PAVEMENT MATERIALS & DESIGN (110 401466)

SPRING 2019-2020

Dr. Hamza Alkuime

January 29, 2020

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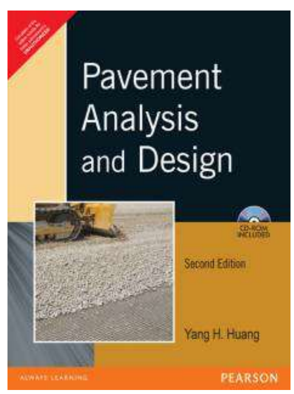
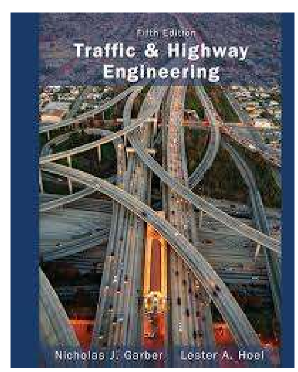
Textbook

- ***Pavement Analysis and Design***, 2nd Edition. Yang Huang. Pearson Publishing, 2012
- ***Traffic & Highway Engineering***, 5th Edition. Nicholas Garber and Lester Hoel. Cengage Learning, 2015





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Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
Highway Materials (Bituminous Materials, Aggregates, and soil),	6	18
Pavement Types,	1	3
Flexible pavement design (design of Hot Mix Asphalt mixture using Marsha method	3	9
Flexible pavement design (design of pavement thicknesses using AASHTO method)	2	6
Earth work operations,	1	3
Drainage and drainage structures, and	1	3
Rehabilitation and Highway Maintenance	1	3
Total	15	45

Grading Plan

- 1st Exam (25 Points)
- 2nd Exam (25 Points)
- Q & P (10 Points)
  - *Quizzes, homework's and/or Participation*
- Final exam (40 Points)

General Notes

- The maximum allowed number of absentees from the course is **six** classes.
  - *Exceeding these limits will lead to prevention from attending the final exam.*
- Beware of ***Plagiarism***: copying and handing in for credit someone else's work. Any plagiarism case will result in an automatic '**F**' for the course
- **No MAKE-UP EXAMS**

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Class Rules

- No side talks, try to minimize distractions and feel free to discuss any matters with all of us. Everyone gets to be involved
- No use of e-devices (phones, Tablets, laptops, etc. (unless permitted)
- It is recommended to bring the course Textbook to access design charts, tables, equations, etc.
- Never handle the work of others
- Cheating will only get you into serious trouble

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Office

- **Office** : E 3029
- **Office Hour :** [S, T, Th. (1:00 – 2:00 p.m.)]

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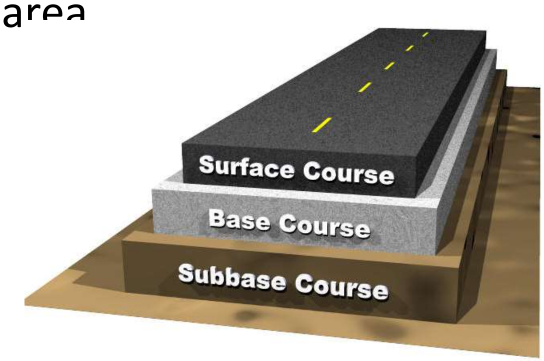
What is a Pavement

- **Pavement** is that part of the road or highway which supports the wheel loads imposed on it from traffic moving over it.
- Pavement is a multi-layered structure put as horizontal layers one above the other, which distributes the vehicular loads over a larger area



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Functions of the pavements

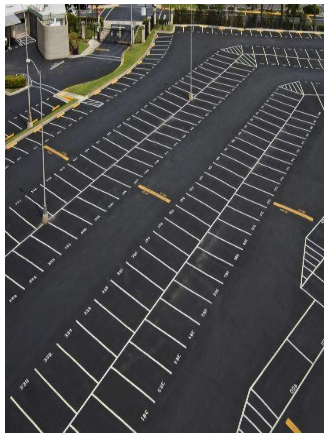
- Reduce and distribute the traffic loading so as not to damage the subgrade
- Provide vehicle access between two points under all-weather conditions
- Provide safe, smooth and comfortable ride to road users without undue delays and excessive wear & tear
- Meet environmental and aesthetics requirement
- Limited noise and air pollution
- Reasonable economy

Requirements of a pavement

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

Classification of pavements

Classification by function



Highway pavement

Parking lots pavements

Airport pavements

Ports and Heavy industrial pavements

Classification of pavements

Classification by structure

Gravel (unpaved) pavements

Flexible pavements (asphalt concrete)

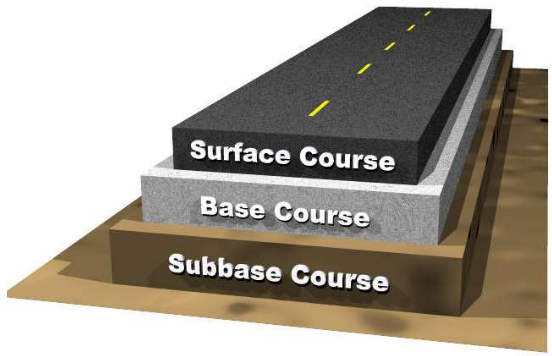
Rigid (concrete) pavement

Composite pavements

Flexible pavements - Definition

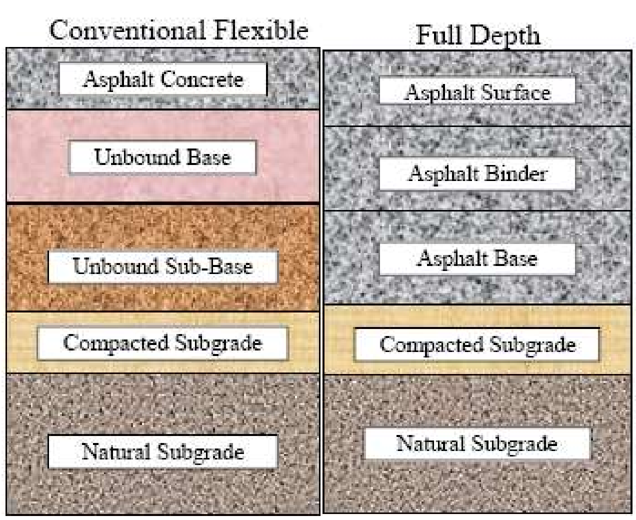
- Pavements typically consist of asphalt concrete placed over granular base/subbase layers supported by the compacted soil (referred to as the *subgrade*)
- Types

1. *Conventional flexible pavements*
2. *Full-depth asphalt flexible pavements*
3. *Semi-rigid pavements*
4. *Contained rock asphalt mat (CRAM),*
   - not widely accepted for practical use widely
5. *Perpetual Pavement*



Conventional vs. Full depth flexible pavements

Cross section

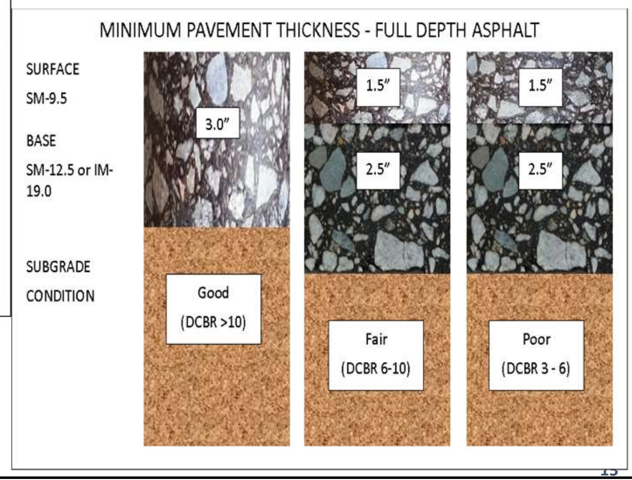


Conventional vs. Full depth flexible pavements

Cross section

Conventional pavement

Full depth pavement



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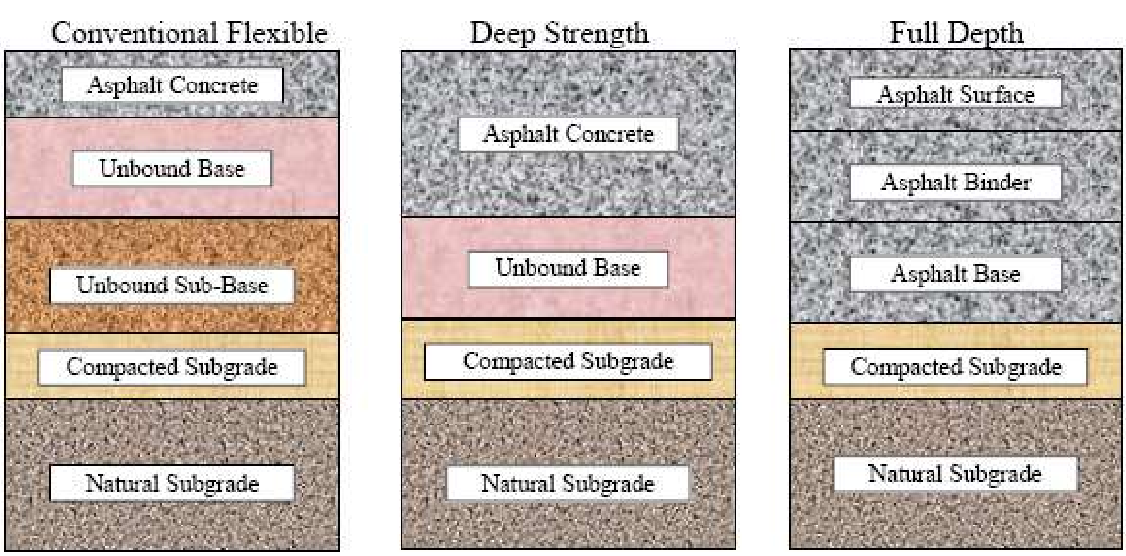
flexible pavements – Others



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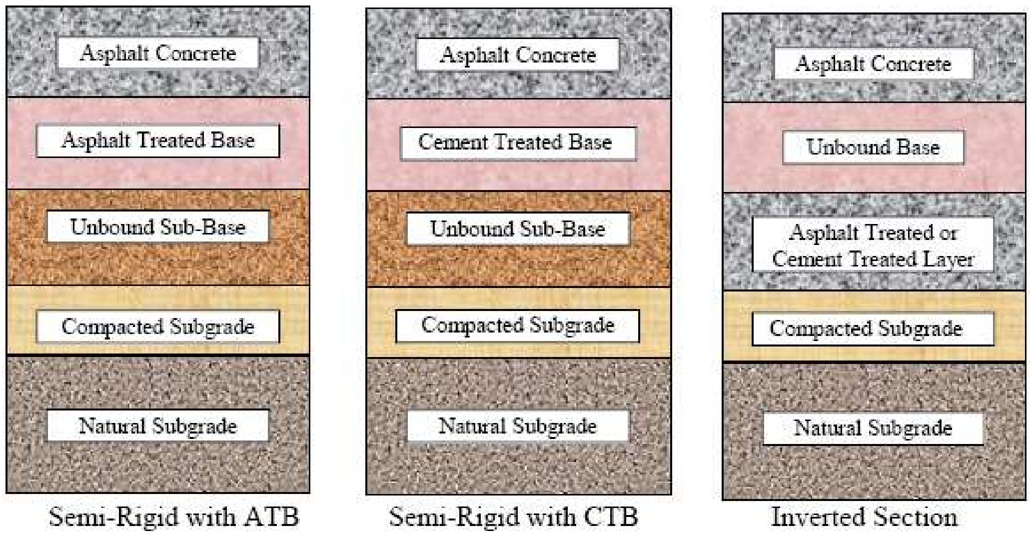
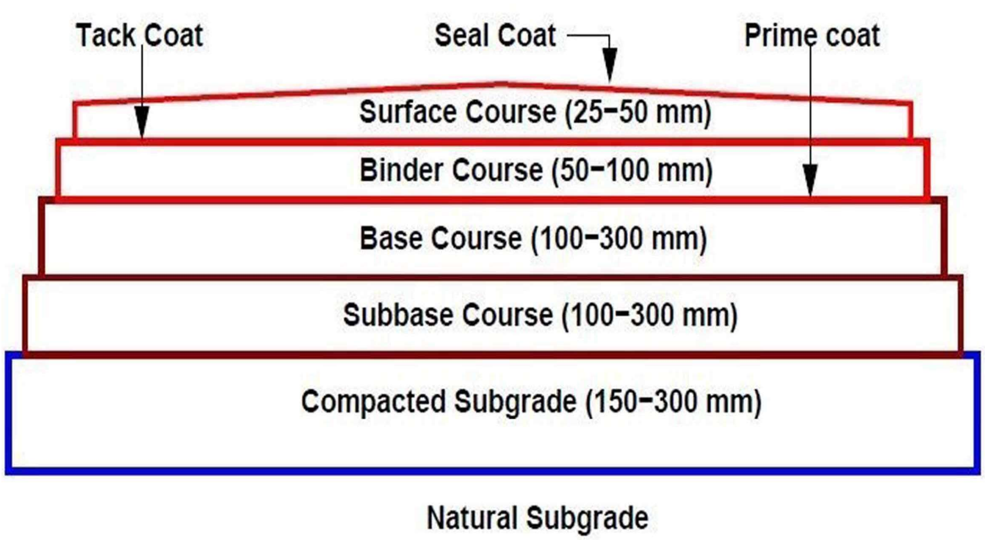
flexible pavements – Others



ATB: Asphalt treated base
CTB : Concrete treated base

Conventional flexible pavements

Typical cross section



Conventional flexible pavements

Typical cross section

- Cross section consist of (from top):
  1. *Seal coat*
  2. *Surface course*
  3. *Tack coat*
  4. *Binder course*
  5. *Prime coat*
  6. *Base course*
  7. *Subbase course*
  8. *Compacted subgrade*
  9. *Natural subgrade*

The use of various courses is based on either necessity or economy, and some of the courses may be omitted

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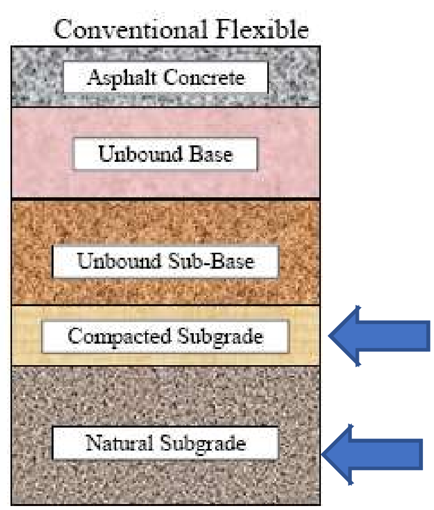
Conventional flexible pavements

*Layers – **Subgrade***

- Subgrade can be either in situ soil or a layer of selected materials.
- The top 6" of subgrade should be scarified and compacted to the desired density near the optimum moisture content.
- Purpose
  - *Provide a platform for construction of the pavement*
  - *support the pavement without undue deflection that would impact the pavement's performance.*



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Conventional flexible pavements

*Layers –**Subgrade layer***

https://www.youtube.com/watch?v=aDe03CSjTSU

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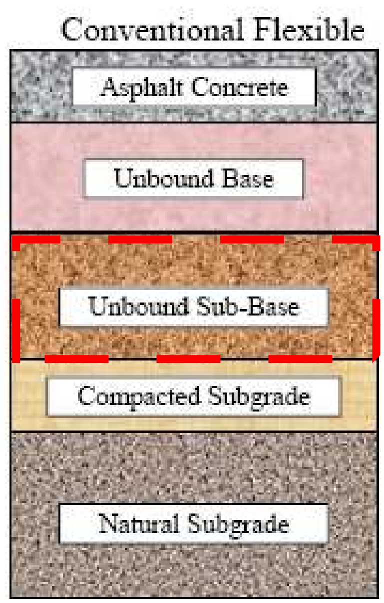
Conventional flexible pavements

*Layers –**Subbase course***

- A layer or layers of specified or selected materials of designed thickness placed on a subgrade to support a base course.
- Usually of somewhat lower quality than the base layer
- In some cases, the subbase may be treated with Portland cement, asphalt, lime, fly ash, or combinations of these admixtures to increase its strength and stiffness



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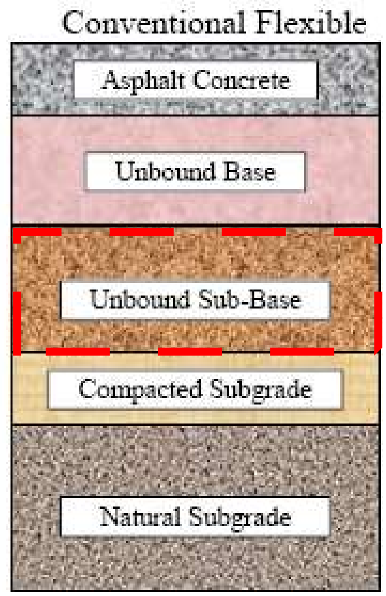
Conventional flexible pavements

*Layers –**Subbase course***

- A subbase layer is not always included, especially with rigid pavements
- Inclusion of a subbase layer is primarily an economic issue
- A subbase layer is typically included when the subgrade soils are of very poor quality and/or suitable material for the base layer is not available locally, and is, therefore, expensive .



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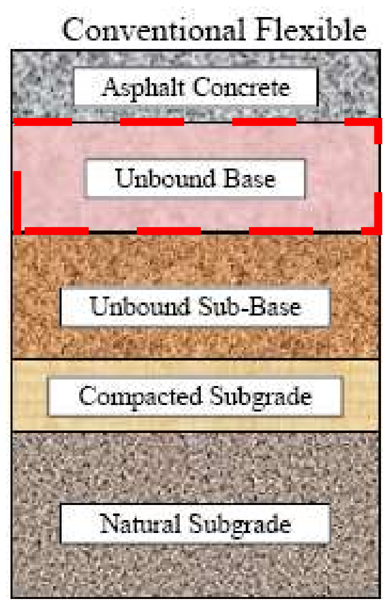
Conventional flexible pavements

*Layers – **Base course***

- A layer or layers of specified or select material of designed thickness placed on a subbase or subgrade (if a subbase is not used) to provide a uniform and stable support for binder and surface courses.
- It usually consists of high-quality aggregates, such as crushed stone, crushed slag, gravel and sand, or combinations of these materials.
- The specifications for base materials are usually more stringent than those for the lower-quality subbase materials.



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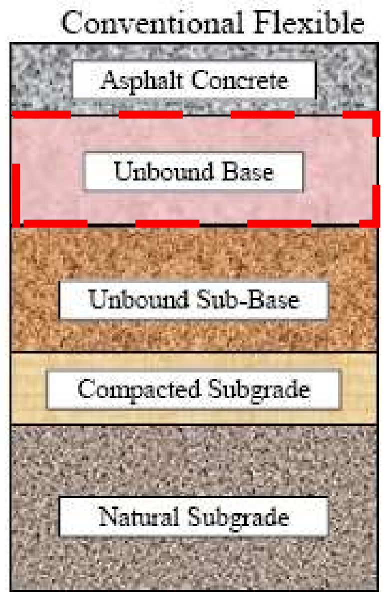
Conventional flexible pavements

*Layers – **Base course***

- The base layer typically provides a significant portion of the structural capacity in a flexible pavement system and improves the foundation stiffness for rigid pavements.



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Conventional flexible pavements

*Layers – **Base and subbase course layers***

https://www.youtube.com/watch?v=aDe03CSITSU

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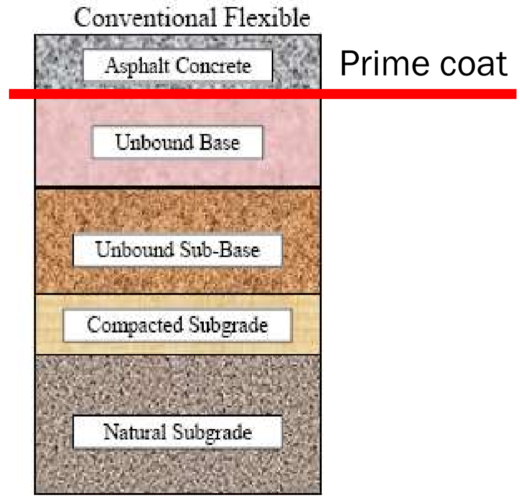
Conventional flexible pavements

*Layers – **Prime coat***

- Application of low viscosity Cutback asphalt to an absorbent surface such as untreated granular base on which asphalt layer will be placed on.
- Uses
  - *Minimize flow of asphalt cement from the asphalt concrete to the aggregate base*
  - Fill the surface voids and protect the subbase from weather.
  - Stabilize the fines and preserve the subbase material.
  - Promote bonding to the subsequent pavement layer



*Cutback asphalt = AC + Petroleum solvent

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Conventional flexible pavements

*Layers – **Prime coat***

https://www.youtube.com/watch?v=aDe03CSITSU

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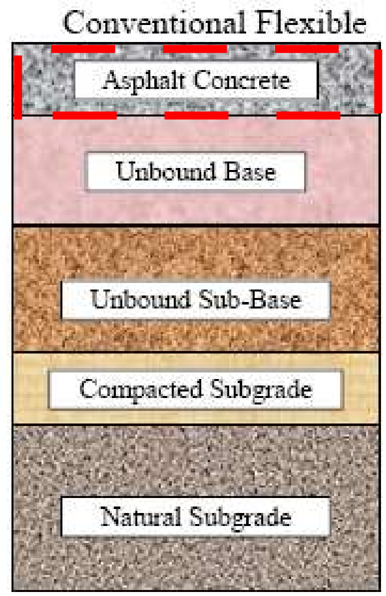
Conventional flexible pavements

Layers – Surface (Wearing) course

- The surface course is usually constructed on top of a base layer of unbound coarse aggregate, but
- often is placed directly on the prepared subgrade for low volume roads
- Must be:
  1. *Tuff to resist distortion under traffic*
  2. *Provide smooth, uniform, and skid resistant riding surface.*
  3. *Waterproof to protect the entire pavement from the weakening effects of water.*
- If the above requirements can not be met, the use of seal coat is recommended.



Conventional flexible pavements

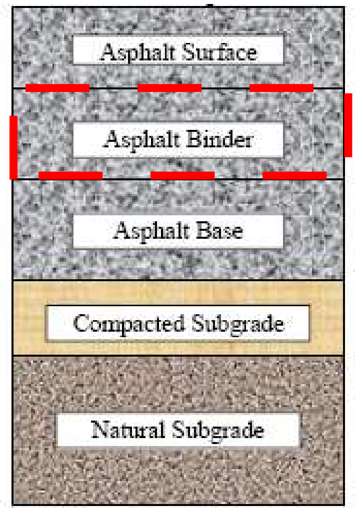
Layers – Surface (Wearing) course

https://www.youtube.com/watch?v=aDe03CSITSU

Conventional flexible pavements

*Layers – **Binder course***

- Binder course (known also as Asphalt base course) is the asphalt layer beneath the surface course.
- Reasons for use:
  1. *HMA is too thick to be compacted in one layer (if the binder course is more than 3" it is placed in two layers).*
  2. *More economical design, since binder course generally consist of larger aggregates and less asphalt and doesn't require high quality.*



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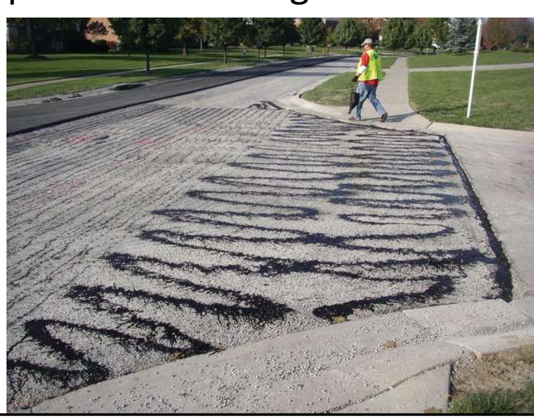
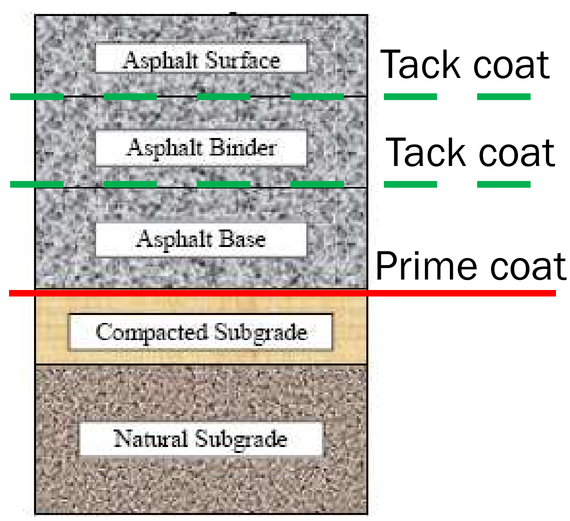
Conventional flexible pavements

*Layers – **Tack coat***

- A thin bituminous liquid asphalt, emulsion or cutback layer applied between HMA pavement lifts to promote bonding.





*Emulsified asphalt = AC + water + emulsifying agent

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Conventional flexible pavements

*Layers – **Tack coat***

- It prevent of Inadequate bonding between layers can result in delamination (debonding) followed by longitudinal wheel path cracking, fatigue cracking, potholes, and other distresses such as rutting that greatly reduce pavement life

Conventional flexible pavements

*Layers – **Seal coat (or chip seal)***

- Thin asphalt surface treatment
- Made of crushed aggregates (chips)embedded in asphalt binders.

