bar method	C586 C289 C227/C126		A23.2-25A	6245
ASR – Effectiveness of mineral admixtures or GGBS in preventing excessive expansion of concrete	C441		A23.2-28A	
Bulk density (or unit weight)	C29	812-2: 1975	A23.2-10A	5845
Bulk density, voids	C29 C1252			5845
Bulking of fine aggregates				5856
Chloride content of aggregates		812-117: 1988		202
Chlorides, presence of				5831
clay content				6244
Clay size particles in aggregate	C117			
Clay, friable particles and fine silt (incl. by sieving)	C142	812-103.1: 1985	A23.2-3A	201
Crushing tests of coarse aggregates, including ACV and 10% FACT (TFV)		812-111: 1990 812-112: 1990		5841 5842

Table 8.2 (Continued)

Test methods	*USA (ASTM)*	*UK (BS)*	*Canada (CSA)*	*SA (SANS)*
Particle density (see 'Specific gravity and absorption')				
Particle shape and texture	D3398 D4791	812-105.2: 1990		
Particle size distribution: see 'Sieve Analysis'				
Particle size distribution of fine aggregate (pipette method)				6244
Petrographic examination of aggregates	C295	812-104: 1994		
Polished stone value		812-114: 1989		
Resistance of fine aggregates to degradation by abrasion in the Micro-Deval apparatus			A23.2-23A A23.2-29A	
Sampling and testing of aggregates	D75 C1077 C702	812-101: 1984 812-102: 1989	A23.2-1A	5827
Sand equivalence of fine aggregate				5838
Shell content of coarse aggregates		812-106: 1985		
Shell content of fine aggregates		812-106: 1985		5840
Shrinkage and expansion of cement: aggregate mixes; drying shrinkage of aggregates in concrete	C342	812-120: 1989		5836
Sieve analysis of fine and coarse aggregates (incl. fines content, dust content, etc.)	C136	812-103.1: 1985 812-103.2: 1989	A23.2-2A	201 6241
Soluble deleterious impurities				5834
Soundness of aggregates by use of sodium sulphate or magnesium sulphate	C88	812-121: 1989	A23.2-9A	5839
Specific gravity (relative density) and absorption	C127 C128	812-2: 1975		5844