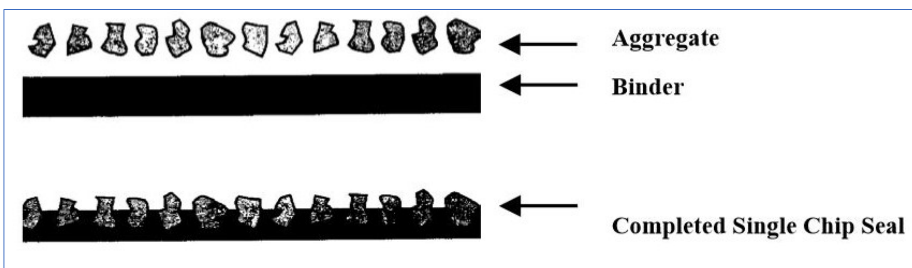

Figure 1: Single Chip Seal

Conventional flexible pavements

Layers – Seal coat (or chip seals)

Asphalt Distributor | Aggregate Spreader | Roller

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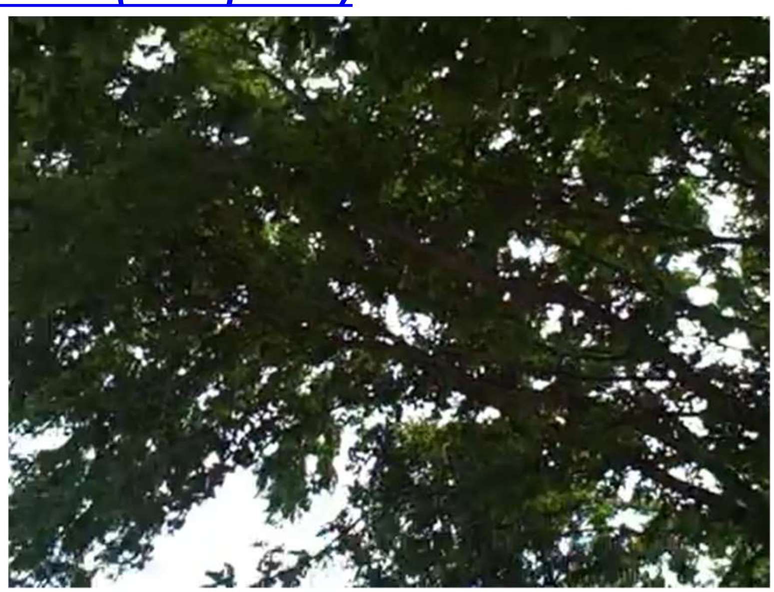
Conventional flexible pavements

Layers – Seal coat (or chip seal)



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Conventional flexible pavements

Layers – ***Seal coat (or chip seal)***

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Conventional flexible pavements

Layers – ***Seal coat (or chip seal)***

Uses:

- Very effective in improving the skid resistance of asphalt pavements
- Prevent moisture infiltration
- retard the oxidation of asphalt in underlying layers
- Extend the service life of dry and weathered and deteriorated surfaces
- Excellent temporary surface, temporary cover of base layers until permanent HMA surface is placed
- Proper surface treatment for light to medium traffic roads; however it is used on higher volume roads
- Popular treatment; low cost

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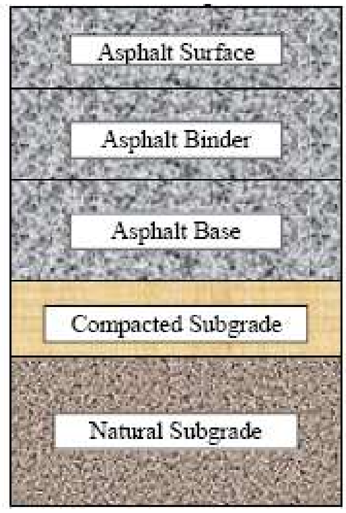
Full depth flexible pavements

- Pavement constructed by placing one or more layers of HMA directly on the subgrade or improved subgrade.
- Used for heavy traffic.
- When local materials are not available to minimize the administration and equipment costs.



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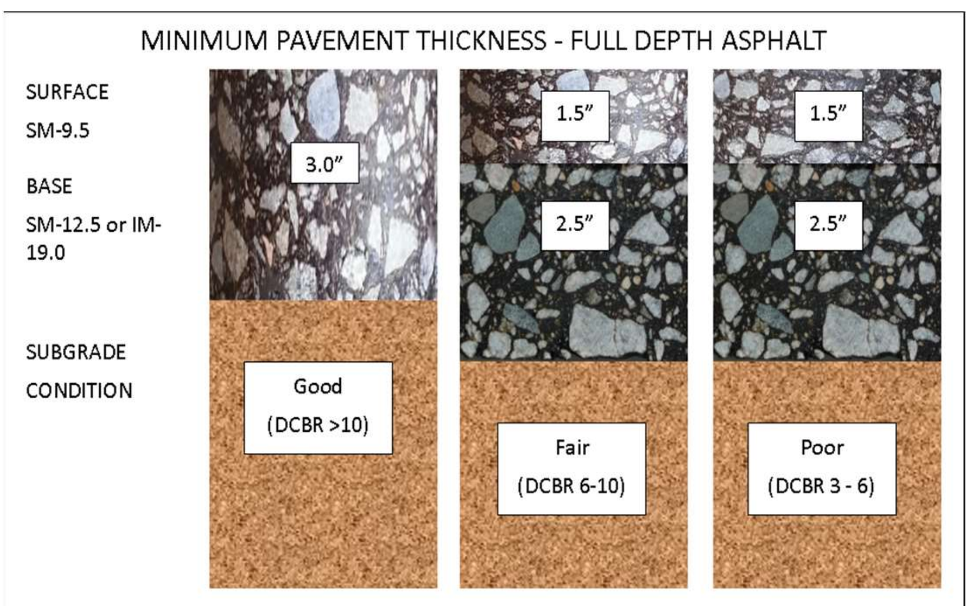
Full depth flexible pavements



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Full depth flexible pavements

Advantages

1. Have no permeable granular layers to entrap water and impair performance.
2. Reduced construction time.
3. Construction seasons may be extended.
4. Provide & retain uniformity in the pavement structures.
5. Less affected by moisture or frost.
6. Little or no reduction in subgrade strength because moisture do not build up in subgrade when full-depth asphalt is used.

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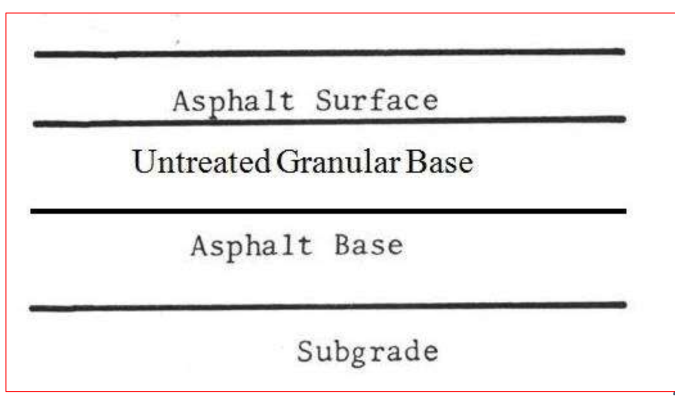
Contained Rock Asphalt Mats

- Place an additional **asphalt layer** below the untreated granular materials but above the subgrade



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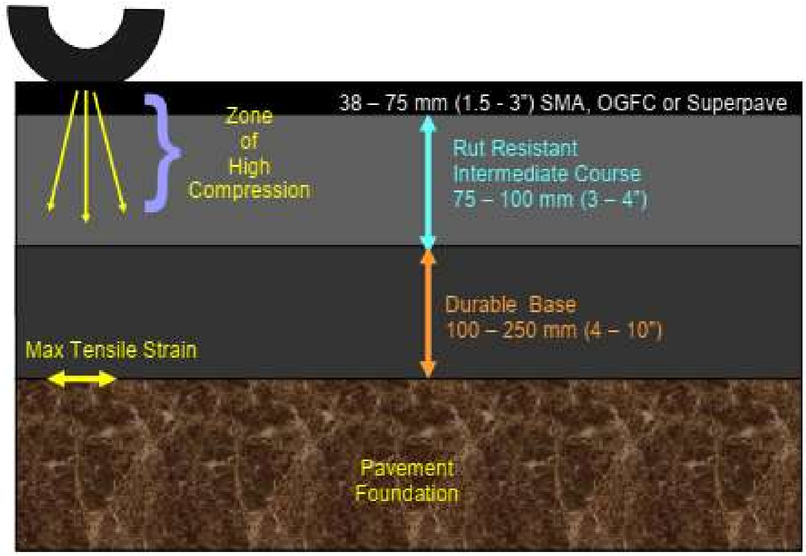
Perpetual Pavement

- a flexible but strong asphalt pavement that doesn't exhibit structural damage even when very high traffic flows over long periods of time



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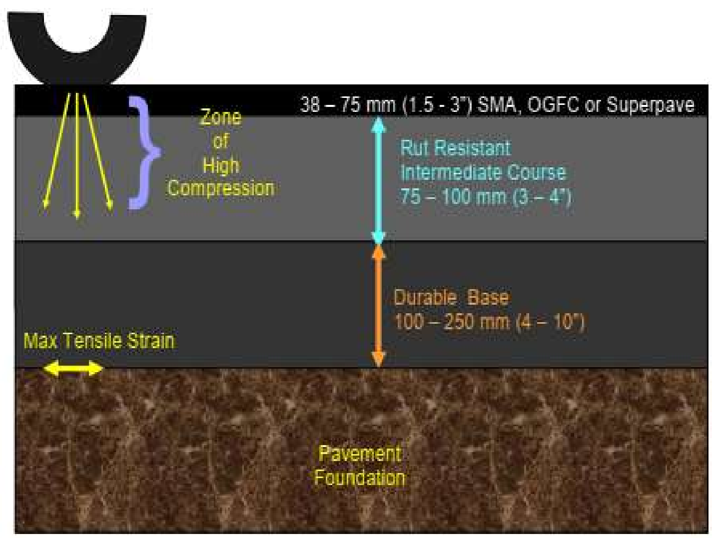
Perpetual Pavement

- The bottom layer is designed to be strong but flexible to resist strains that could cause cracks to form from the bottom up.
- Intermediate layer adds additional structural protection,
- Final layer, made of rut-resistant hot-mix asphalt (HMA), requires only minimal maintenance



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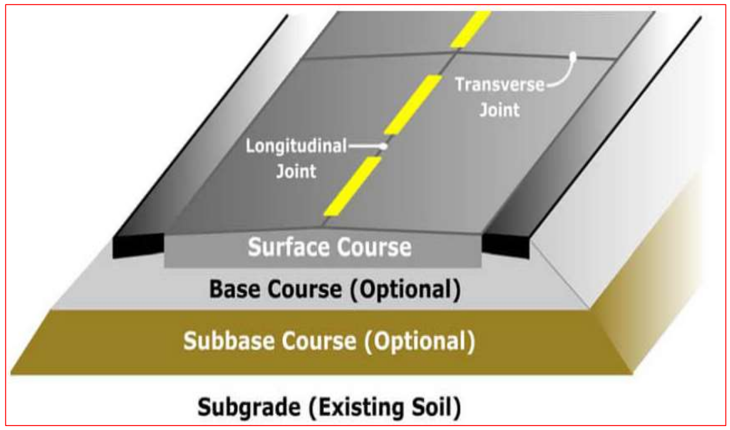
Rigid pavements

- Pavement constructed of Portland cement concrete Pavements (150 -300 mm) placed over granular base/subbase layers (100-300 mm) supported by the *subgrade.*



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Rigid pavements

Surface course

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Rigid pavements

Types

- *Jointed Plain Concrete Pavements (JPCP)*
- *Jointed Reinforced Concrete Pavements (JRCP)*
- *Continuously Reinforced Concrete Pavements (CRCP)*
- *Prestressed Concrete Pavements (PCP)*

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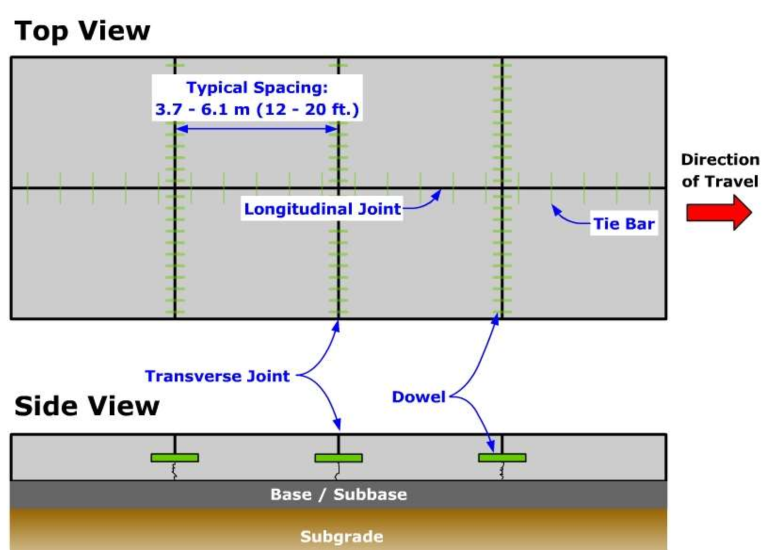
Jointed Plain Concrete Pavements (JPCP)

- No reinforcement distributed throughout the pavement slabs
- Contain tie bars across longitudinal lane-lane joints and
- May contain dowel bars across transverse joints; modern designs include dowel bars,
- Short joint spacing (15 and 30 ft)



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Jointed Plain Concrete Pavements (JPCP)

The Hashemite University

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Jointed Plain Concrete Pavements (JPCP)

The Hashemite University

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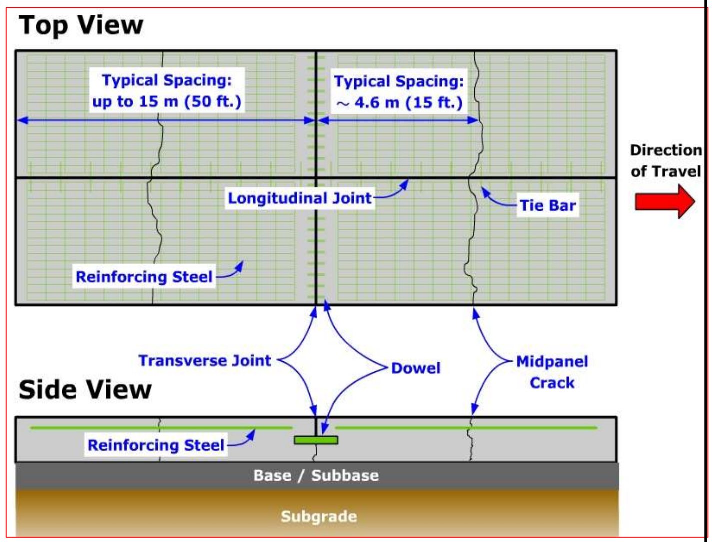
Jointed Reinforced Concrete Pavements (JRCP)

- Contain steel reinforcement distributed throughout the interior portion of the slabs.
- JRCP have longer joint spacing (30 to 100 ft) compared to JPCP
- Steel reinforcement holds the cracks tightly odowels are used at the transverse joints



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Jointed Reinforced Concrete Pavements (JRCP)

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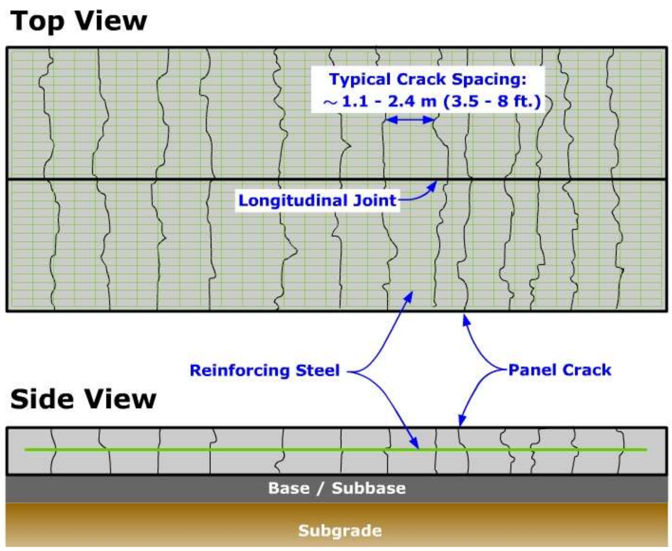
Continuously reinforced concrete pavements (CRCP)

- Contain steel reinforcement distributed throughout the interior portion of the slabs.
- The longitudinal reinforcing bars are larger than those found in JRCP
- Its only joints are made at the end of a day's construction
- Steel reinforcement holds the cracks tight



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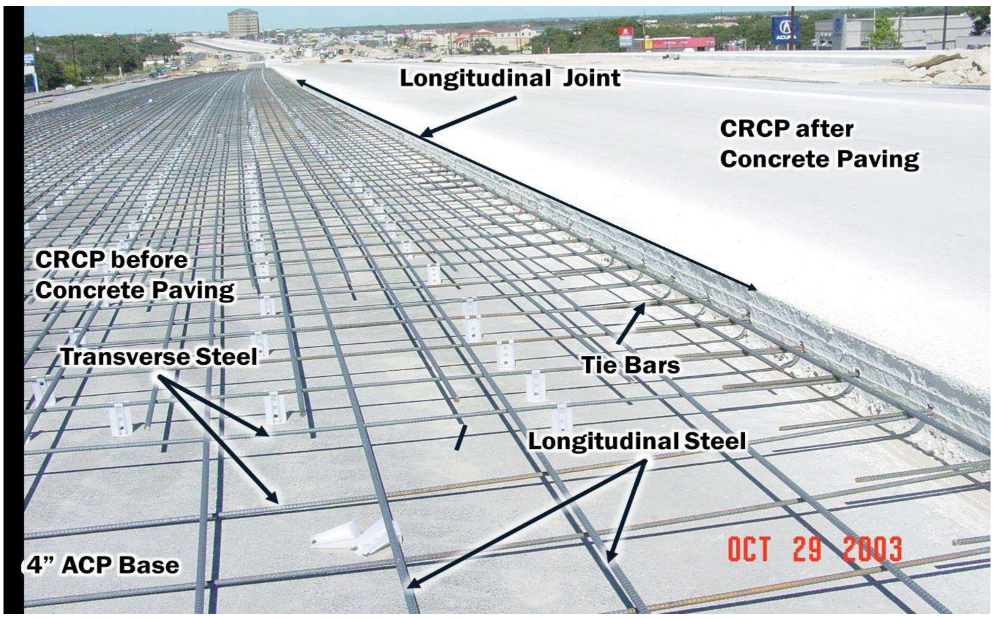
Continuously reinforced concrete pavements (CRCP)



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Continuously reinforced concrete pavements (CRCP)

Prestressed Concrete Pavements (PCP)

- The pre application of a compressive stress to the concrete greatly reduces the tensile stresses caused by traffic and thus decrease the thickness of concrete required.
- Has less probability of cracking and fewer transverse joints and therefore results in less maintenance and longer pavement life.
- Used more frequently for airport pavements than for highway pavements because the saving of thickness for airport pavements is much greater than for highways.

Rigid pavement construction

https://www.youtube.com/watch?v=Vet1ZMcvXIE

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3. Semi-rigid pavements

- Similar to the rigid pavements except that
  – *bonded materials like the pozzolanic concrete, lean cement concrete, or soil-cement are used in the base course or sub-base course layer,*
- The pavement layer has considerably higher flexural strength than the common flexible layers.

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Composite pavements

- Consists of multiple structurally significant layers of different heterogeneous compositions
- Composed of both HMA & PCC.
- Using PCC bottom layer & HMA top layer results in an ideal pavement with most desirable characteristics.
- PCC provide strong base
- HMA provides a smooth non-reflective surface.
- Very expensive and rarely used.
- Most of the available are the rehabilitation of PCC using asphalt overlays.

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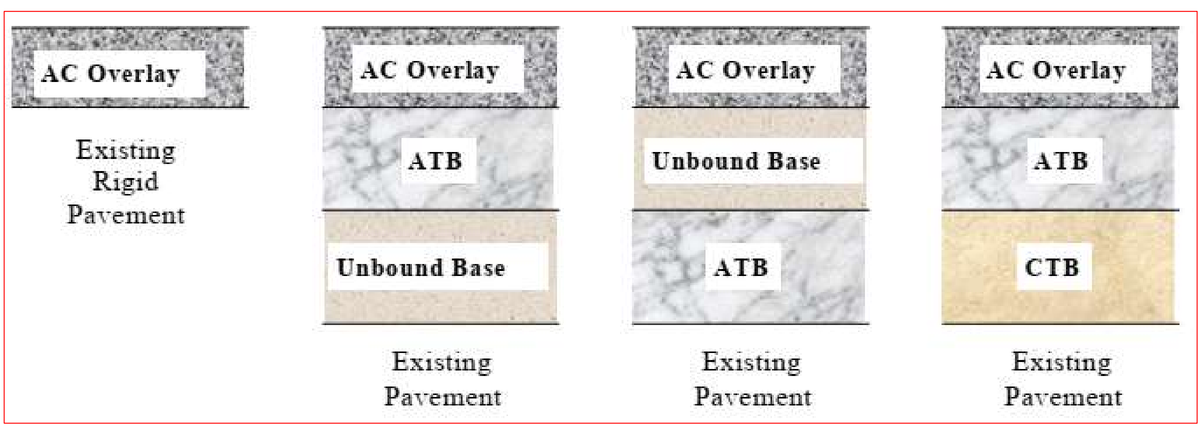
Composite pavements

Typical composite pavement sections.



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References

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6. https://www.slideshare.net/arslan000/lecture01-33441631?from_action=save
7. https://vaasphalt.org/pavement-guide/pavement-design-by-use/driveways/residentail-driveway1revised/
8. https://www.youtube.com/watch?v=aDe03CSlTSU
9. https://www.academia.edu/30421209/CONSTRUCTION_OF_SUBGRADE_SUBBASE_AND_BASE_LAYERS
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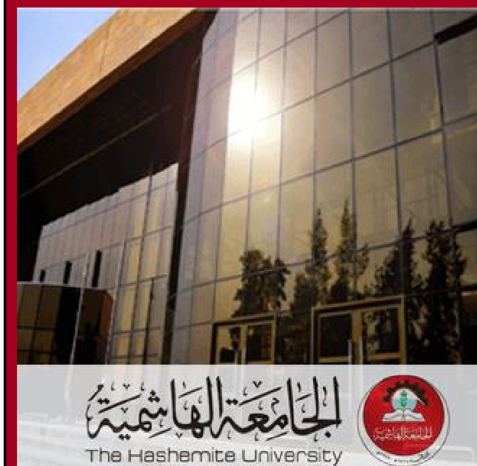

PAVEMENT MATERIALS & DESIGN (110 401466) SPRING 2019-2020

Lecture. No. 2
Bituminous materials
Part I
(asphalt types, uses, and behavior)

Dr. Hamza Alkuime

Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
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Earth work operations,	1	3
Drainage and drainage structures, and	1	3
Rehabilitation and Highway Maintenance	1	3

Highway Materials

References

- Federal Highway Administration, ***Superpave Fundamentals***,(https://idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-Handbooks/T2/P028.pdf)
- E. Ray and Prithvi S. Kandhal and Freddy et al., ***hot mix asphalt materials mixture design and construction***, 2th Edition., 1996
  - *Chapter 2 :Ashalt refning, uses and properties*

Highway Materials

References

- Nicholas Garber and Lester Hoel ,***Traffic & Highway Engineering***, 5th Edition.. Cengage Learning, 2015
  - *Chapter 18 :Bituminous materials*
- Michael S. Mamlouk and JohnP, Zaniewski, ***Traffic & Highway Engineering***, 3th Edition.. Pearson, 2011
  - *Chapter 19 :ASPHALT BINDERS AND ASPHALT MIXTURES*

Historical Background

- Bituminous Materials are used for highway construction because:
  1. *Excellent binding & cementing power.*
  2. *Water-proofing properties.*
  3. *Relatively low cost.*
- Bituminous materials are classified as asphalts and tars
  - *Often, these two terms are used interchangeable.*
  - *However, these are two distinctly different materials with different origins and different chemical and physical characteristics*

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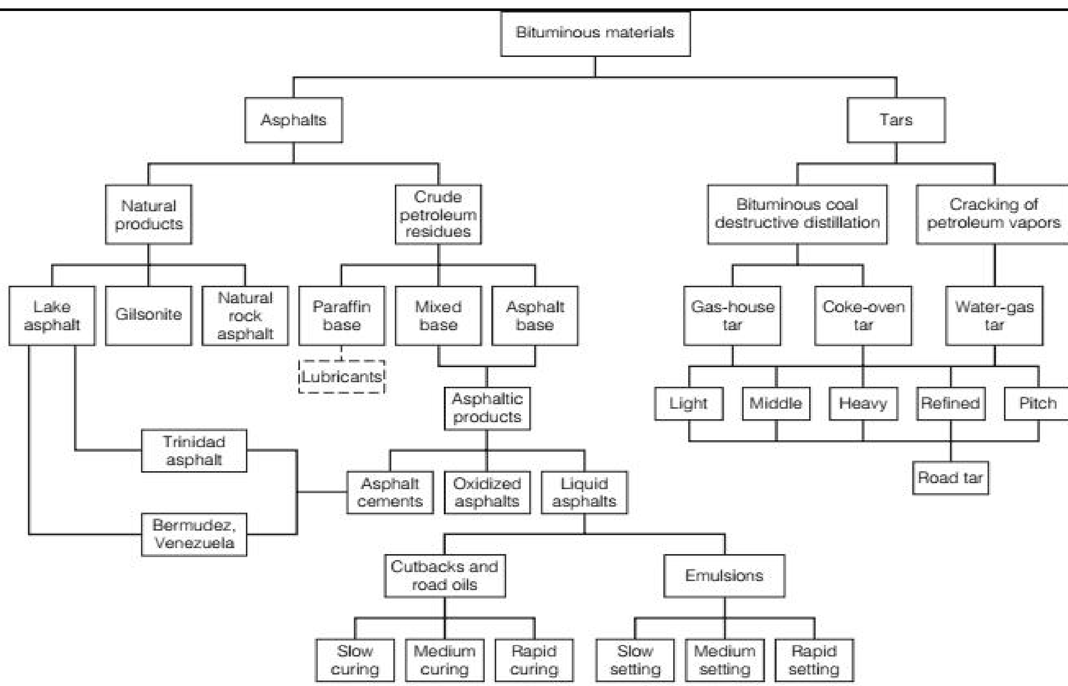


FIGURE 9.1 Classification of bituminous materials (Goetz and Wood, 1960).

Historical Background

Asphalt VS. Tars

ASPHALT	TARS
●Residue of petroleum (Separated by fractional distillation) or as native asphalt ●Used extensively as binders for highways ●Dissolve in petroleum oils ●Black color ●More resistance to weathering ●Less susceptible to temp. ●Has no odor ●Used in highways & airports	●Residues from the destructive distillation (chemical change) of organic substances such as coal, wood, or petroleum ●Crude tars must undergo further refinement to become road tars ●Do not dissolve in petroleum oils, therefore it is used to seat asphalt concrete surfaces to improve oil resistance of asphalt surfaces ●Brown or Black color ●Used in airport, auto parking, fueling areas. ●More expensive

Sources of asphalt

Natural Deposits
(Trinidad Lake Asphalt)

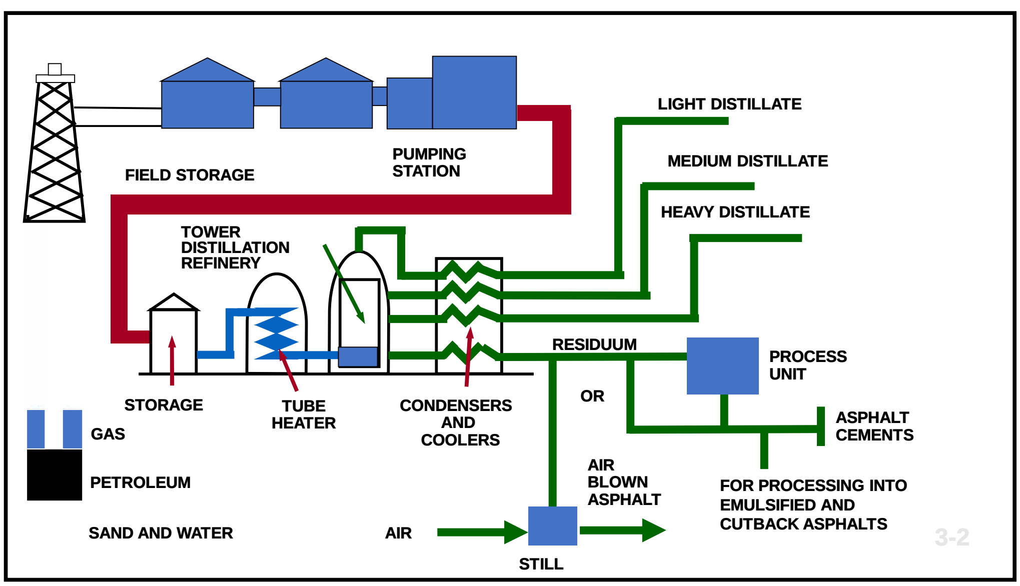
Petroleum Asphalt
(Chevron Hawai'I Refinery)

Images source : https://pavementinteractive.org/reference-desk/materials/asphalt/

Historical Background

- All bituminous materials have strong adhesive properties with colors ranging from dark brown to black.
- They vary in consistency from liquid to solid; thus, they are divided into liquids, semisolids, and solids.
- Asphalt cement is used **principally** in United States in paving application, since the Tar has
  - *some undesirable physical characteristics (e.g.. Very high temperature susceptibility)*
  - *Significant health hazards (e.g., sever eye and skin irritation when exposed to its fumes)*

Refinery Operation



Refinery Operation

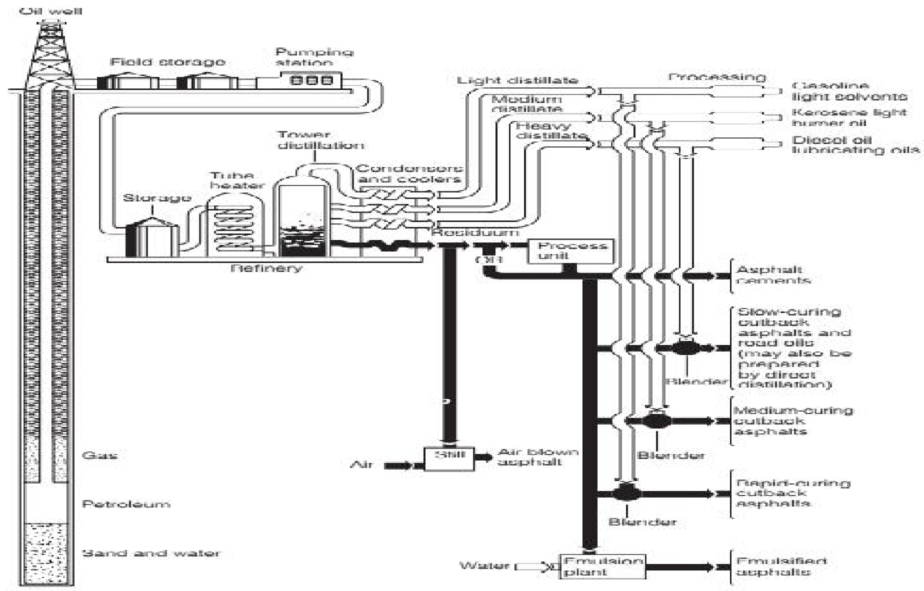


FIGURE 9.2 Distillation of crude petroleum (The Asphalt Institute, 2007).

Hi

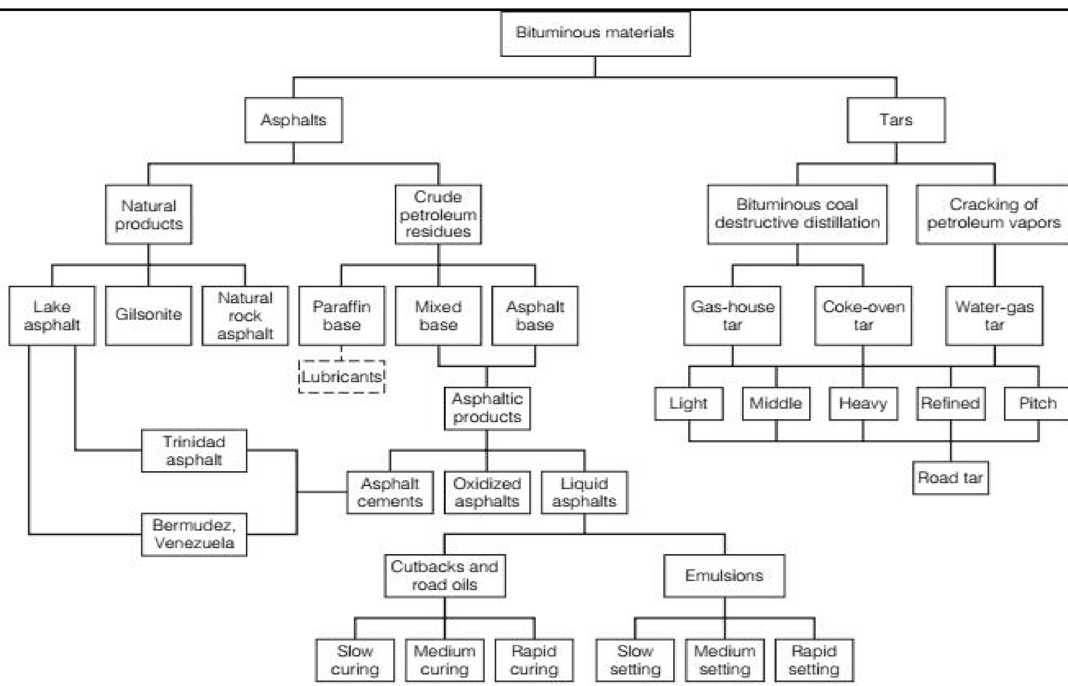


FIGURE 9.1 Classification of bituminous materials (Goetz and Wood, 1960).

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Asphalt types

- Asphalt most commonly used in flexible pavement construction can be divided into:

Asphalt cement (binder)

Emulsified asphalt

Cutback asphalt

Image source https://vaasphalt.org/liquid-asphalt/

Images soure https://pavementinteractive.org/sweet-emulsion-how-asphalt-and-water-combine/

https://www.wataniyagroup.com/productsdetail/11

Asphalt types

Asphalt cement

- Asphalt cement is a blend of hydrocarbons of different molecular weights.
- The characteristics of the asphalt depend on the chemical composition and the distribution of the molecular weight hydrocarbons.
  - *As the distribution shifts toward heavier molecular weights, the asphalt becomes harder and more viscous.*
- At room temperatures, asphalt cement is a semisolid material that cannot be applied readily as a binder without being heated
- Asphalt cement has excellent adhesive characteristics as compared to the liquid asphalt (cutback and emulsified asphalt), which make it a superior binder for pavement applications
- Asphalt cements are used mainly in the manufacture of hot-mix asphalt (HMA)

Asphalt types

Cutback asphalt

- A liquid asphalt which are manufactured by adding (cutting back) petroleum solvents to asphalt cement
  - *Cutback asphalt = AC + Petroleum solvent*
- They are made to reduce the asphalt viscosity for lower application temperature
- Application to aggregate or pavement causes the **solvent to escape by evaporation**, thus leaving the asphalt cement residue on the surface

Asphalt types

Cutback asphalt

Based on the relative rate of evaporation, cutback asphalts are divided into

- Rapid –Curing (RC)
  - *Produced by adding a high volatility solvent (generally gasoline or naphtha)*
  - *Primarily used for tack coat and surface treatment*
- Medium – Curing (MC)
  - *Produced by adding a intermediate volatility solvent (generally kerosene)*
  - *Primarily used for prime coat, stockpile patching mixtures, and road-mixing operation*
- Slow-Curing (SC) (or road oils)
  - *Produced by adding a low volatility solvent (generally diesel or other gas oils)*
  - *Primarily used for prime coat, stockpile patching mixtures, and dust palliatives*

Asphalt types

Cutback asphalt

Commercially available in different grades

- ➢*RC-70, RC-250, RC-800, RC-3000*
- ➢*MC-30, MC-70, MC-250, MC-800, MC-3000*

- The suffix numbers (i.e.,70, 250, 800, and 3000) represent the minimum kinematic viscosity in centistokes at 140 F
  - ➢ *The increase in the suffix numbers denoting increasingly higher viscosities number*
- The specifications for SC, MC, and RC cutbacks are given in ASTM D2026, D2027, and D2028, respectively

Asphalt types

Cutback asphalt

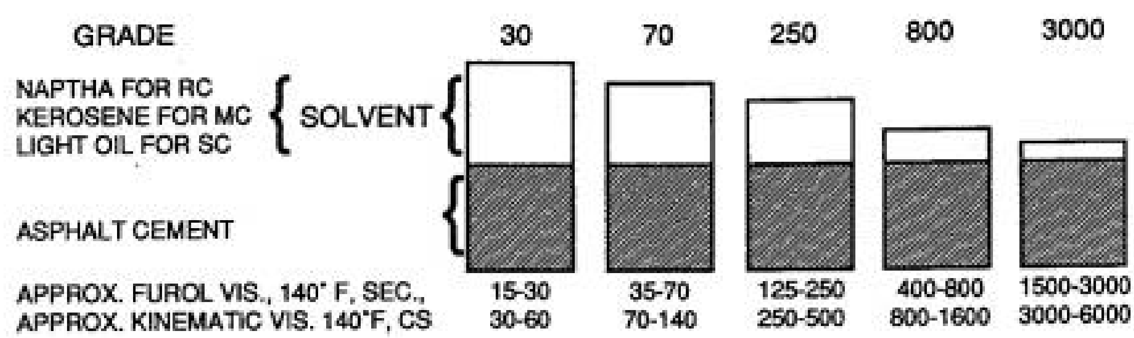


Figure 2–10. Composition of Cutback Asphalts

Asphalt types

Cutback asphal

Table 2–4. Selected Requirements for Rapid–Curing (RC) Cutback Asphalts

Tests	RC-70	RC-250	RC-800	RC-3000
Kinematic viscosity at 140°F(60°C),cSt	70-140	250-500	800-1600	3000-6000
Flash Point (Tag Open-cup) °F(°C), minimum	-	80(27)	80(27)	80(27)
Residue from distillation to 680°F(360°C), percent by volume, minimum	55	65	75	80
Tests on residue from distillation:				
Viscosity at 140°F(60°C), P	600-2400	600-2400	600-2400	600-2400
Ductility at 77°F(25°C), cm, minimum	100	100	100	100

Asphalt types

Cutback asphalt

Table 2–5. Selected Requirements for Medium–Curing (MC) Cutback Asphalts

Tests	MC-30	MC-70	MC-250	MC-800	MC-3000
Kinematic viscosity at 140°F(60°C),cSt	30-60	70-140	250-500	800-1600	3000-6000
Flash Point (Tag Open-cup) °F(°C), minimum	100(38)	100(38)	150(66)	150(66)	150(66)
Residue from distillation to 680°F(360°C), percent by volume, minimum	50	55	67	75	80
Tests on residue from distillation:					
Viscosity at 140°F(60°C), P	300-1200	300-1200	300-1200	300-1200	300-1200
Ductility at 77°F(25°C), cm, minimum	100	100	100	100	100

Specifications for highway and bridge construction

٨/أ– الوجه اللاصق (Tack Coat) :

••••••••••••••••••••

– تتم هذه الأعمال وفقاً لمواصفات انشاء الطرق والجسور لعام ١٩٩١ .
– تتم أعمال الوجه اللاصق بحيث يكون الاسفلت المستعمل من نوع (RC 250) أو (RC 800) وحسب طلب المهندس المشرف وبالمعدل الذي يتطلب واقع العمل وحسب نوع السطح المراد رشه .

٦– الوجه التأسيسي (Prime Coat) :

••••••••••••••••••••

١/٦– يجب أن يكون الاسفلت من نوع (MC-70) على أن يرش بمعدل(٧٥ر٠–٠ر٢) كغم/م٢ حسب نوعية السطح المراد رشه وبموجب تعليمات المهندس المشرف .

٧– الوجه الختامي (Seal Coat) :

••••••••••••••••••••

١/٧– تستعمل حصمة ناتج تكسير حجر جيري أو جرانيتي أو بازلتي وبالخواص المبينة في جدول رقم (٥) المرفق , وحسب مواصفات انشاء الطرق والجسور لعام ١٩٩١ .

٢/٧– يجب استعمال موزع حصمة ميكانيكي ورشاش أسفلت ميكانيكي .

٣/٧– يستعمل أسفلت أو (RC 800) أو (RC 250) ومعدل الرش حسب ما ورد في جدول رقم (٥) المرفق .

Asphalt types

Cutback asphalt

Cutback Asphalts used less frequently now and use of emulsions becoming more common because of :

- Env. Concerns (especially with RC's)
  - *Hydrocarbons evaporate into air.*
- Economic - costly to buy 2 petroleum products.
- Safety - low flash pts - danger of fire.
- Higher application temp, dry conditions required

Asphalt types

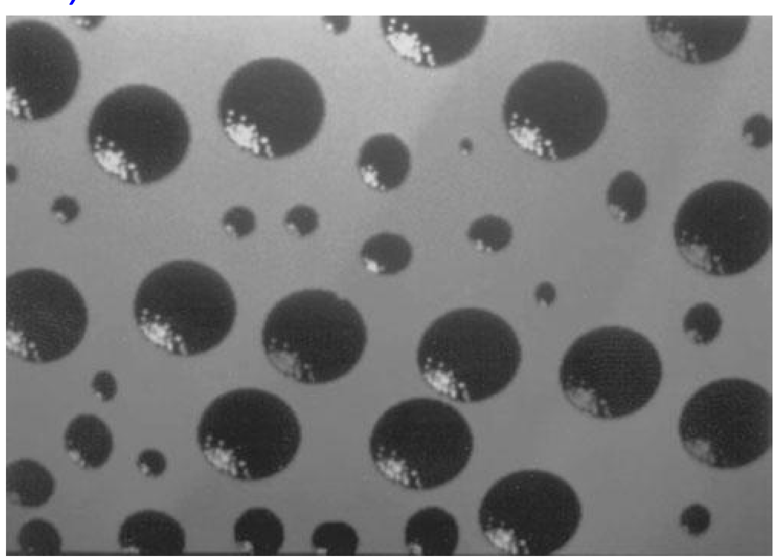
Emulsified asphalt (emulsion)

- It's a mixture of asphalt cement, water, and emulsifying agent (e.g., soap) (1-2% by volume).
- It classified as liquid asphalts because they are liquid at ambient temperatures
- Emulsions are made to reduce the asphalt viscosity for lower application temperatures
- Emulsifier gives surface charge to asphalt droplets suspended in water medium

Asphalt types

Emulsified asphalt (emulsion)

Photo of magnified asphalt emulsion showing minute droplets of asphalt cement dispersed in a water medium.



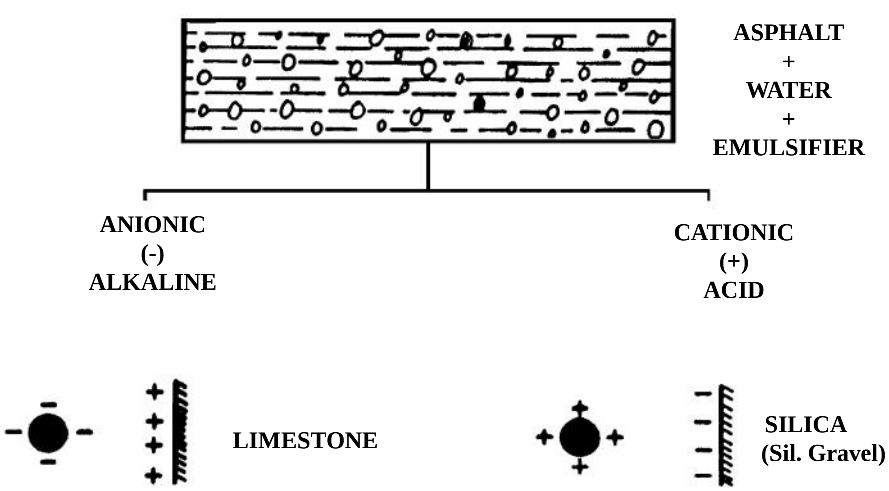
Asphalt types

Emulsified asphalt (emulsion)

- Two types of emulsified asphalts are commonly used (ASTM D977 and D2397)
- Anionic
  - *electro-negatively charged asphalt droplet*
  - *Alkaline*
  - *Good with aggregate that have a positive charge (limestones)*
- Cationic
  - *electro--positively charged asphalt droplet*
  - *Acid*
  - *Good with aggregate that have a negative charge (siliceous aggregate[sandstone, quartz, and siliceous gravel)*

Asphalt types

Emulsified asphalt (emulsion)



Asphalt types

Emulsified asphalt (emulsion)

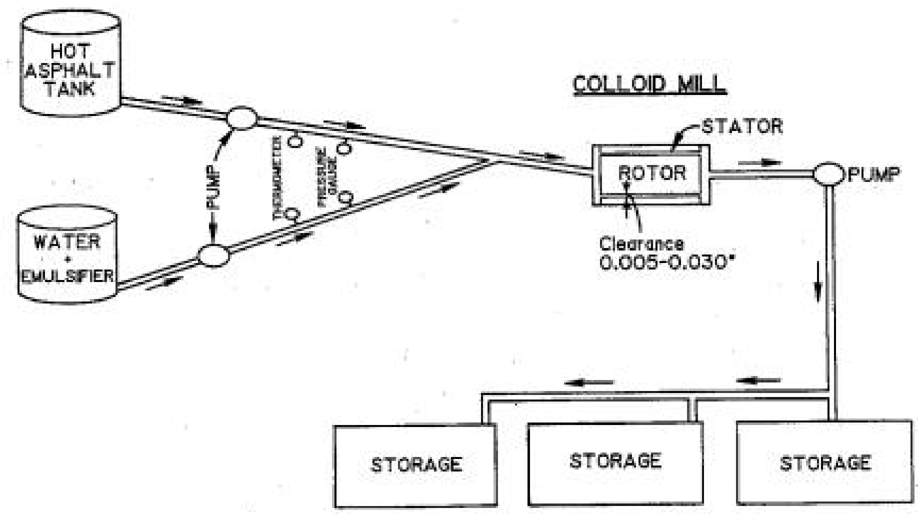


Figure 2–9. Manufacture of Emulsified Asphalt

Asphalt types

Emulsified asphalt (emulsion)

When an emulsified asphalt is mixed with an aggregate, it "sets" or "breaks" because the asphalt droplets react with the surface of the aggregate and coalesce, squeezing out the water between them. The evaporation of water is the primary method which finally causes the anionic emulsified asphalt to "break" or "set" and produce a continuous film of asphalt on the aggregate or pavement. Cationic emulsified asphalts break primarily by electro–chemical processes.

Asphalt types

Emulsified asphalt (emulsion)

- Emulsified asphalts are further graded according to their “setting” rate including
- The setting rate is controlled by the type and amount of the emulsifying agent
- Anionic emulsified asphalts are classified into
  - *Rapid setting (RS)*
  - *Medium setting(MS)*
  - *Slow setting (SS)*
- cationic emulsified asphalts are classified into
  - *Rapid setting (CRS)*
  - *Medium setting(CMS)*
  - *Slow setting (CSS)*

Table 2-2. Selected Requirements for Anionic Emulsified Asphalts

Tests	Rapid-Setting			Medium-Setting						Slow-Setting		
	RS-1	RS-2	HFRS-2	MS-1	MS-2	MS-2h	HFMS-1	HFMS-2	HFMS-2h	HFMS-2s	SS-1	SS-1h
Tests on emulsions:												
Viscosity, Saybolt Furol at 77°F	20-100	-	-	20-100	100+	100+	20-100	100+	100+	50+	20-100	20-100
Viscosity, Saybolt Furol at 122°F	-	75-400	75-400	-	-	-	20-100	100+	100+	50+	20-100	20-100
Minimum Residue by distillation, %	55	63	63	44	65	65	55	65	65	65	57	57
Tests on residue from distillation:												
Penetration at 77°F, 100 g, 5s	100-200	100-200	100-200	100-200	100-200	40-90	100-200	100-200	40-90	200+	100-200	40-90
Float test, 140°F, s	-	-	1200	-	-	-	1200	1200	1200	1200	-	-

Table 2–3. Selected Requirements for Cationic Emulsified Asphalts

Tests	Rapid-Setting		Medium Setting		Slow-Setting	
	CRS-1	CRS-2	CMS-2	CMS-2h	CSS-1	CSS-1h
Tests on emulsions: Viscosity, Saybolt Furol at 77°F	-	-	-	-	20-100	20-100
Viscosity, Saybolt Furol at 122°F	20-100	100-400	50-450	50-450	-	-
Distillation: Oil distillate, %	3	3	12	12	-	-
Minimum residue,%	60	65	65	65	57	57
Tests on residue from distillation test:						
Penetration at 77°F, 100 g, 5s	100-250	100-250	100-250	40-90	100-250	40-90

Asphalt types

Emulsified asphalt (emulsion)

- Rapid-setting grades are used for
  - *Surface treatment*
  - *Penetration macadams*
- Medium-setting grades are used for
  - *open-graded cold asphalt-aggregate mixture*
- Slow-setting grades are used for
  - *tack coat, fog seal, dense-graded cold asphalt-aggregate mixtures, and slurry seals*

Asphalt types

Emulsified asphalt (emulsion)

- Advantages of Emulsions
  - *Pollution free (i.e. no solvents required).*
  - *Used with no additional heat.*
  - *Less cost than cutback.*
  - *More energy efficient than cutback.*

Asphalt uses

TABLE 9.1 Paving Applications of Asphalt

Term	Description	Application
Hot mix asphalt	Carefully designed mixture of asphalt cement and aggregates	Pavement surface, patching
Cold mix	Mixture of aggregates and liquid asphalt	Patching, low volume road surface, asphalt stabilized base
Fog seal	Spray of diluted asphalt emulsion on existing pavement surface	Seal existing pavement surface
Prime coat	Spray coat asphalt emulsion to bond aggregate base and asphalt concrete surface	Construction of flexible pavement
Tack coat	Spray coat asphalt emulsion between lifts of asphalt concrete	Construction of new pavements or between an existing pavement and an overlay
Chip seal	Spray coat of asphalt emulsion (or asphalt cement or cutback) followed with aggregate layer	Maintenance of existing pavement or low volume road surfaces
Slurry seal	Mixture of emulsion, well-graded fine aggregate and water	Resurface low volume roads
Microsurfacing	Mixture of polymer modified emulsion, well-graded crushed fine aggregate, mineral filler, water, and additives	Texturing, sealing, crack filling, rut filling, and minor leveling

Asphalt uses

- Compaction of hot mix asphalt

Asphalt uses

- Applying fog seal (diluted emulsion) for preserving existing pavement

Asphalt uses

- Spraying tack coat (emulsion) on existing asphalt pavement before placing an asphalt overlay

Asphalt uses

- Applying microsurfacing for preserving existing pavement.

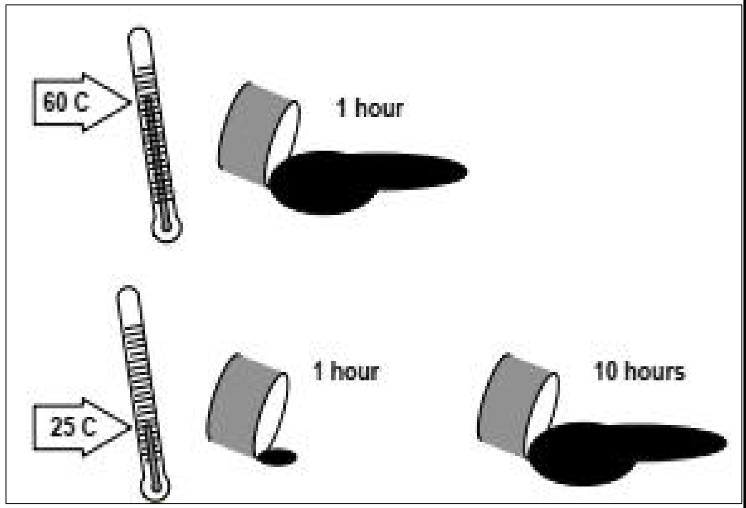
HOW ASPHALT BEHAVES

HOW ASPHALT BEHAVES

- Asphalt is a viscoelastic material.
  - *This term means that asphalt has the properties of*
    - a viscous material, such as motor oil, or more realistically, water,
    - an elastic material, such as a rubber. However, the property that
- Asphalt exhibits, whether viscous, elastic, or most often, a combination of both, depends on temperature and time of loading.
  - *The flow behavior of an asphalt could be the same for one hour at 60°C or 10 hours at 25°C*

HOW ASPHALT BEHAVES

- The behavior at high temperatures over short time periods is equivalent to what occurs at lower temperatures and longer times. This is often referred to as the time-temperature shift or superposition concept of asphalt cement



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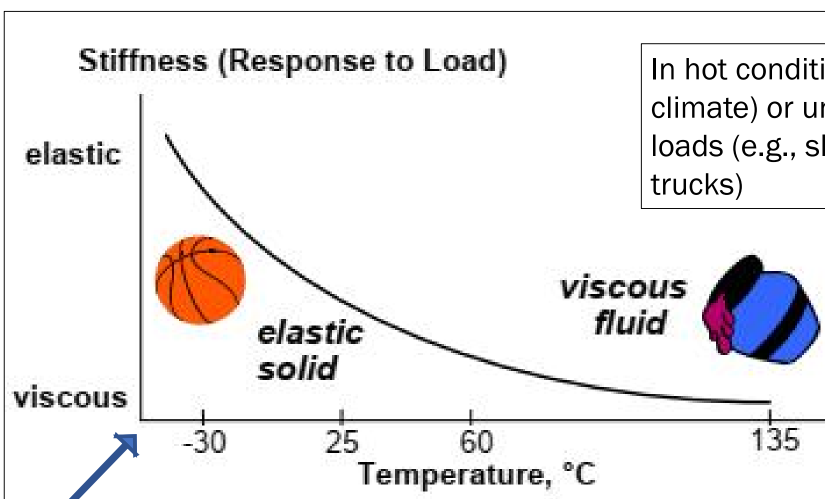
HOW ASPHALT BEHAVES

Temperature and loading effects



In hot conditions (e.g., desert climate) or under sustained loads (e.g., slow moving trucks)

In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks),

42

42

HOW ASPHALT BEHAVES

High Temperature Behavior

- In hot conditions (e.g., desert climate) or under sustained loads (e.g., slow moving trucks), asphalts cements behave like viscous liquids and flow.
- Viscosity is the material characteristic used to describe the resistance of liquids to flow
- Viscous liquids like hot asphalt are sometimes called *plastic* because once they start flowing, they do not return to their original position
  - ➢ *This is why in hot weather, some asphalt pavements flow under repeated wheel loads and wheel path ruts form.*

Flexible pavement distress

High severity rutting

HOW ASPHALT BEHAVES

Low Temperature Behavior

- In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks), asphalt cement behaves like an *elastic* solid.
- Elastic solids are like rubber bands; when loaded they deform, and when unloaded, they return to their original shape. Any elastic deformation is completely recovered

Flexible pavement distress

Transverse Cracking

HOW ASPHALT BEHAVES

Intermediate Temperature Behavior

- Most environmental conditions lie between the extreme hot and cold situations. In these climates, asphalt binders exhibit the characteristics of both viscous liquids and elastic solids

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Flexible pavement distress

High severity fatigue cracking

48

HOW ASPHALT BEHAVES

Aging Behavior

- Because asphalt cements are composed of organic molecules, they react with oxygen from the environment.
- This reaction is called oxidation and it changes the structure and composition of asphalt molecules.
- Oxidation causes the asphalt cement to become more brittle, generating the term oxidative hardening or age hardening
- Because of this hardening, old asphalt pavements are more susceptible to cracking

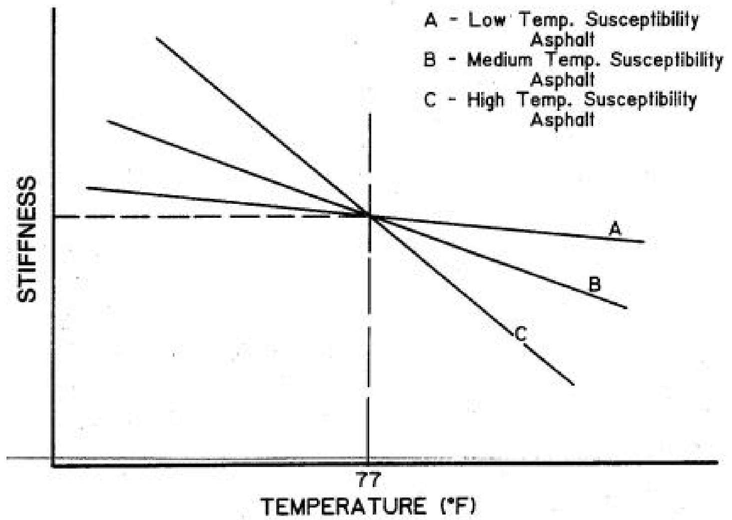
HOW ASPHALT BEHAVES

Aging Behavior

- There are two types of oxidations :
- Short-term aging
  - *During asphalt mix production and construction*
  - *Happens at fast rate*
- Long-term aging
  - During the life of the pavement, due to exposure to air and water
  - *Happens at a relatively slow rate in a pavement*

Asphalt binder grading systems

Temperature susceptibility of viscousity grading system



PAVEMENT MATERIALS & DESIGN (110 401466) SPRING 2019-2020

Lecture. No. 3
Bituminous materials
Part II
(Asphalt cement physical tests)

Dr. Hamza Alkuime

Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
Highway Materials • **Bituminous materials** • Soil • Aggregates	6	18
Pavement Types,	1	3
Flexible pavement design (design of Hot Mix Asphalt mixture using Marsha method	3	9
Flexible pavement design (design of pavement thicknesses using AASHTO method)	2	6
Earth work operations,	1	3
Drainage and drainage structures, and	1	3
Rehabilitation and Highway Maintenance	1	3

Highway Materials

References

- Federal Highway Administration, ***Superpave Fundamentals***,(https://idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-Handbooks/T2/P028.pdf)
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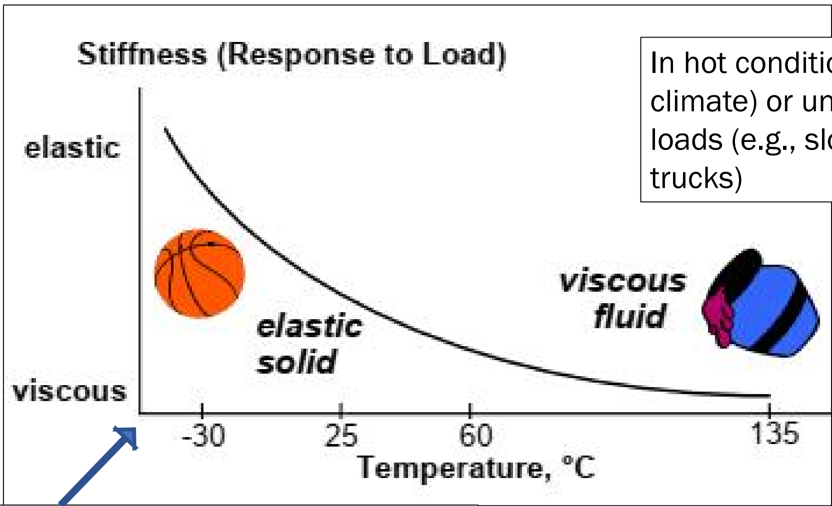
HOW ASPHALT BEHAVES

Temperature and loading effects



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In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks),

HOW ASPHALT BEHAVES

Aging Behavior

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HOW ASPHALT BEHAVES

Aging Behavior

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- Long-term aging
  - During the life of the pavement, due to exposure to air and water
  - *Happens at a relatively slow rate in a pavement*

Asphalt cement physical tests

- Physical testing on asphalt cements can be categorized as follows :
  - *Consistency tests*
  - *Durability tests*
  - *Purity tests*
  - *Safety tests*
  - *Other tests*

Asphalt cement physical tests

Consistency (viscosity) tests

- viscosity is the measure of a fluid's resistance to flow
  - *Golden syrup is highly viscous*
  - *Water is medium viscous*
  - *Gas is low viscous*
- Consistency describes the degree of fluidity of asphalt cement at any particular temperature.
- Higher **viscosity** usually means a comparatively higher **consistency**

Properties of Asphaltic Materials

Consistency

- Asphalt is a thermoplastic materials, thus it consistency varies with the temperature
- Considered under two conditions:
  - ➢ *Variation of consistency with temperature (temperature susceptibility)*
    - ❖ Consistency of any asphaltic material changes as temperature changes.
    - ❖ The change in consistency of different asphaltic materials may differ considerably even for the same amount of temperature change.
  - ➢ *Consistency at specified temperature*
    - ❖ Consistency of asphalt material will vary from solid to liquid depending on the temperature.
    - ❖ It is essential that when consistency is given the associated temperature should be given too.

Asphalt cement physical tests

Consistency (viscosity) tests

- Viscosity is the ratio between the applied shear stress and rate of shear is called the coefficient of viscosity.
- This coefficient is a measure of the resistance to flow of the
- liquid.
  - ➢ *It is commonly called the viscosity of the liquid.*
  - ➢ *The SI unit of viscosity is 1 Pa · s (1 N·s/m2) and is called a Pascal-second.*
- The cgs unit of viscosity is 1 g/cm·s (1 dyne·s/cm2) and is called a poise (P).
- 1 Pa · s is equivalent to 10 P.

Asphalt cement physical tests

Consistency (viscosity) tests

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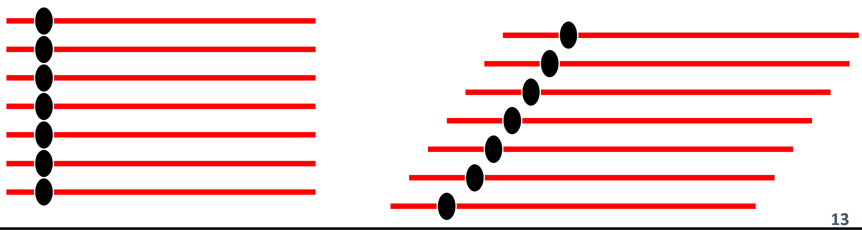
$$\eta = \tau^{\circ} / \gamma$$



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Asphalt cement physical tests

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity at 140°F (60° C)
2. Kinematic viscosity at 275 F (135° C)
3. Penetration test
4. Softening point
5. Ductility test

14

14

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

- Dynamic (absolute) viscosity is the tangential force per unit area required to move one horizontal plane with respect to an other plane - at an unit velocity
  - *It is a measure of internal resistance.*
- This test is performed **at 140îF (60î C)**,
  - *This temperature represent the maximum Hot Mix Asphalt (HMA) pavement **surface temperature** during the summer in the United states*
- Two types of capillary tube are used to perform the viscosity test
  - *Asphalt Institute Tube*
  - *Zietfuchs Cross-Arm Tube*

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

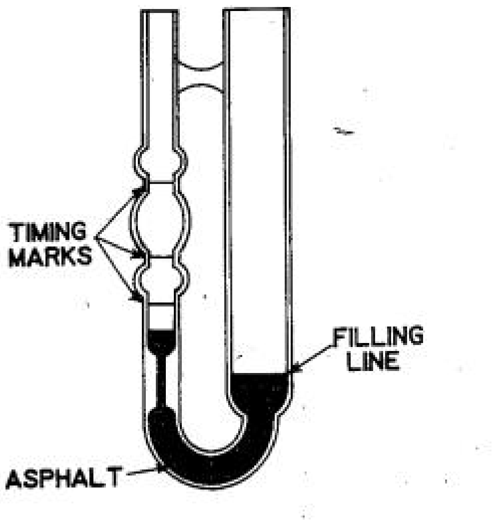


Figure 2–11. Cannon–Manning Vacuum Viscometer

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

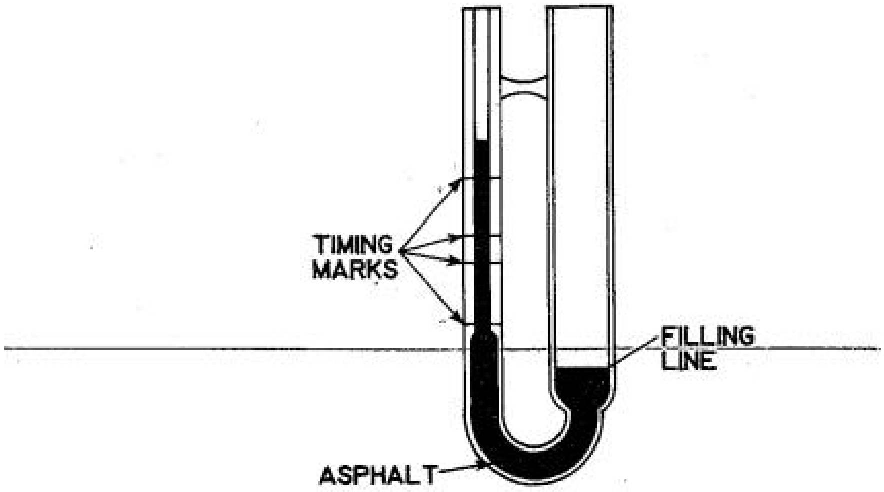
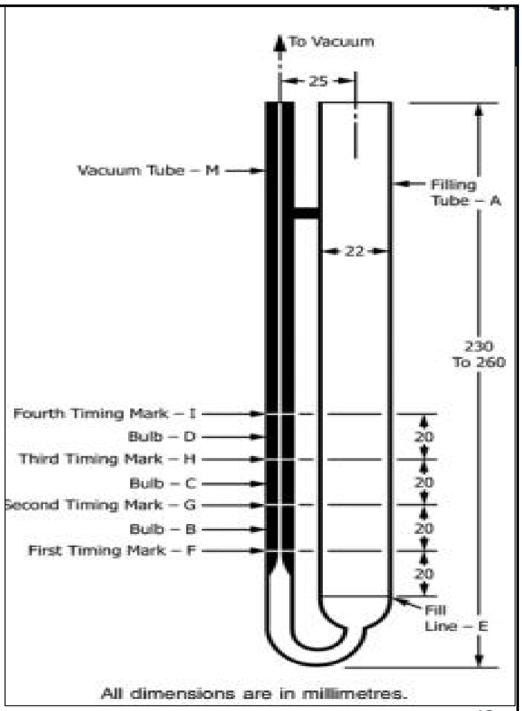


Figure 2–12. The Asphalt Institute Vacuum Viscometer

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

- The test is performed in accordance to ASTM D2171
- Summary of test method
  - *The time is measured for a fixed volume of the liquid to be drawn up through a capillary tube by means of vacuum, under closely controlled conditions of vacuum and temperature. The viscosity in Pascal-seconds is calculated by multiplying the flow time in seconds by the viscometer calibration factor*



Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

■ Calculation

➢ *Calculate and report the viscosity to three significant figures using the following equation:*

■ . ( ) (. .) = . ×

➢ *K = selected calibration factor, (Pa · s/s)*

➢ *t = flow time (s)*

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

TABLE X1.1 Standard Viscometer Sizes, Approximate Calibration Factors, *K* and Viscosity Ranges for Cannon-Manning Vacuum Capillary Viscometers

Viscometer Size Number	Approximate Calibration Factor, K,[A] 40 kPa [300 mm Hg] Vacuum, Pa · s/s (P/s/10)		Viscosity Range, Pa · s[B]	Viscosity Range, P[B]
	Bulb B	Bulb C		
4	0.0002	0.00006	0.0036 to 0.08	0.036 to 0.8
5	0.0006	0.0002	0.012 to 0.24	0.12 to 2.4
6	0.002	0.0006	0.036 to 0.8	0.36 to 8
7	0.006	0.002	0.12 to 2.4	1.2 to 24
8	0.02	0.006	0.36 to 8	3.6 to 80
9	0.06	0.02	1.2 to 24	12 to 240
10	0.2	0.06	3.6 to 80	36 to 800
11	0.6	0.2	12 to 240	120 to 2 400
12	2.0	0.6	36 to 800	360 to 8000
13	6.0	2.0	120 to 2 400	1 200 to 24 000
14	20.0	6.0	360 to 8 000	3 600 to 80 000

[A] Exact calibration factors must be determined with viscosity standards.
[B] The viscosity ranges shown in this table correspond to a filling time of 60 to 400 s. Longer flow times (up to 1000 s) may be used.

Consistency (viscosity) tests

1. Absolute (dynamic) viscosity test

Video source : https://www.youtube.com/watch?v=6NDjfKhkOn8&t=611s

Consistency (viscosity) tests

2. Kinematic viscosity test at 275îF (135î C)

- Kinematic viscosity
  - *is the ratio of - absolute (or dynamic) viscosity to density*
  - *a quantity in which no force is involved*
- This test is performed **at 275îF (135î C**),
  - *This temperature a approximates the **mixing and laydown** temperature used in the construction of HMA pavements*
- The test is performed in accordance with ASTM D2170
- The Zietfuchs Cross-Arm Tube are used to perform the Kinematic viscosity test
- The Kinematic viscosity is reported using unit of centistokes
  - *1 stoke = 100 centistokes*

Consistency (viscosity) tests

2. Kinematic viscosity test at 275îF (135î C)

- The Kinematic viscosity is reported using unit of centistokes
  - *1 centistokes (cSt) = 1 mm^2/s*
  - *1 stoke = 100 centistokes m*
- . ( ) = ———— ( )

Consistency (viscosity) tests

2. Kinematic viscosity test at 275îF (135î C)

Example 2–1: An asphalt cement has a kinematic viscosity of 800 centistokes. Its specific gravity is 1.03. What is its absolute viscosity in poises?

1 stoke = 100 centistokes

Absolute viscosity in poises = kinematic viscosity in stokes x specific gravity
= 8 x 1.03
= 8.24

Consistency (viscosity) tests

3. Penetration test

- At **<u>77îF (25î C</u>**), there is not simple method to measure the consistancey of asphalt binder
  - *This temperature a approximates the* ***<u>average service temperature of the HMA pavements</u>***
  - *Thus, the penetration test is used to measure the consistency of asphalt binder at this temperature* ***<u>empirically</u>***
- The test is performed in accordance to ASTM D5

Consistency (viscosity) tests

3. Penetration test

- The test is performed in accordance to ASTM D5
- *Penetration*
  - consistency of a bituminous material expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature
- Significance and Use
  - *The penetration test is used as a measure of consistency.*
  - *Higher values of penetration indicate softer consistency.*

Consistency (viscosity) tests

3. Penetration test

- The depth of penetration is measured in units of 0.1 mm (dmm)
  - ➢ *For example, if the needle penetrates 8 mm, the penetration of asphalt cement is 80*

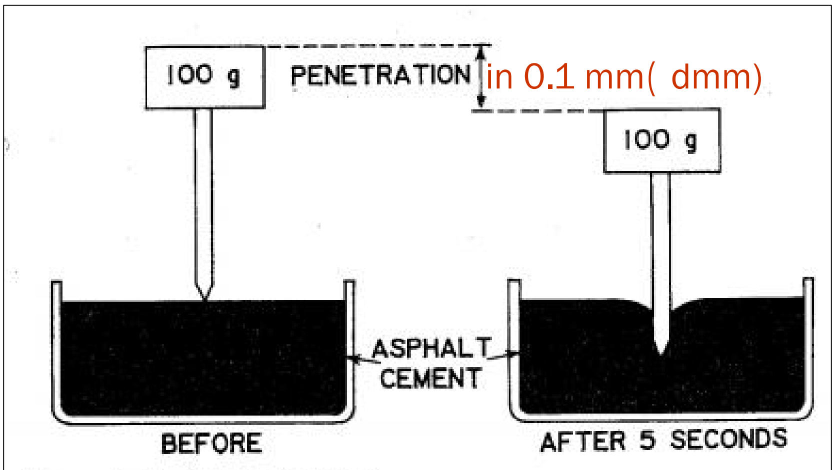


Figure 2–14. Penetration Test

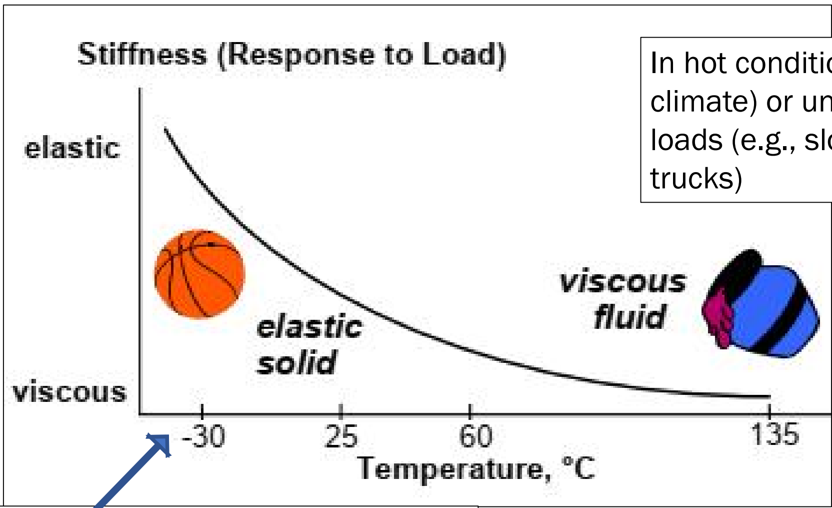
Consistency (viscosity) tests

3. Penetration test

Video source : https://www.youtube.com/watch?v=IGIFmQ3u-jE

HOW ASPHALT BEHAVES

Temperature and loading effects



In hot conditions (e.g., desert climate) or under sustained loads (e.g., slow moving trucks)

In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks),

Consistency (viscosity) tests

3. Penetration test

- The test is performed at 77 °F (25° C), but it could be perfumed at other temperatures (0,4, and 46° C)
- The needle load (penetration time) will be varied when using different temperature
  - *At low temperature (e.g. 46î C)*
    - The asphalt cement is very stiff and therefore pentratio of the needle is significantly lower
    - At these temperature, a 200 g weight and 60 second penetration time have been used

Consistency (viscosity) tests

3. Penetration test

8.1 Where the conditions of test are not specifically mentioned, the temperature, load, and time are understood to be 25°C [77°F], 100 g, and 5 s, respectively. Other conditions may be used for special testing, such as the following:

Temperature, °C [°F]	Load, g	Time, s
0 [32]	200	60
4 [39.2]	200	60
45 [113]	50	5
46.1 [115]	50	5

In such cases the specific conditions of test shall be reported.

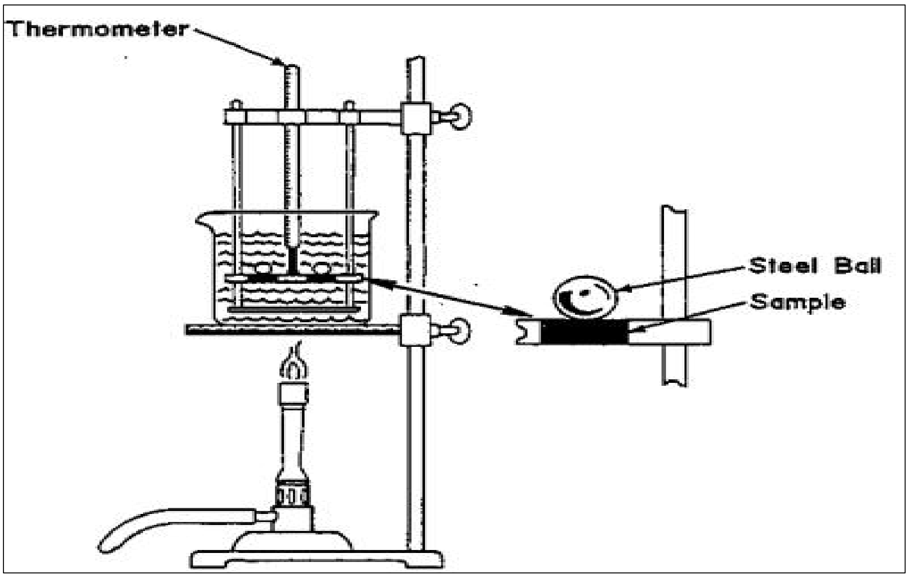
Consistency (viscosity) tests

4. Softening point test

- Definition
  - *It is the temperature at which an ashphalt cement cannot support the weight of a steel ball and starts flowing*
- Significance and use
  - *To determine the temperature at which a phase change occurs in the asphalt cement*
- It is measured by the ring and balls method in accordance with ASTM D36

Consistency (viscosity) tests

4. Softening point test



Consistency (viscosity) tests

4. Softening point test

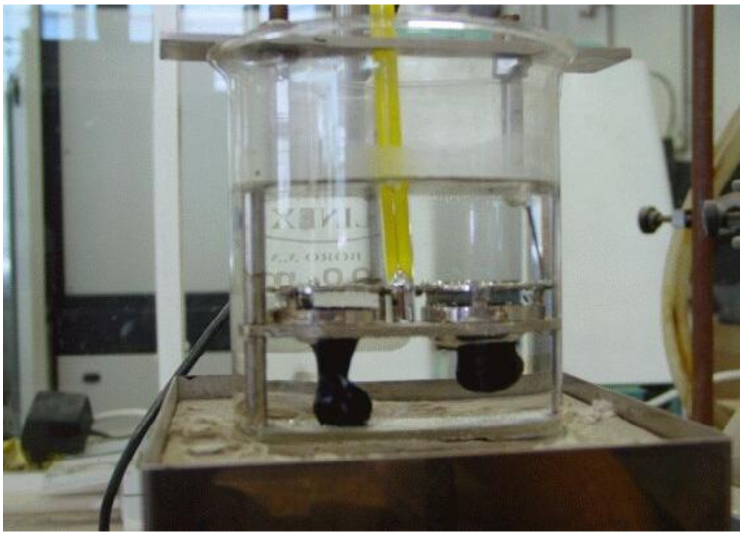


Image source :https://www.quora.com/What-is-penetration-test-and-softening-point-test-for-bitumen

Consistency (viscosity) tests

4. Softening point test

https://www.youtube.com/watch?v=wBptuNTDs1g

Consistency (viscosity) tests

6. Ductility test

- It is the distance in centimeters to which a standard sample may elongate without breaking.
- It is considered an important property of asphalt cement
- The test is performed in accordance with ASTM D113

Consistency (viscosity) tests

6. Ductility test

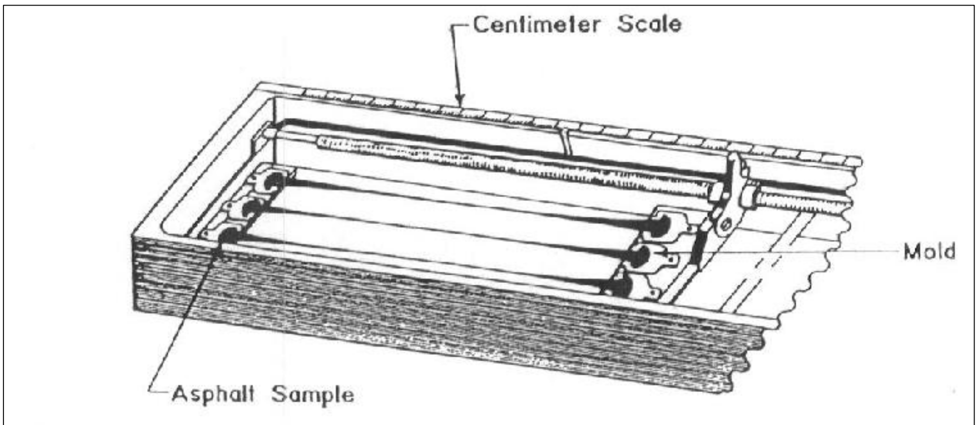


Figure 2-19. Ductility Test

- 25 ^{o}C, 5cm/min,
- Spec. +100 cm

Consistency (viscosity) tests

Ductility test

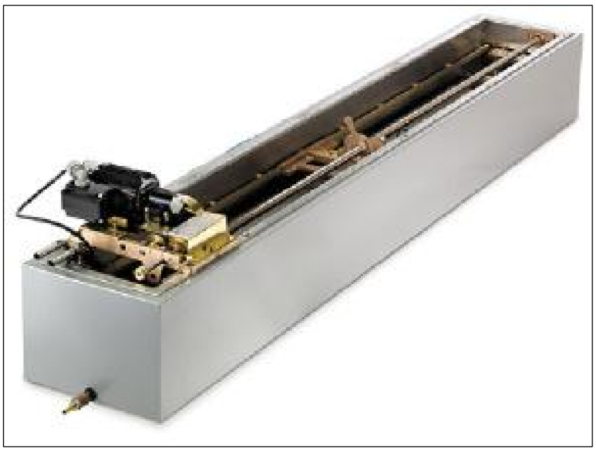


Image source : https://civilengineerspk.com/transportation-engineering-experiments/exp-11-ductility-test-on-asphalt/

Image source https://www.aboutcivil.org/to-perform-ductility-test-on-bitumen.html

Image source :https://docplayer.org/46071730-M-a-s-t-e-r-a-r-b-e-i-t-alterungsmechanismen-von-bitumen-und-simulation-der-alterung-im-labor-verfasser-markus-hospodka-bakk-techn.html

Consistency (viscosity) tests

Ductility test

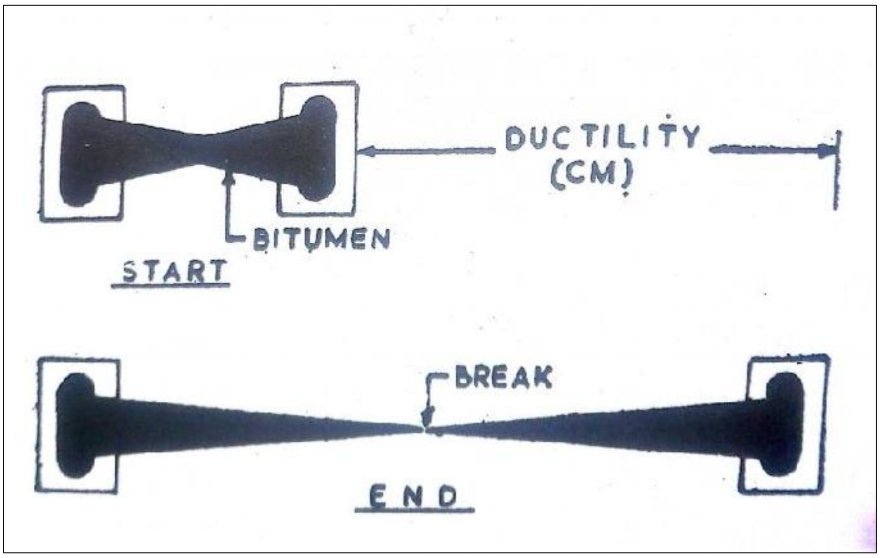


Image source :https://readcivil.com/ductility-test-of-bitumen-definition-procedure-determination-methods/

Consistency (viscosity) tests

Ductility test

Ductility test of bitumen (at beginning) sample in the Briquette

Image source https://cementconcrete.org/material-testing-guide/pavement-materials/ductility-test-of-bitumen/1204/

Consistency (viscosity) tests

Ductility test

Ductility test (At the yield point)

Image source https://cementconcrete.org/material-testing-guide/pavement-materials/ductility-test-of-bitumen/1204/

Consistency (viscosity) tests

Ductility test

Ductility test of Bitumen (on the stage of failure)

Image source https://cementconcrete.org/material-testing-guide/pavement-materials/ductility-test-of-bitumen/1204/

Properties of Asphaltic Materials

Durability

- When asphalt is exposed to environment, natural deterioration (weathering) gradually takes place, and the materials lose their plasticity and become brittle.
- For better performance weathering must be minimized.
- Durability :The ability of asphalt to resist weathering.
- Factors influencing weathering:
  - *Oxidation.*
  - *Volatilization.*
  - *Temperature.*
  - *Exposed surface area.*
  - *Age hardening.*

Properties of Asphaltic Materials

Durability

- Oxidation:
  - *oxygen attack asphalt…*
  - *cause hardening and loss of plastic characteristics.*
- Volatilization:
  - *evaporation of lighter hydrocarbons from asphalt…. Cause loss of plastic characteristics.*

Properties of Asphaltic Materials

Durability

- Temperature:
  - *higher temperature cause higher oxidation and volatilization… non linear.*
- Exposed surface area:
  - *as area increases rate of oxidation and volatilization increases.*
- Age hardening:
  - *if sample is heated and then allowed to cool, its molecules will be rearranged to form a gel-like structure, which will cause continuous hardening of the asphalt over time even if its protected from oxidation or volatilization. Rate of age hardening is high in the first few hours but gradually decrease (negligible after 1 year).*

Durability tests

1. Thin Film Oven test
2. Rolling Thin Film Oven Test
3. Distillation
4. Loss on heating

Durability tests

1. Thin Film Oven test (TFO)

- It is used to simulate hardening (durability) characteristic of asphalt binder during mix production and construction (Short-term ageing)
- The test is performed in accordance with ASTM D1754

Durability tests

1. Thin Film Oven test (TFO)

- The consistency of the material is determined before and after the TFO procedure using either the penetration test or a viscosity test to estimate the amount of hardening that will take place in the material when used to produce plant hot-mix asphalt.
  - *The specimen shall have a minimum percentage retained penetration or maximum viscosity*

Durability tests

1. Thin Film Oven test (TFO)

Asphalt cement (original)

Short-term

Consistency tests (Asphalt residue)

- Viscosity
- Penetration
- Ductility

Durability tests

1. Thin Film Oven test

Video source : https://www.youtube.com/watch?v=VSg0EXqbNak

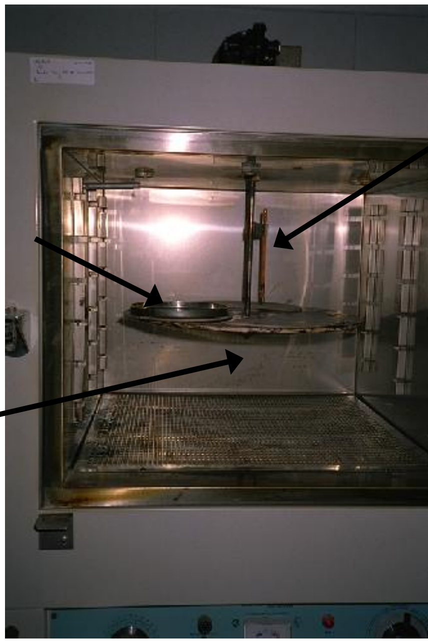
Durability tests

1. Thin Film Oven test

Outside of Oven

Pan

Rotating Shelf



Thermometer

Durability tests

2. Rolling Thin Film Oven test (RTFO)

- It has the same purpose as the TFO, but the test setup was modified
- The RTFO have several advantages over the TFO including
  - *Less testing time*
  - *Applity to test large number of samples*

HOW ASPHALT BEHAVES

Aging Behavior

- There are two types of oxidations :
- Short-term aging
  - *During asphalt mix production and construction*
  - *Happens at fast rate*
- Long-term aging
  - During the life of the pavement, due to exposure to air and water
  - *Happens at a relatively slow rate in a pavement*

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Durability tests

2. Rolling Thin Film Oven test (RTFO)

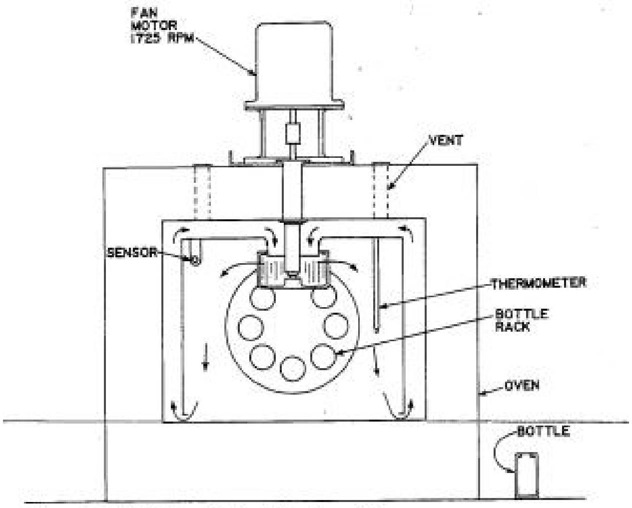

Figure 2–18. Rolling Thin Film Oven Test

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Durability tests

2. Rolling Thin Film Oven test (RTFO)

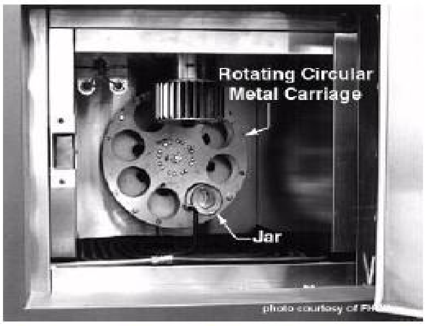


Figure : Rolling Thin-Film Oven Test

Figure : RTFO Samples
(left - after aging in the RTFO,
center - before aging in the RTFO,
right - empty sample jar)

Durability tests

2. Rolling Thin Film Oven test (RTFO)

Video source : https://www.youtube.com/watch?v=3SwRYEg1FCQ

Durability tests

3. Distillation test

- Used to separate volatile from nonvolatile substances.
- Distillation used in Cutback asphalt

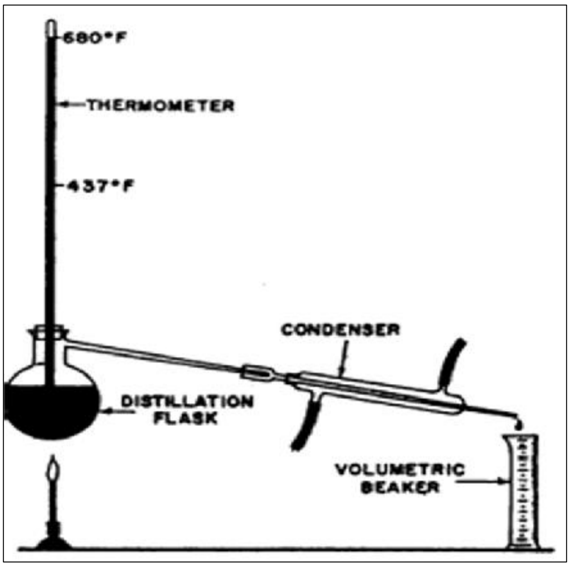


Image source: http://www.tpub.com/inteng/13s.htm

57

57

Durability tests

3. Distillation test

Image source: https://www.humboldtmfg.com/product-images/std/H-1910.png

58

58

Durability tests

4. Loss on Heating test

- Loss on heating: determine % of volatile material.
- 50 g in container put in oven @ 163 o C for 5 hrs, then find loss in wt.

Purity tests

1. Solubility test.
2. Presence of water

Purity tests

1. Solubility test

1. Measures the purity of asphalt
2. The test is conducted in accordance with ASTM D2042
3. 2 g of AC dissolved in 100 ml of trichloroethylene and filtered through a fiberglass filter pad.
4. Amount of material retained on the filter is weighed and expressed as % of original sample.
5. Spec. + 99% pure.

Purity tests

1. Solubility test

Purity tests

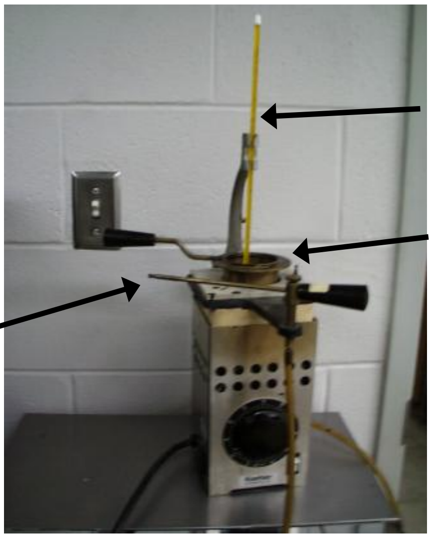
2. Presence of Water

- Water present in asphalt cause asphalt to foam when heated above 100 C.
- Water content test:
  - *Asphalt sample mixed with suitable distillate in a distillation flask connected with a condenser.*
  - *Sample gradually heated.*
  - *The quantity of water collected is then expressed as a percent of the total sample volume.*

Safety test (Flash and fire point test)

- The test is conducted in accordance with ASTM D2042 (Cleveland Open cup).
- AC heated at specified rate.
  - *Flames pass across the surface.*
  - *Min temp. at which sparks appear on the AC surface is reported as flash point.*
  - *Min temp. at which the AC surface ignite and burn at least for 5 second is reported as fire point.*

Safety test (Flash and fire point test)



Thermometer

Cup filled with asphalt

Wand attached to gas line

Safety test (Flash and fire point test)

Video source: https://www.youtube.com/watch?v=uUjqdxt7ud0

Other tests

Specific Gravity (S.G)

- Specific gravity is defined as the ratio of the mass of the material at a given temperature to the mass of an equal volume of water at the same temperature.
- The asphalt cement expands on heating, therefore, a specific gravity determination is useful for
  - *Making temperature-volume corrections*
  - *Determining the weight per unit volume of asphalt cement heated to its application temperature.*

Other tests

Specific Gravity (S.G)

- The test is performed in accordance with ASTM D70 (the pycnometer method)
- The results reported the S.G at a given temperature for both asphalt and water
  - *For example S.G of 1..02 ar 15.6 îC/15.6 î C*
    - Means that the asphalt cement specific gravity is 1.02 when both the asphalt and water has temperature of 15.6 ° C

Other tests

Specific Gravity (S.G)

- The pycnometer method is used to determine the specific gravity of asphalt cements.

Other tests

Specific Gravity (S.G)

- Calculate the S.G. as indicated in the following equ:
- $. \; . \quad = \frac{(\quad . \quad)}{[(\quad . \quad) - (\quad\quad)]}$
- A = mass of pycnometer (plus stopper),
- B = mass of pycnometer filled with water,
- C = mass of pycnometer partially filled with asphalt
- D = mass of pycnometer plus asphalt plus water.

Other tests

Specific Gravity (S.G)

- . = . . ×
- Where
  - = *density of water at the test temperature*
    - At 25ºC, = 997.0 kg/m3

Superpave physical tests for asphalt binders

Superpave: The Future of Asphalt

- Superpave is an acronym for Superior Performing Asphalt Pavements
- Superpave is a new, comprehensive asphalt mix design and analysis system, a product of the Strategic Highway Research Program.
- Congress established SHRP in 1987 as a five-year, $150 million research program to improve the performance and durability of United States roads and to make those roads safer for both motorists and highway workers.
  - *$50 million of the SHRP research funds were used for the development of performance-based asphalt material specifications to relate laboratory analysis with field performance*

Superpave: The Future of Asphalt

Limitation of pre-superpave asphalt property measurements

- Many of these tests are empirical, meaning that field experience is required before the test results yield meaningful information.
  Penetration is an example of this.
  - *The penetration test represents the stiffness of the asphalt, but any relationship between asphalt penetration and performance has to be gained by experience.*
  - *An additional drawback of empiricism is that the relationship between the test and performance may not be very good.*

Superpave: The Future of Asphalt

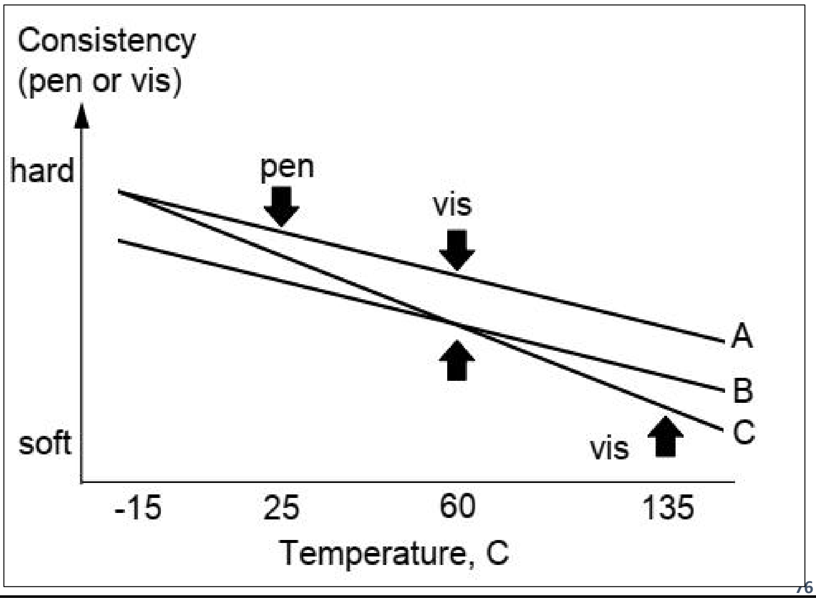
Limitation of pre-superpave asphalt property measurements

- Another limitation to these tests and specifications is that the tests do not give information for the entire range of typical pavement temperatures.
  - *Although viscosity is a fundamental measure of flow, it only provides information about higher temperature viscous behavior -- the standard test temperatures are 60°C and 135 °C.*
  - *Lower temperature elastic behavior cannot be realistically determined from this data to completely predict performance.*
  - *As well, penetration describes only the consistency at a medium temperature (25°C). No low temperature properties are directly measured in the current grading systems*
- The penetration and viscosity asphalt specifications can classify different asphalts with the same grading, when in fact these asphalts may have very different temperature and performance characteristics

Superpave: The Future of Asphalt

Limitation of pre-superpave asphalt property measurements

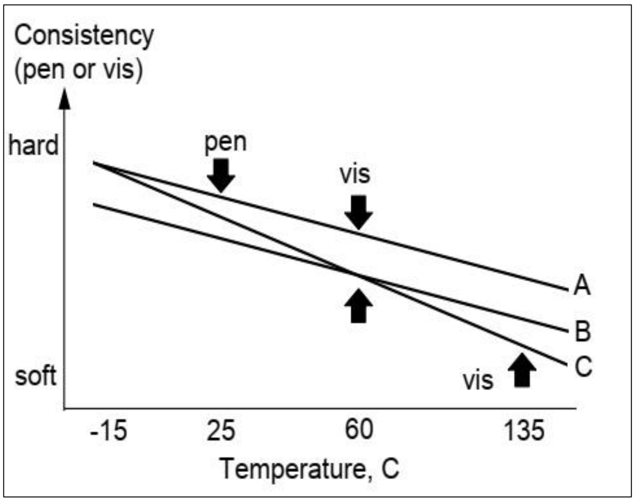
- This figure shows three asphalts that have the same viscosity grade because they are within the specified viscosity limits at 60°C, have the minimum penetration at 25°C, and reach the minimum viscosity at 135°C



Superpave: The Future of Asphalt

Limitation of pre-superpave asphalt property measurements

- Asphalts A and B display the same temperature dependency, they have much different consistency at all temperatures
- Asphalts A and C have the same consistency at low temperatures, but remarkably different high temperature consistency
- Asphalt B has the same consistency at 60°C, but shares no other similarities with Asphalt
- Because these asphalts meet the same grade specifications, one might erroneously expect the same characteristics during construction and the same performance during hot and cold weather conditions.



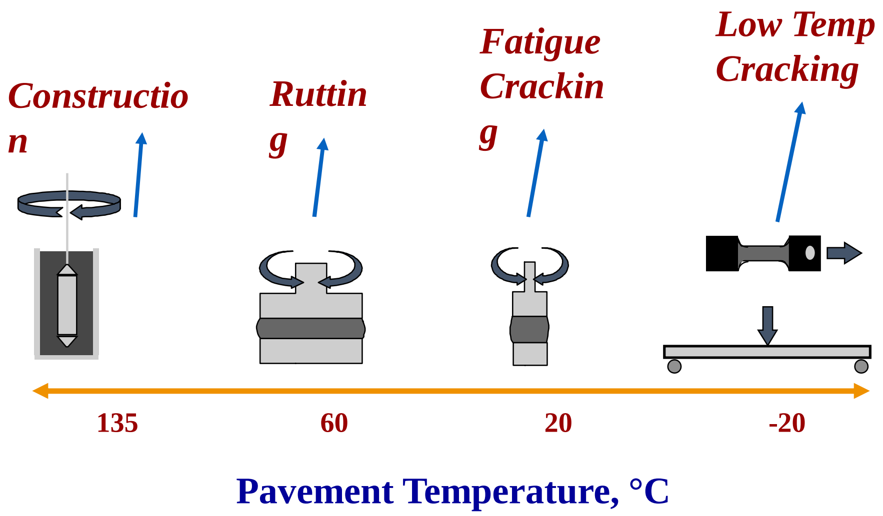
Superpave: The Future of Asphalt

Superpave binder property measurements

Equipment	Purpose	Performance Parameter
Rolling Thin Film Oven (RTFO)	Simulate binder aging (hardening) during HMA production and construction	Resistance to aging (durability) during construction
Pressure Aging Vessel (PAV)	Simulate binder aging (hardening) during HMA service life	Resistance to aging (durability) during service life
Rotational Viscometer (RV)	Measure binder properties at high construction temperatures	Handling and pumping
Dynamic Shear Rheometer (DSR)	Measure binder properties at high and intermediate service temperatures	Resistance to permanent deformation (rutting) and fatigue cracking
Bending Beam Rheometer (BBR)	Measure binder properties at low service temperatures	Resistance to thermal cracking
Direct Tension Tester (DTT)	Measure binder properties at low service temperatures	Resistance to thermal cracking

Superpave: The Future of Asphalt

Superpave binder property measurements



Superpave: The Future of Asphalt

Superpave binder property measurements

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Superpave: The Future of Asphalt

Superpave binder property measurements

struction temperatures

Dynamic Shear Rheometer (DSR)	Measure binder properties at high and intermediate service temperatures	Resistance to permanent deformation (rutting) and fatigue cracking
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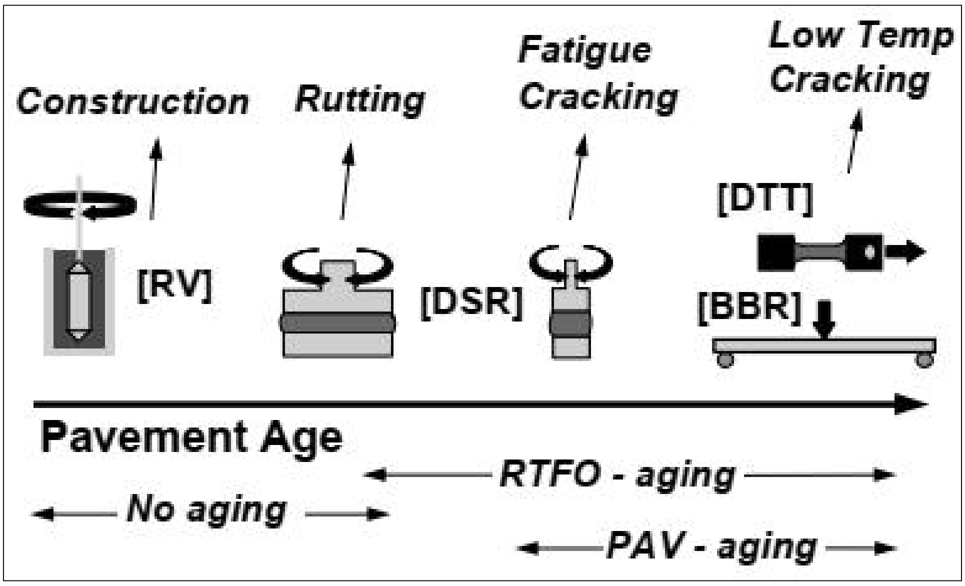
Superpave: The Future of Asphalt

Superpave binder property measurements



Superpave: The Future of Asphalt

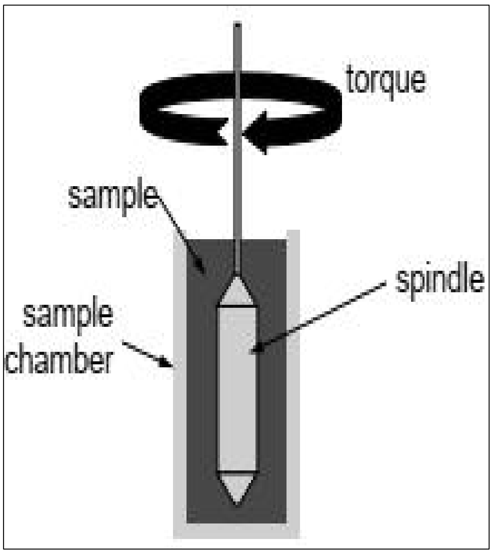
Rotational viscometer (Brookfield viscosity)

- Rotational viscosity is used to evaluate high temperature workability of binders
  - *High temperature binder viscosity is measured to ensure that the asphalt is fluid enough when pumping and mixing*
- A rotational coaxial cylinder viscometer, such as the Brookfield apparatus is used rather than a capillary viscometer
- The test is performed in accordance with AASHTO TP48

Superpave: The Future of Asphalt

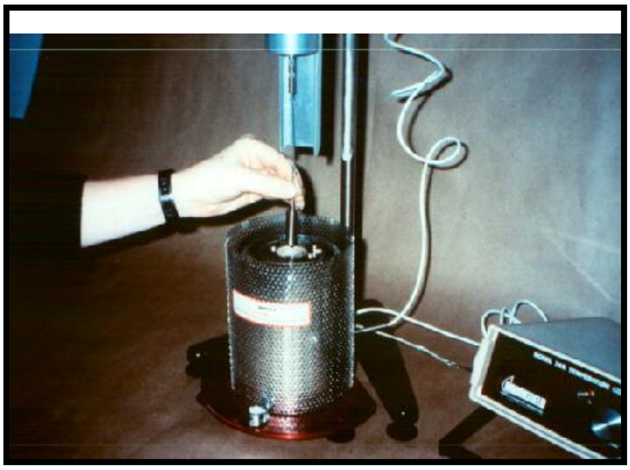
Rotational viscometer (Brookfield viscosity)

- Rotational viscosity is determined by measuring the torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in a sample at a constant temperature
- The torque required to rotate the spindle at a constant speed is directly related to the viscosity of the binder sample, which is determined automatically by the viscometer



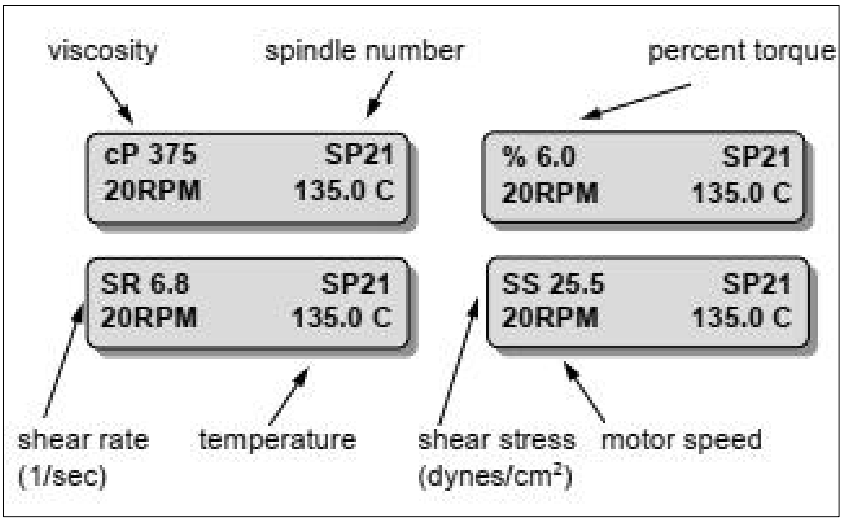
Superpave: The Future of Asphalt

Rotational viscometer (Brookfield viscosity)



Superpave: The Future of Asphalt

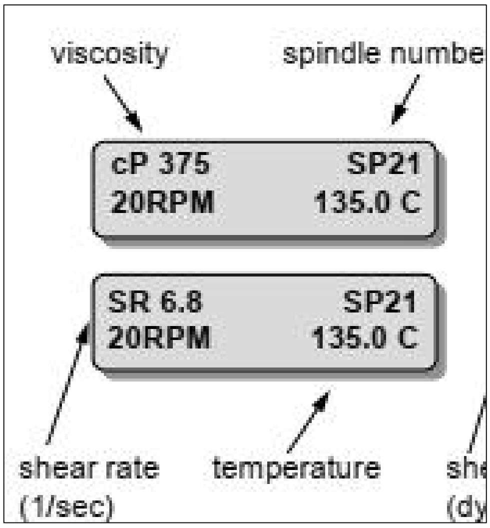
Rotational viscometer (Brookfield viscosity)



Superpave: The Future of Asphalt

Rotational viscometer (Brookfield viscosity)

- The viscosity at 135°C is reported.
- The digital output of the rotational viscosity test is viscosity in units of centipoise (cP)
  - *1000 cP = 1 Pa.s*



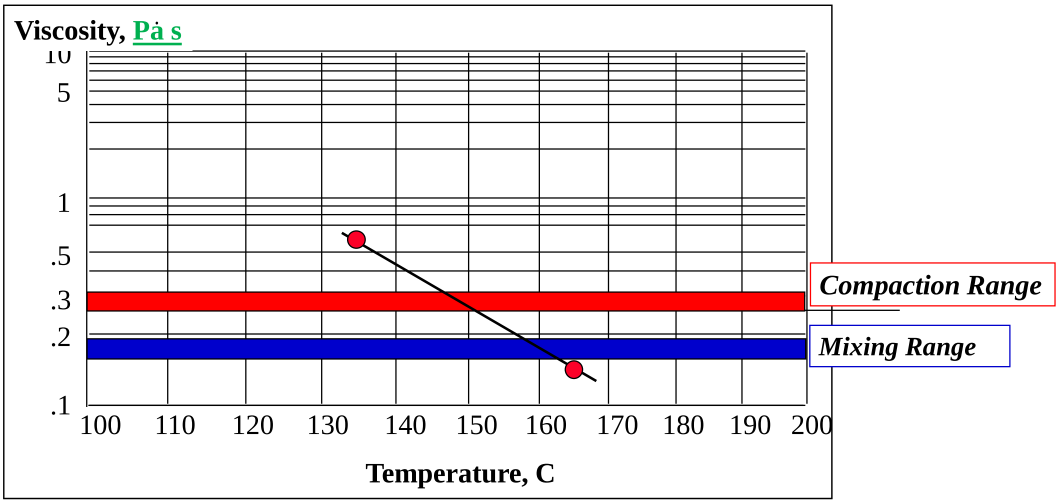
Superpave: The Future of Asphalt

Rotational viscometer (Brookfield viscosity)

Video source :https://www.youtube.com/watch?v=qhFVc5bw3bc

Superpave: The Future of Asphalt

Rotational viscometer (Brookfield viscosity)



Mixing viscosity range (0.170 ± 20 Pa·s) or (170 +- 20 CSt)

Compaction viscosity range (0.280 ± 30 Pa·s) or (280 +- 30 Cst)

Other Properties of Asphaltic Materials

Properties of Asphaltic Materials

Rate of Curing

- Rate of curing of Asphalt Emulsions
  - *Lower curing with high humidity, loDepend on the rate of water evaporates from the mixture.*
  - *temperature, and rain.*
  - *Cationic release their water more rapidly.*

Properties of Asphaltic Materials

Resistance to Water Action

- Its important that asphalt continue to adhere to the aggregate even with the presence of water.
- Asphalt will strip from the aggregate if the bond is lost which will result in deterioration of the pavement.
- In HMA stripping does not normally occur.
- Commercial anti stripping additives are usually added to improve asphalt ability to adhere to asphalt.

PAVEMENT MATERIALS & DESIGN (110 401466) SPRING 2019-2020

Lecture. No. 4
Bituminous materials
Part III
(Asphalt cement grading systems)

Dr. Hamza Alkuime

Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
Highway Materials • **Bituminous materials** • Soil • Aggregates	6	18
Pavement Types,	1	3
Flexible pavement design (design of Hot Mix Asphalt mixture using Marsha method	3	9
Flexible pavement design (design of pavement thicknesses using AASHTO method)	2	6
Earth work operations,	1	3
Drainage and drainage structures, and	1	3
Rehabilitation and Highway Maintenance	1	3

Highway Materials

References

- Federal Highway Administration, ***Superpave Fundamentals***,(https://idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-Handbooks/T2/P028.pdf)
- E. Ray and Prithvi S. Kandhal and Freddy et al., ***hot mix asphalt materials mixture design and construction***, 2th Edition., 1996
  - *Chapter 2 :Ashalt refning, uses and properties*

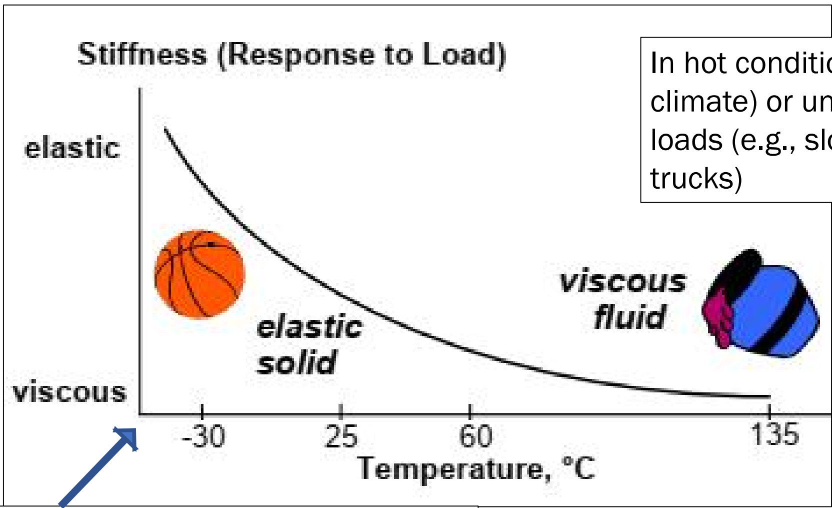
Highway Materials

References

- Nicholas Garber and Lester Hoel ,***Traffic & Highway Engineering***, 5th Edition.. Cengage Learning, 2015
  - *Chapter 18 :Bituminous materials*
- Michael S. Mamlouk and JohnP, Zaniewski, ***Traffic & Highway Engineering***, 3th Edition.. Pearson, 2011
  - *Chapter 19 :ASPHALT BINDERS AND ASPHALT MIXTURES*

Review

Temperature and loading effects



In hot conditions (e.g., desert climate) or under sustained loads (e.g., slow moving trucks)

In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks),

Review

Aging Behavior

- There are two types of oxidations :
- Short-term aging
  - *During asphalt mix production and construction*
  - *Happens at fast rate*
- Long-term aging
  - During the life of the pavement, due to exposure to air and water
  - *Happens at a relatively slow rate in a pavement*

Review

■ Physical testing on asphalt cements can be categorized as follows :

- *Consistency tests*
- *Durability tests*
- *Purity tests*
- *Safety tests*
- *Other tests*

Review

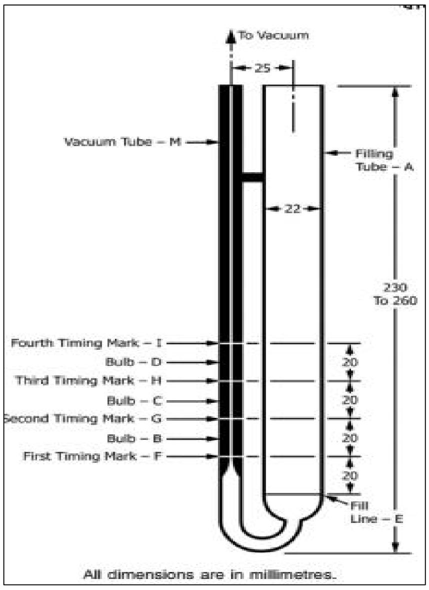
Consistency (viscosity) tests

1. Absolute (dynamic) viscosity at 140°F (60° C)
2. Kinematic viscosity at 275 F (135° C)
3. Penetration test
4. Softening point
5. Ductility test

Review

1. Absolute (dynamic) viscosity test

- This test is performed **<u>at 140îF (60î C</u>)**,
- Calculation
  - ➢ *Calculate and report the viscosity to three significant figures using the following equation:*
- ( ) (.) = ×
  - ➢ *K = selected calibration factor, (Pa · s/s)*
  - ➢ *t = flow time (s)*



Review

2. Kinematic viscosity test at 275îF (135î C)

- Kinematic viscosity
  - ➢ *is the ratio of - absolute (or dynamic) viscosity to density*
- This test is performed **<u>at 275îF (135î C</u>)**,
- The Kinematic viscosity is reported using unit of centistokes
  - ➢ *1 stoke = 100 centistokes*
- ( ) = $\frac{(\quad)}{\quad}$

Review

3. Penetration test

- At **77îF (25î C)**, there is not simple method to measure the consistancey of asphalt binder
- The depth of penetration is measured in units of 0.1 mm (dmm)
  - *For example, if the needle penetrates 8 mm, the penetration of asphalt cement is 80*

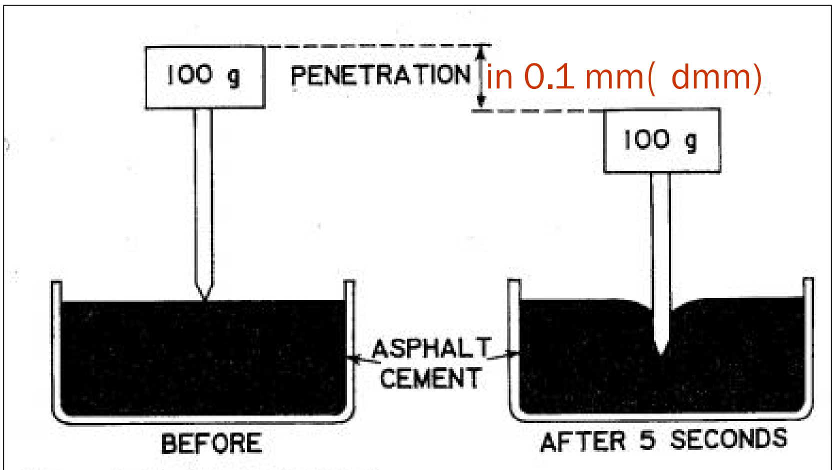


Figure 2–14. Penetration Test

Review

1. Thin Film Oven test (TFO)

It is used to simulate hardening (durability) characteristic of asphalt binder during mix production and construction (Short-term ageing)

Asphalt cement (original)

↓

Short-term

↓

Consistency tests (Asphalt residue)

Viscosity	Penetration	Ductility

Asphalt Cement Grading System

13

Asphalt binder grading systems

- Grading By Chewing
- Penetration Grading system
- Viscosity Grading system based on original asphalt cement (AC system)
- Viscosity Grading system based on aged asphalt cement (AR system)
- Superpave Performance Grade (PG) system

14

Asphalt binder grading systems

Penetration Grading system

- Binder are classified based on penetration test results
- Five penetration results are specified

Grade	Penetration min.	Penetration max.
40–50	40	50
60–70	60	70
85–100	85	100
120–150	120	150
200–300	200	300

Asphalt binder grading systems

Penetration Grading system

- The lower the penetration, the harder the asphalt
- The softest grade (200-300) is used in cold climate, while the hardest grade (40-50) is used in hot Ares (WHY)
- The system also add specification for:
  - *Flash point test*
  - *Ductility*
  - *Solubility*
  - *Thin film oven aging*
    - Penetration
    - Ductility

Asphalt binder grading systems

Penetration Grading system (ASTM D946)

Table 2–6. ASTM Requirements for Penetration Graded Asphalt Cements

	Penetration Grade									
	40-50		60-70		85-100		120-150		200-300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 77°F (25°C), 100 g, 5 s	40	50	60	70	85	100	120	150	200	300
Flash point, °F (Cleveland open cup)	450	—	450	—	450	—	425	—	350	—
Ductility at 77°F (25°C), 5 cm/min, cm	100	—	100	—	100	—	100	—	100	—
Solubility in trichloroethylene, %	99.0	—	99.0	—	99.0	—	99.0	—	99.0	—
Retained penetration after thin-film oven test, %	55+	—	52+	—	47+	—	42+	—	37+	—
Ductility at 77°F (25°C), 5 cm/min, after thin-film oven test, cm	—	—	50	—	75	—	100	—	100*	—

*If ductility at 77°F (25°C) is less than100 cm, material will be accepted if ductility at 60°F (15.5°C) is 100 cm minimum at the pull rate of 5 cm/min.

Asphalt binder grading systems

Penetration Grading system

- Advantages
  - *Grades asphalt near average Inservice temp.*
  - *Fast*
  - *Can be used in field labs*
  - *Low capital costs*
  - *Precision well established*
  - *Temp. susceptibility can bedetermined*

Asphalt binder grading systems

Penetration Grading system

- Disadvantages
  - *Empirical test*
  - *Shear rate*
    - High
    - Variable
  - *Mixing and compaction temp.*
  - *information not available*
  - *Similar penetrations at 25C (77F) do not*
  - *reflect wide differences in asphalts*

Asphalt binder grading systems

Viscosity Grading system based on ***original asphalt cement*** *(AC system)*

- The system classified asphalt cement based on the viscosity of the original (as supplied) asphalt cement (ASTM D3381)
- It requires
  - *Viscosities at 60 îC (Absolute viscosity [Pa.s])*
  - *Viscosities at 135 îC (Kinematic viscosity [1 centistokes (cSt) = 1 mm2/s])*
  - *Penetrations at 25 îC*
  - *Flash point*
  - *Solubility*
  - *TFO aged residue*
    - Viscosity at 60 °C
    - Ductility at 25 °C

Asphalt binder grading systems

*Viscosity Grading system based on **original asphalt cement** (AC system)*

TABLE 1 Requirements for Asphalt Cement, Viscosity Graded at 60°C [140°F] Based on Original Asphalt

Test	Viscosity Grade					
	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 60°C [140°F], Pa·s	25 ± 5	50 ± 10	100 ± 20	200 ± 40	300 ± 60	400 ± 80
Viscosity, 135°C [275°F], min, mm^2/s	80	110	150	210	250	300
Penetration, 25°C [77°F], 100 g, 5 s, min	200	120	70	40	30	20
Flash point, Cleveland open cup, min,°C [°F]	165 [325]	175 [350]	220 [425]	230 [450]	230 [450]	230 [450]
Solubility in trichloroethylene,[A] min, %	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:						
Viscosity, 60°C [140°F], max, Pa·s	125	250	500	1000	1500	2000
Ductility, 25°C [77°F], 5 cm/min, min, cm	100[B]	100	50	20	15	10

[A] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE.
[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.

Asphalt binder grading systems

*Viscosity Grading system based on **original asphalt cement** (AC system)*

TABLE 2 Requirements for Asphalt Cement Viscosity Graded at 60°C [140°F] Based on Original Asphalt

NOTE 1—Table 2 specifies asphalts that are less temperature susceptible than those specified by Table 1. Asphalts that meet Table 2 requirements will also meet Table 1 requirements of the same grade.

Test	Viscosity Grade					
	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 60°C [140°F], Pa·s	25 ± 5	50 ± 10	100± 20	200 ± 40	300 ± 60	400 ± 80
Viscosity, 135°C [275°F], min, mm^2/s	125	175	250	300	350	400
Penetration, 25°C [77°F], 100 g, 5 s, min	220	140	80	60	50	40
Flash point, Cleveland open cup, min,°C [F]	165 [325]	175 [350]	220 [425]	230 [450]	230 [450]	230 [450]
Solubility in trichloroethylene,[A] min, %	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:						
Viscosity, 60°C [140°F], max, Pa·s	125	250	500	1000	1500	2000
Ductility[B], 25°C [77°F], 5 cm/min, min, cm	100[B]	100	75	50	40	25

[A] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE.
[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.

Asphalt binder grading systems

*Viscosity Grading system based on **original asphalt cement** (AC system)*

- Advantages
  - *Fundamental property*
  - *Wide range of temperatures*
  - *Based on max. pavement surface temp.*
  - *Wide range of instruments*
  - *Test method precision established*
  - *Temperature susceptibility is controlled*
  - *Limits aging*
  - *Information on mixing & compaction temps*

Asphalt binder grading systems

*Viscosity Grading system based on **original asphalt cement** (AC system)*

- Disadvantages
  - *More expensive*
  - *Longer testing time*
  - *More technician skill needed*
  - *Not applicable for Non-Newtonian materials*
  - *Wide range of properties for same grad*

Asphalt binder grading systems

Viscosity Grading system based on ***aged asphalt cement*** *(AR system)*

- Tests on RTFO aged residue
  - *Viscosities at 60 îC (Absolute viscosity [Pa.s])*
  - *Viscosities at 135 îC (Kinematic viscosity [1 centistokes (cSt) = 1 mm2/s])*
  - *Penetrations at 25oC*
  - *% of Original Penetration*
  - *Ductility*
  - *Properties of unaged asphalt*
  - *Flash point and solubility*

Asphalt binder grading systems

Viscosity Grading system based on ***aged asphalt cement*** *(AR system)*

TABLE 3 Requirements for Asphalt Cement Viscosity Graded at 60°C [140°F] Based on Residue from Rolling Thin-Film Oven Test

Tests on Residue from Rolling Thin-Film Oven Test:[A]	Viscosity Grade				
	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000
Viscosity, 60°C [140°F], Pa•s	100 ± 25	200 ± 50	400 ± 100	800 ± 200	1600 ± 400
Viscosity, 135°C [275°F], min, mm²/s	140	200	275	400	550
Penetration, 25°C [77°F], 100 g, 5 s, min	65	40	25	20	20
% of original penetration, 25°C [77°F], min	...	40	45	50	52
Ductility, 25°C [77°F], 5 cm/min, min, cm	100[B]	100[B]	75	75	75
Tests on original asphalt:					
Flash point, Cleveland open cup, min, °C [°F]	205 [400]	220 [425]	225 [440]	230 [450]	240 [460]
Solubility in trichloroethylene,[C] min, %	99.0	99.0	99.0	99.0	99.0

[A] Thin-film oven test may be used but the rolling thin-film oven test shall be the referee method.
[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.
[C] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE..

Asphalt binder grading systems

Viscosity Grading system based on ***<u>aged asphalt cement</u>*** *(AR system)*

- Advantages
  - *Represents asphalt properties after mixing*
  - *Fundamental properties*
  - *Covers wide range of temperatures*
  - *Limits aging*

Asphalt binder grading systems

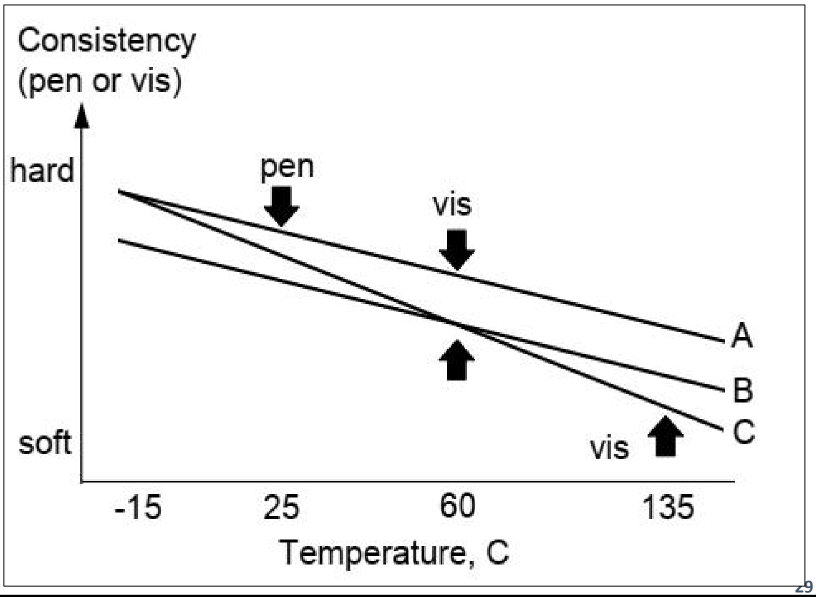
Viscosity Grading system based on ***<u>aged asphalt cement</u>*** *(AR system)*

- Disadvantages
  - *Highly regional*
  - *Requires different testing equipment*
  - *Longer testing time*
  - *No consistency test on original AC*
  - *Not applicable for Non-Newtonian*
  - *materials*
  - *Wide range of properties for same grade*

Superpave: The Future of Asphalt

Limitation of pre-superpave asphalt property measurements

- This figure shows three asphalts that have the same viscosity grade because they are within the specified viscosity limits at 60°C, have the minimum penetration at 25°C, and reach the minimum viscosity at 135°C



Superpave: The Future of Asphalt

Superpave Performance Grade (PG) system (AASHTO M320)

PAVEMENT MATERIALS & DESIGN (110 401466) SPRING 2019-2020

Lecture. No. 5
Aggregates

Dr. Hamza Alkuime

Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
Highway Materials • **Bituminous materials** • **Aggregates** • Soil	6	18
Pavement Types,	1	3
Flexible pavement design (design of Hot Mix Asphalt mixture using Marsha method	3	9
Flexible pavement design (design of pavement thicknesses using AASHTO method)	2	6
Earth work operations,	1	3
Drainage and drainage structures, and	1	3
Rehabilitation and Highway Maintenance	1	3

Highway Materials

References

- Federal Highway Administration, ***Superpave Fundamentals***,(https://idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-Handbooks/T2/P028.pdf)
- E. Ray and Prithvi S. Kandhal and Freddy et al., ***hot mix asphalt materials mixture design and construction***, 2th Edition., 1996
  - *Chapter 2 :Asphalt refining, uses and properties*

3

3

Highway Materials

References

- Nicholas Garber and Lester Hoel ,***Traffic & Highway Engineering***, 5th Edition.. Cengage Learning, 2015
  - *Chapter 18 :Bituminous materials*
- Michael S. Mamlouk and JohnP, Zaniewski, ***Traffic & Highway Engineering***, 3th Edition.. Pearson, 2011
  - *Chapter 19 :ASPHALT BINDERS AND ASPHALT MIXTURES*

4

4

Aggregate

Definition

- Aggregate" is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as asphalt concrete and Portland cement concrete).
  - *By volume, aggregate generally accounts for*
    - 92 to 96 percent of HMA
    - 70 to 80 percent of Portland cement concrete.
- Aggregate is also used for base and subbase courses for both flexible and rigid pavements.

Aggregate

Importance

- Aggregates form a skeleton through which load is transferred
  - *Which provides* skid resistance, stability and workability.

Aggregate

Sources

1. Natural
   - Sand and Gravel
   - Crushed Stone
2. Synthetic (artificial)
   - *Lightweight*
   - *Slag*
     - Blast Furnace
     - Steel Slag
3. Recycled
   - *Reclaimed (or recycled) Asphalt Pavement (RAP)*
   - *Recycled Concrete*

Aggregate

Sources

Sand and Gravel

Crushed Stone

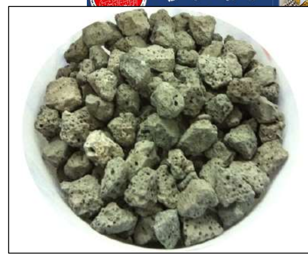
Image source: https://www.alibaba.com/product-detail/Black-aggregate-crushed-stone-for-sale_50037574758.html

Aggregate

Sources

Slag

- Typical by-product from processing of steel, tin and copper
- It have the properties of igneous rocks



Steel Slag

Blast Furnace slag

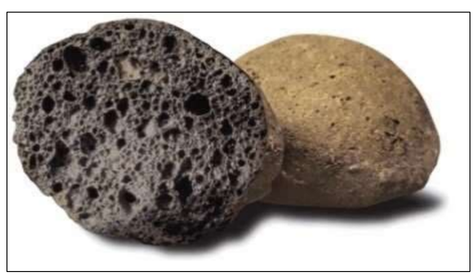
https://www.researchgate.net/publication/263098181_Beneficial_Use_of_Qatar%27s_Steel_Slag_and_Gravel_Deposits_in_Road_Construction/figures?lo=1

Image source :
https://www.researchgate.net/publication/301570845_Plant_Growth_and_Water_Purification_of_Porous_Vegetation_Concrete_Formed_of_Blast_Furnace_Slag_Natural_Jute_Fiber_and_Styrene_Butadiene_Latex/figures?lo=1

Aggregate

Sources

Recycled Concrete



Lightweight

https://www.google.com/search?q=Recycled+Concrete++aggregate&tbm=isch&tbs=rimg:CQox2yi1noP6IggKMdsotZ6D-ioSCQox2yi1noP6EQfTqSTQ2hp-YQfTqSTQ2hp-&tbo=u&ved=2ahUKEwjxmfDp39XnAhUMyqQKHR8kC48QiRx6BAgBEA0&ictx=1&uact=3#imgrc=Fmbo2K_18v-itM

Image source:
ttps://www.researchgate.net/publication/315379227_Comparative_analysis_of_the_prediction_of_the_mechanical_properties_of_lightweight_aggregate_concrete_via_Artificial_Neural_Network_and_Finite_Elements_Method/figures?lo=1&utm_source=google&utm_medium=organic

Aggregate

Sources

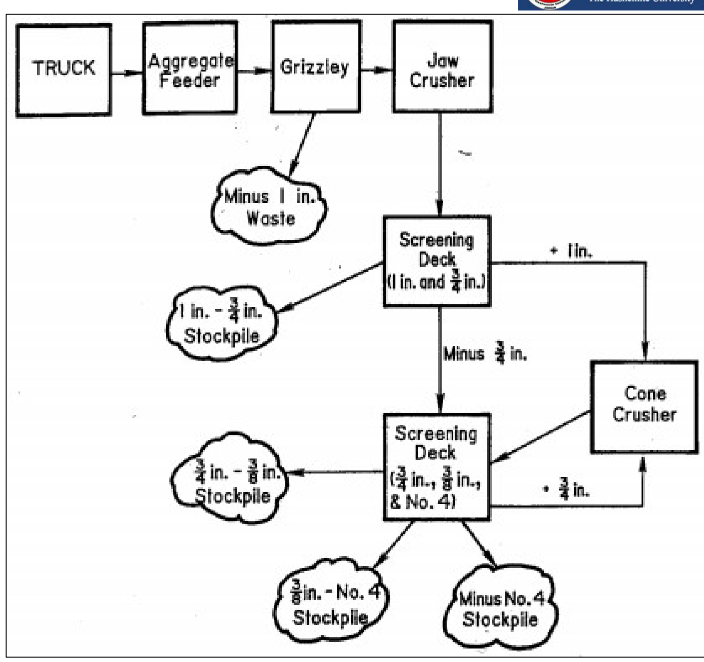
Reclaimed (or recycled) Asphalt Pavement (RAP)

http://www.project-cornerstone.org/news/2014/12/16/board-of-supervisors-approve-salvaged-construction-aggregate-recycling-zoning-ordinance-change

Aggregate

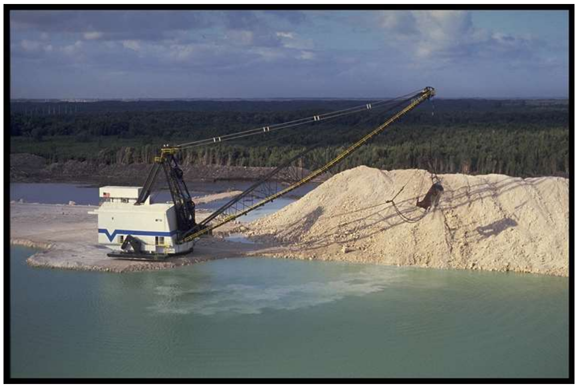
Production process

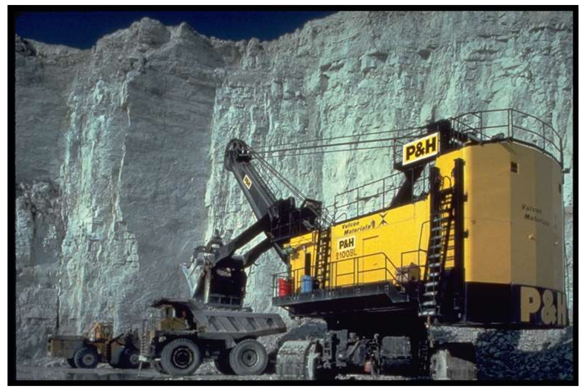
- Excavations
- Transportation
- Crushing
- Sizing
- Stockpiling



Aggregate

Production process – Excavation





Aggregate

Production process – Transportation

Aggregate

Production process –Crushing

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.mylittlesalesman.com%2F2018-rock-tough-ab-12-screening-plant-9407569&psig=AOvVaw1AlwWDnJDkSDEVdadv-0zD&ust=1582008089687000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCLDdqMT91-cCFQAAAAAdAAAAABAK

Aggregate

Production process – Crushing

Aggregate

Production process – Crushing

Aggregate

Production process – Sizing

Aggregate

Production process – Stockpiling

Aggregate

Production process – Transportation

Aggregate

Production process

Aggregate

Properties of aggregate

1. Particle size and gradation.
2. Hardness or resistance to wear.
3. Durability or resistance to weathering.
4. Specific gravity & absorption.
5. Chemical stability
6. Particle shape and surface texture.
7. Freedom from deleterious particles or substances.

Aggregate

Particle size and gradation

- Gradation
  - *Blend of particle sizes in the mix.*
  - *It is the most important property of an aggregate*
- Gradation affects on HMA mixes
  - *Stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, resistance to moisture damage Economy of pavement structure.*

Aggregate

Particle size and gradation

- Gradation is evaluated by passing the aggregates through a series of sieves "Sieve analysis"
- Sieve analysis:
  - *Determination of particle size distribution of fine and coarse aggregates by sieving, expressed as %.*
- Grain size analysis data are plotted on aggregate gradation chart

Aggregate

Mechanical Sieve

Aggregate

Mechanical Sieve

Sieve analysis example

Example -1

A sieve analysis test was performed on a sample of fine aggregate and produced the following results:

Sieve, mm	4.75	2.36	2.00	1.18	0.60	0.30	0.15	0.075	pan
Amount retained, g	0	33.2	56.9	83.1	151.4	40.4	72.0	58.3	15.6

Calculate the percent passing each sieve, and draw a 0.45 power gradation chart with the use of a spreadsheet program.

Sieve analysis example

Example 1 – Solution

Sieve size	Amount Retained, g (a)	Cumulative Amount Retained, g (b)	Cumulative Percent Retained (c) = (b) × 100/Total	Percent Passing* (d) = 100 − (c)
4.75 mm (No. 4)	0	0	0	100
2.36 mm (No. 8)	33.2	33.2	6	94
2.00 mm (No. 10)	56.9	90.1	18	82
1.18 mm (No. 16)	83.1	173.2	34	66
0.60 mm (No. 30)	151.4	324.6	64	36
0.30 mm (No. 50)	40.4	365.0	71	29
0.15 mm (No. 100)	72.0	437.0	86	14
0.075 mm (No. 200)	58.3	495.3	96.9	3.1
Pan	15.6	510.9	100	
Total	510.9			

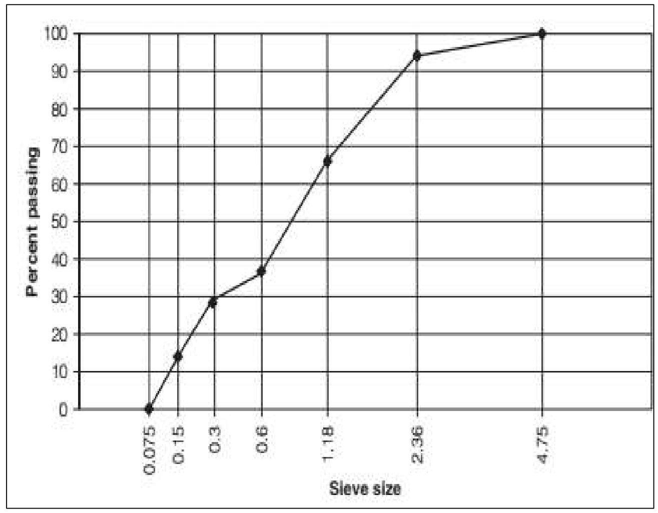
*Percent passing is computed to a whole percent, except for the 0.075 mm (No. 200) material, which is computed to 0.1%.

Sieve analysis example

Example 1 – Solution

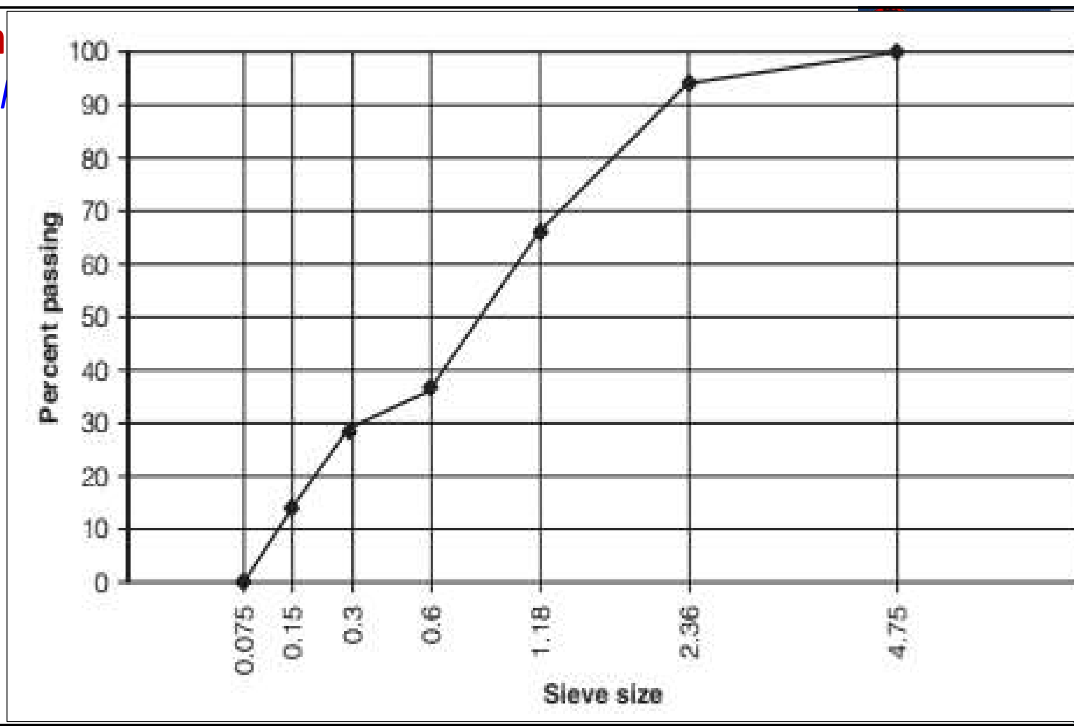
Sieve size	Percent Passing* (d) = 100 − (c)
4.75 mm (No. 4)	100
2.36 mm (No. 8)	94
2.00 mm (No. 10)	82
1.18 mm (No. 16)	66
0.60 mm (No. 30)	36
0.30 mm (No. 50)	29
0.15 mm (No. 100)	14
0.075 mm (No. 200)	3.1
Pan	
Total	

*Percent passing is co. 200) material, which is computed to 0.1%.



Sieve a

Exampl



Aggregate

Aggregate classifications- by size based on ***ASTM standard***

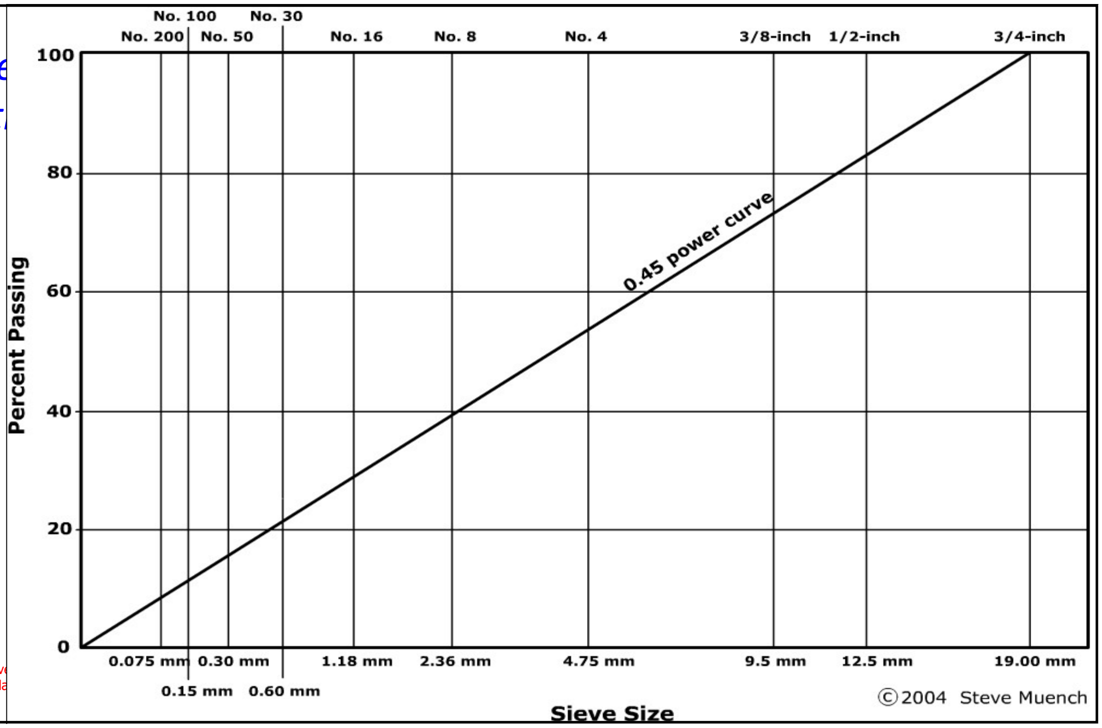
- **Coarse aggregate:**
  - ➢ *Aggregate* ***retained*** *on Sieve* ***No. 4*** *(4.75 mm)*
- **Fine aggregate:**
  - ➢ *Aggregate* ***passing*** *Sieve* ***No. 4*** *(4.75 mm)*
- **Mineral fillers/dust/fines:**
  - ➢ *Aggregate* ***passing*** *Sieve* ***No. 200*** *(75 mm)*

Aggregate

Aggregate classifications- by size based on ***Asphalt institute***

- **Coarse aggregate:**
  - ➢ *Aggregate* ***retained*** *on Sieve* ***No. 8*** *(2.36 mm)*
- **Fine aggregate:**
  - ➢ *Aggregate* ***passing*** *Sieve* ***No. 8*** *(2.36 mm)*
- **Mineral fillers/dust/fines:**
  - ➢ *Aggregate* ***passing*** *Sieve* ***No. 200*** *(75 mm)*

Aggregate classificati by size



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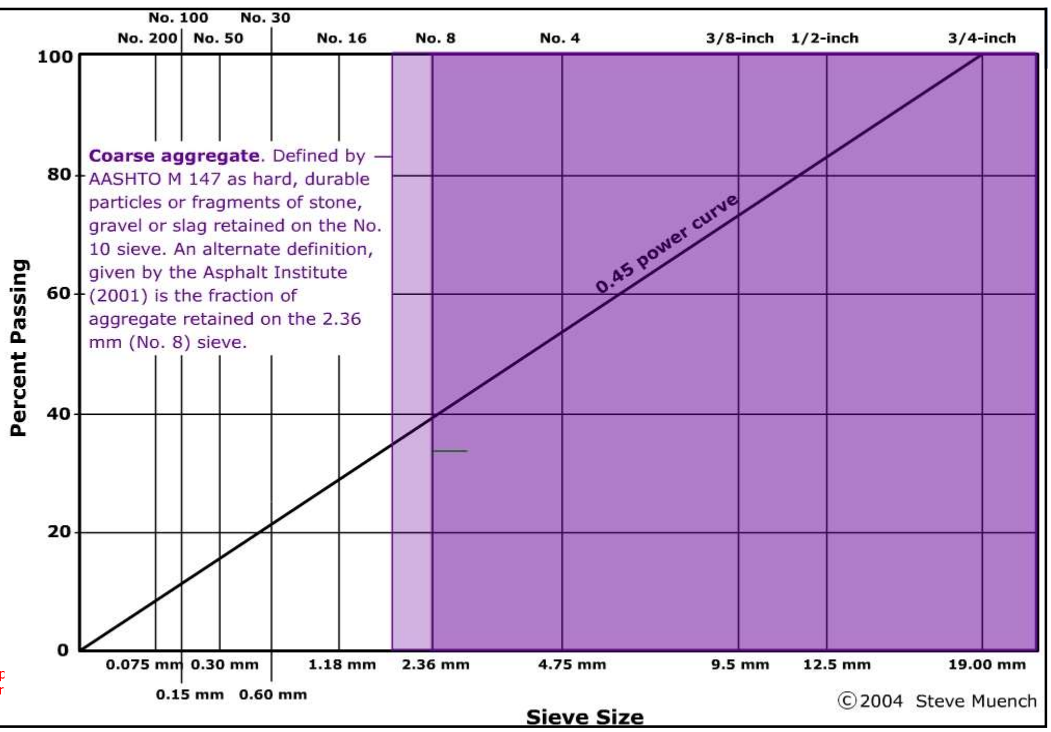
Aggregate classificati ons by size



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content/uploads/2011/07/Gradation_ter
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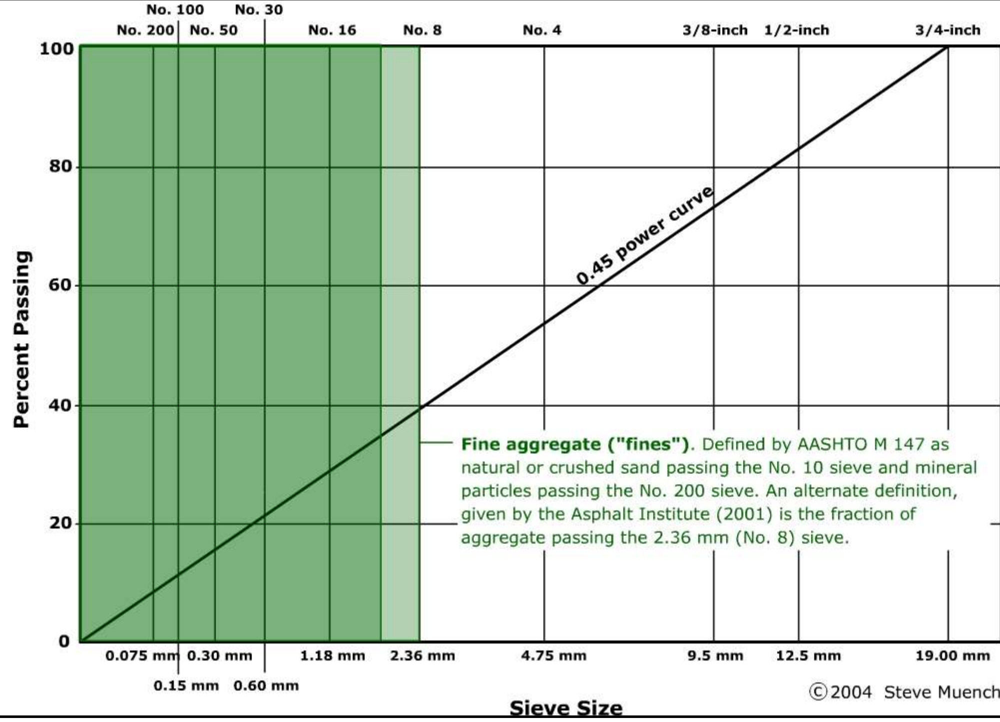
Aggregate classifications by size



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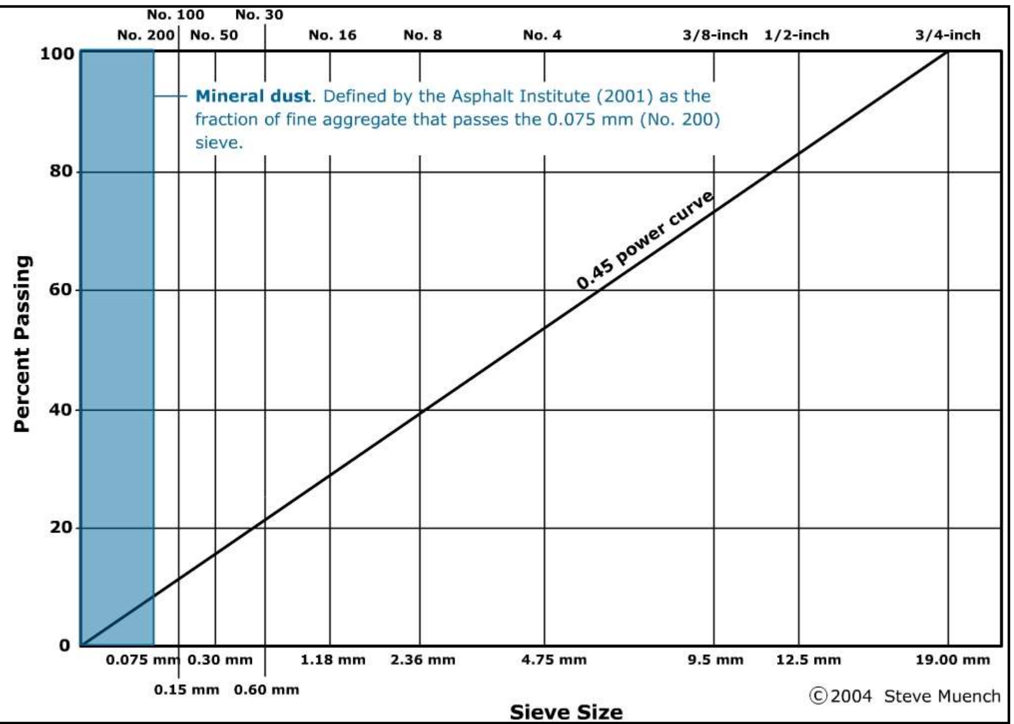
Aggregate classifications by size



http://www.pavementinteractive.org/wp-content/uploads/2011/07/Gradation_terms.swf

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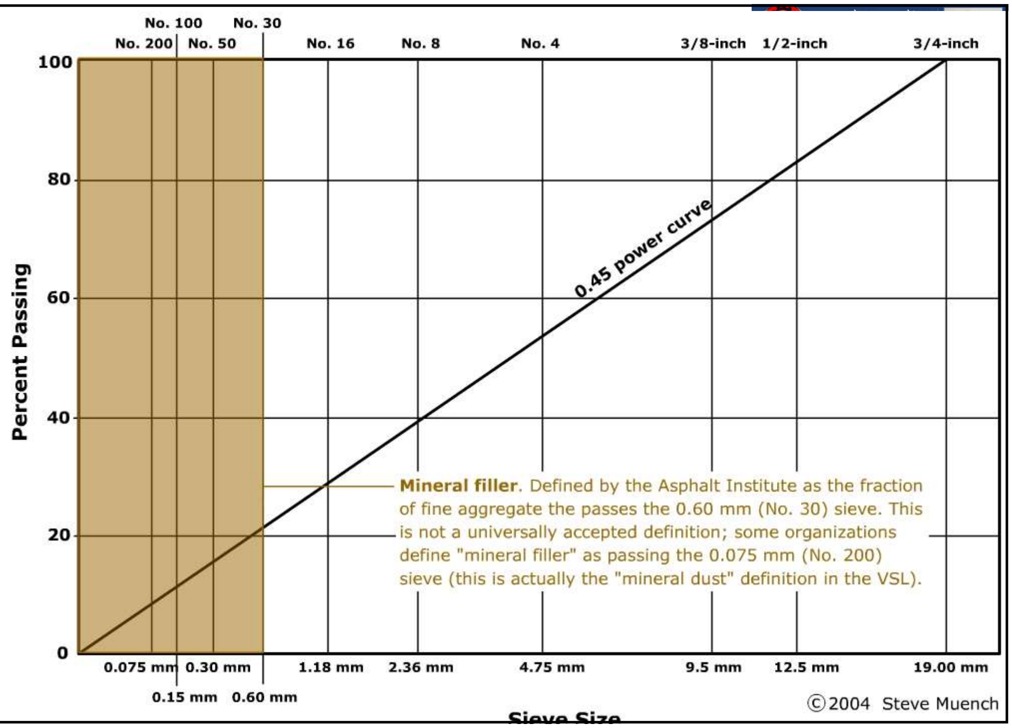
Aggregate classifications by size



http://www.pavementinteractive.org/wp-content/uploads/2011/07/Gradation_terms.swf

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Aggregate

Maximum aggregate size

- Nominal Maximum Aggregate Size (NMAS)
  - ASTM
    - The largest sieve that **retains** some of the aggregate particles but generally not more than 10 percent by weight
  - Superpave
    - One sieve size larger than the first sieve to retain more than 10 percent of the material

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Aggregate

Example -2

- Determine Nominal Maximum Aggregate Size (NMAS)

Sieve size	Cumulative Percent Retained (c) = (b) × 100/Total
4.75 mm (No. 4)	0
2.36 mm (No. 8)	6
2.00 mm (No. 10)	18
1.18 mm (No. 16)	34
0.60 mm (No. 30)	64
0.30 mm (No. 50)	71
0.15 mm (No. 100)	86
0.075 mm (No. 200)	96.9
Pan	100
Total	

*Percent passing is cqpt for the 0.075 mm (N
is computed to 0.1%.

Aggregate

Maximum aggregate size

- Maximum aggregate size
  - ASTM
    - The smallest sieve through which 100 percent of the aggregate sample particles pass (or retained 0)
  - Superpave
    - One sieve larger than the nominal maximum size

Aggregate

Example -2

- Determine the maximum size

Sieve size	Cumulative Percent Retained (c) = (b) × 100/Total
4.75 mm (No. 4)	0
2.36 mm (No. 8)	6
2.00 mm (No. 10)	18
1.18 mm (No. 16)	34
0.60 mm (No. 30)	64
0.30 mm (No. 50)	71
0.15 mm (No. 100)	86
0.075 mm (No. 200)	96.9
Pan	100
Total	

*Percent passing is co pt for the 0.075 mm (N
is computed to 0.1%.

Aggregate

Maximum aggregate size

Maximum aggregate size is important to ensure good performance

- If the maximum size is too small
  - *The mix may be unstable*
- If the maximum size is too large
  - *Workability and segregation may be problems*

Ideal aggregate gradation

- Theoretically, the best gradation or HMA mix is the one that gives the densest particle packing (or maximum density)
- Pros
  - *It would provide the increased stability through increased interparticle contacts and reduced void in mineral aggregates.*
- cons
  - *Sufficient air void space is need to permit enough asphalt cement to be incorporated to* ***ensure durability and to avoid bleeding and/or rutting***

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Ideal aggregate gradation

maximum density gradation

- Fuller maximum density curve is

$$P_i = 100\left(\frac{d_i}{D}\right)^n$$

where

P_i = percent passing a sieve of size d_i
d_i = the sieve size in question
D = maximum size of the aggregate

Federal Highway Administration recommended a value of 0.45 for *n* and introduced the "0.45 power"

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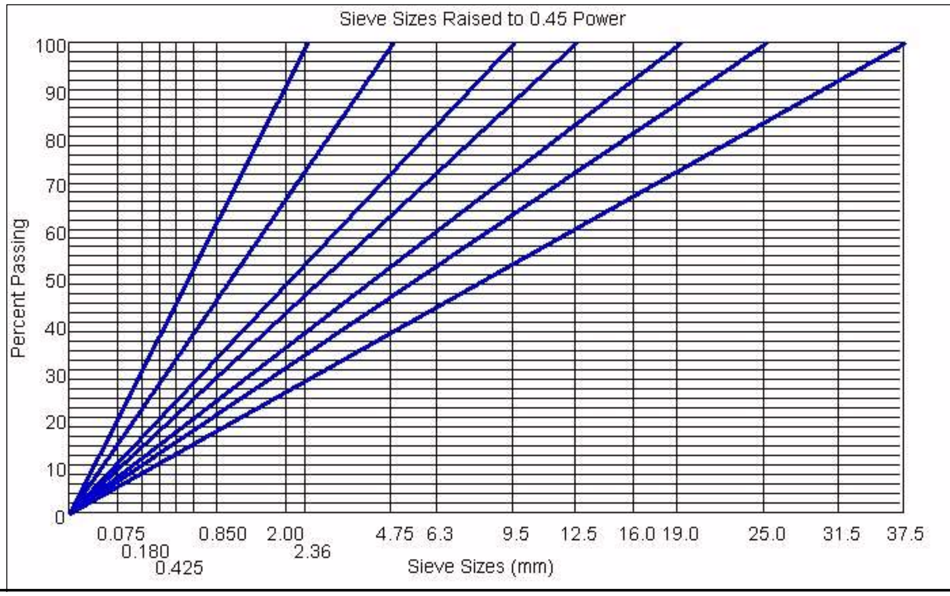
Ideal aggregate gradation

Maximum density gradations for different maximum size



Ideal aggregate gradation

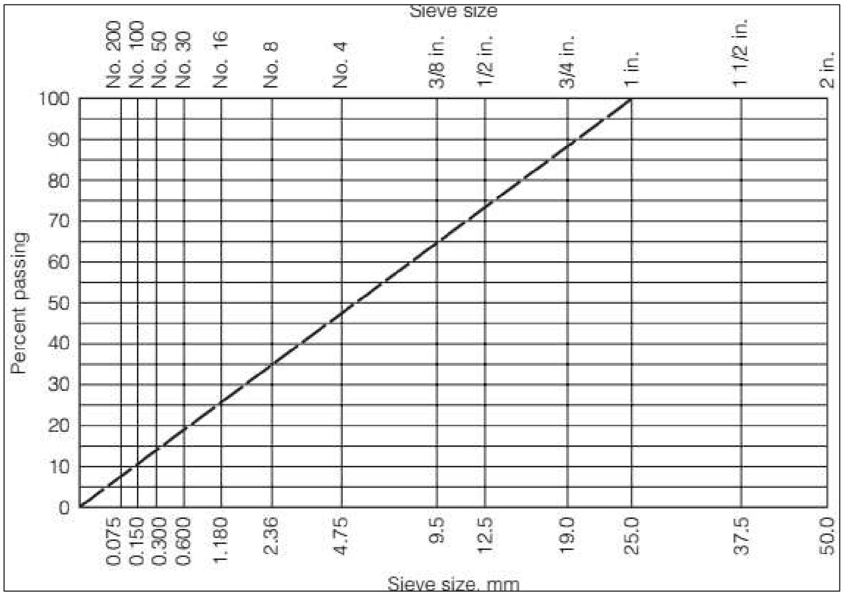
Example 2 – maximum density gradation for a maximum size of 25 mm.

TABLE 5.2 Sample Calculations of Aggregate Distribution Required to Achieve Maximum Density

Sieve	$P_i = 100(d_i/D)^{0.45}$
25 mm (1 in.)	100
19 mm (3/4 in.)	88
12.5 mm (1/2 in.)	73
9.5 mm (3/8 in.)	64
4.75 mm (No. 4)	47
2.36 mm (No. 8)	34
0.60 mm (No. 30)	19
0.30 mm (No. 50)	14
0.075 mm (No. 200)	7.3

Ideal aggregate gradation

Example 2 – maximum density gradation for a maximum size of 25 mm.



Sieve analysis example

Example -3

Sieve No.	Sieve Size	Wt. Retained (g)	% Retained	Cumulative % Retained	Cum. % Passing
inch	mm		(wt. ret./ Total) 100%	Sum % Retained	100 - Cum. Ret.
1.5"	37.5	0	0	0	100
1"	25	0	0	0	100
3/4"	19	25	2.5	2.5	97.5
1/2"	12.5	50	5	7.5	92.5
3/8"	9.5	120	12	19.5	80.5
# 4	4.75	195	19.5	39	61
# 8	2.36	110	11	50	50
# 16	1.18	125	12.5	62.5	37.5
# 30	0.6	145	14.5	77	23
# 50	0.3	115	11.5	88.5	11.5
# 100	0.15	75	7.5	96	4
# 200	0.075	30	3	99	1
Pan	Pan	10	1	100	0
Total		1000	100		

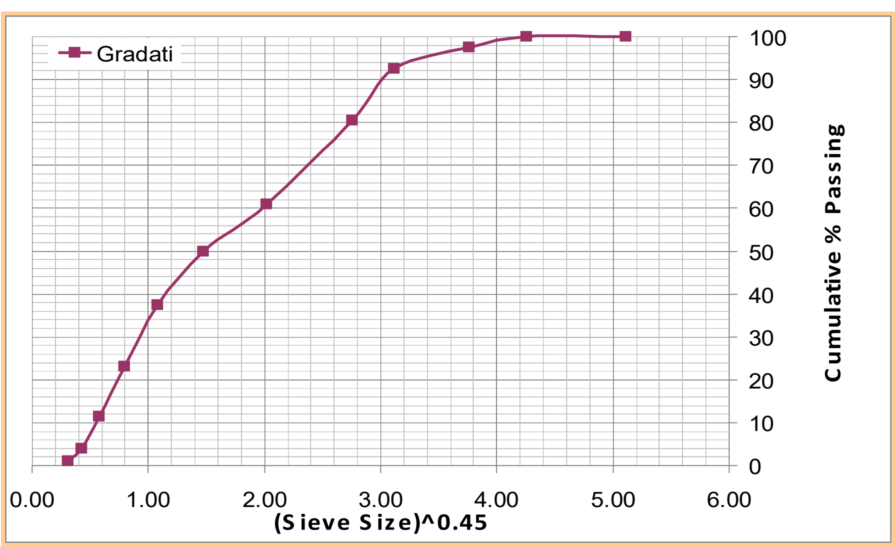
Sieve analysis example

Example -2

Sieve Size	Log (Sieve Size)	(Sieve Size)^0.45	Cum. % Passing
mm			100 - Cum. Ret.
37.5	1.57	5.11	100
25	1.40	4.26	100
19	1.28	3.76	97.5
12.5	1.10	3.12	92.5
9.5	0.98	2.75	80.5
4.75	0.68	2.02	61
2.36	0.37	1.47	50
1.18	0.07	1.08	37.5
0.6	-0.22	0.79	23
0.3	-0.52	0.58	11.5
0.15	-0.82	0.43	4
0.075	-1.12	0.31	1
Pan			0

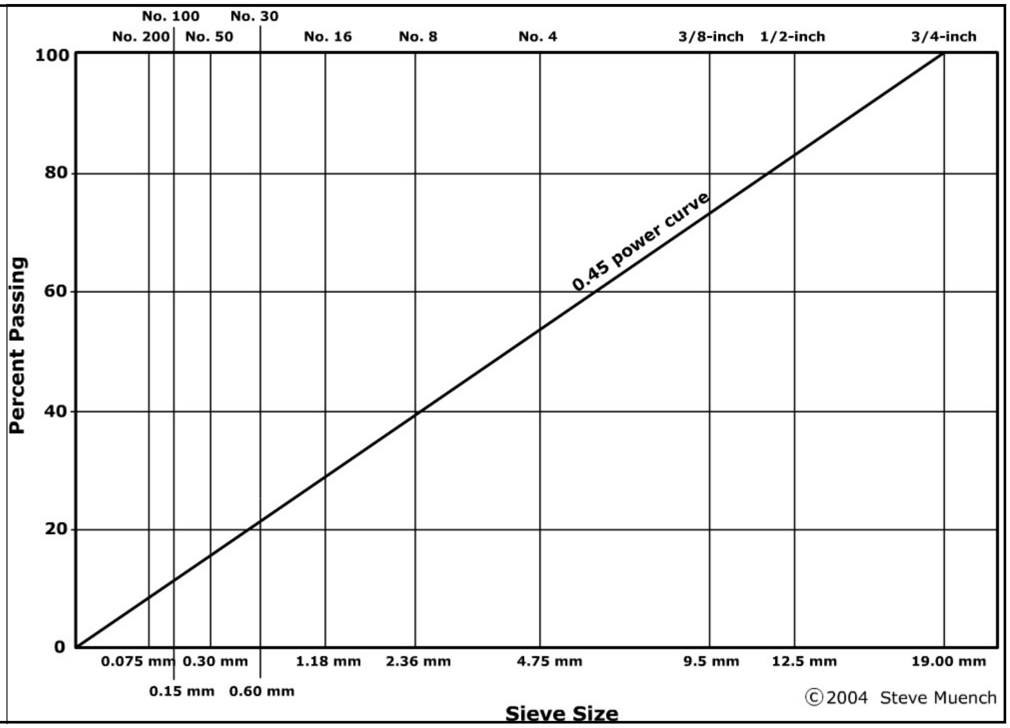
Sieve analysis example

Example -3



Aggregate classifications by size

Maximum density line

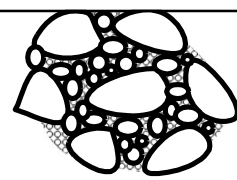


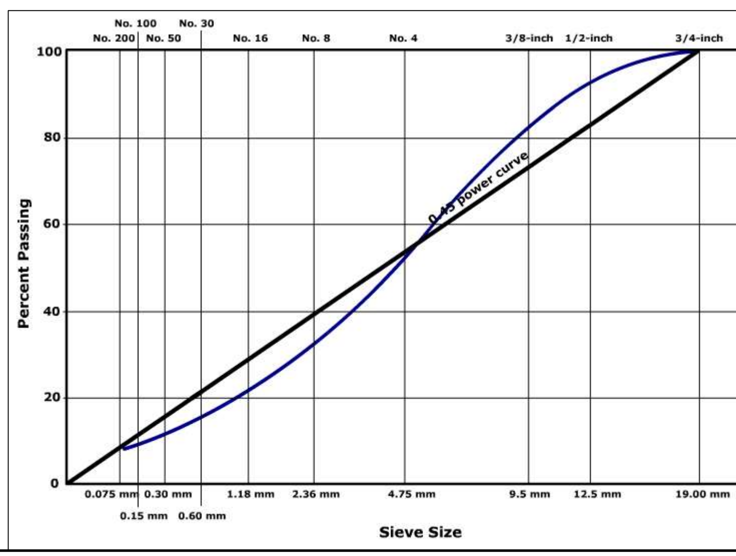
http://www.pavementinteractive.org/wp-content/uploads/2011/07/Gradation_terms.swf

Aggregate

Other typical Gradations

- *Dense or well-graded.*
  - *Refers to a gradation that is near **maximum density**.*
  - *The most common HMA mix designs in the U.S. tend to use dense graded aggregate.*
- *Properties*
  - Good interlock
  - Low permeability



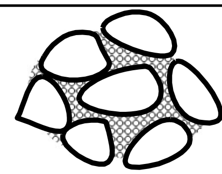


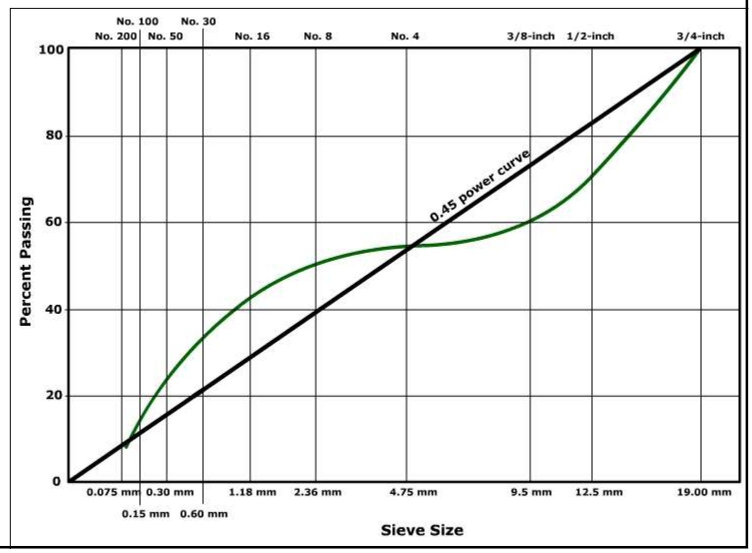
https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

Aggregate

Typical Gradations

- Gap graded
  - Refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range.
  - The curve is flat in the mid-size range.
- Properties
  - Only limited sizes
  - Good interlock
  - Low permeability
  - These mixes can be prone to segregation during placement.



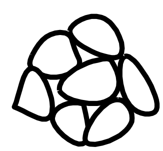


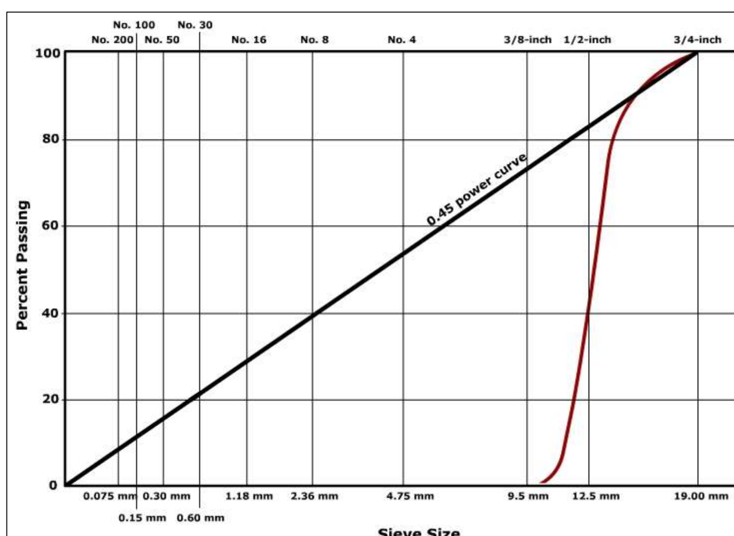
https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

Aggregate

Typical Gradations

- Uniformly graded
  - Refers to a gradation that contains most of the particles in a very narrow size range.
  - The curve is steep and only occupies the narrow size range specified
- Properties
  - Few points of contact
  - Poor interlock (shape dependent)
  - High permeability





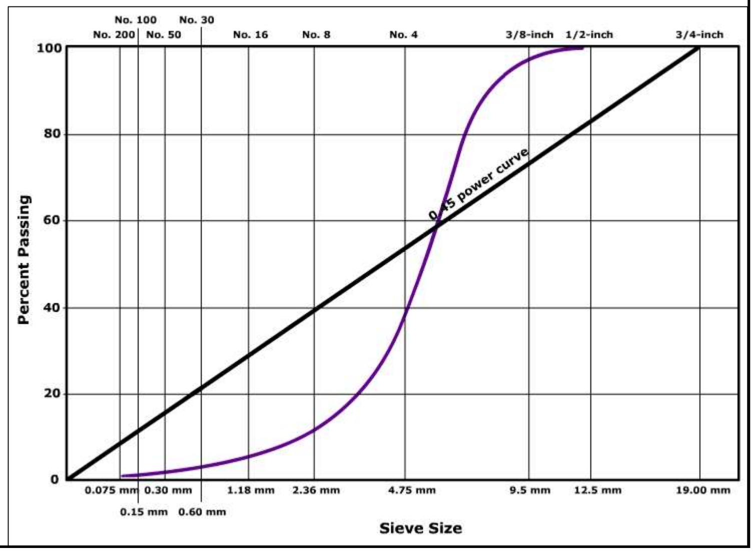
https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

Aggregate

Typical Gradations

■ *Open graded*

- *Refers to a gradation that contains only a small percentage of aggregate particles in the small range.*
- *This results in more [air voids] because there are not enough small particles to fill in the voids between the larger particles.*
- *The curve is flat and near-zero in the small-size range.*



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https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Aggregate

Gradation specifications (limits)

- Gradation specifications is used to define maximum and minimum cumulative percentages of material passing each sieve

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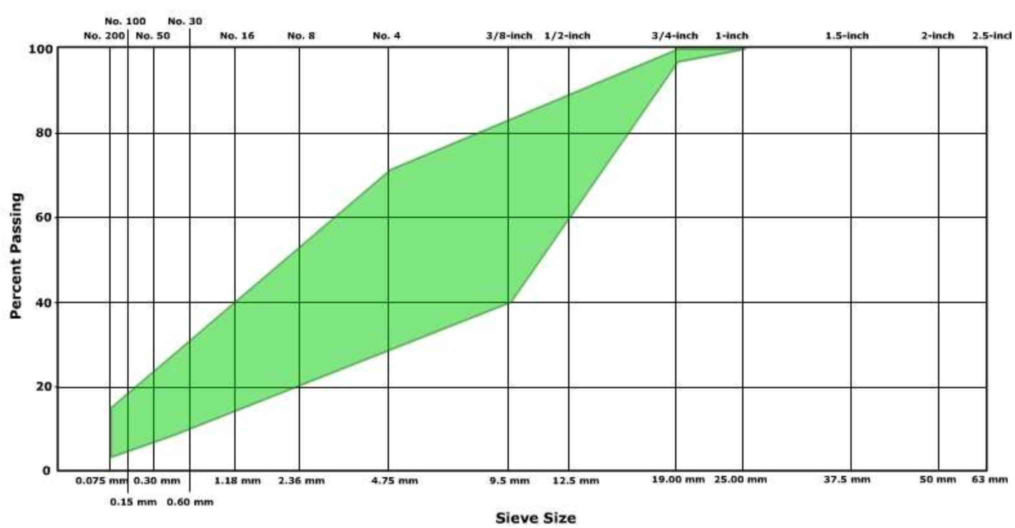
Aggregate

Gradation specifications



https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

Representative Gradation Specifications for surface Course

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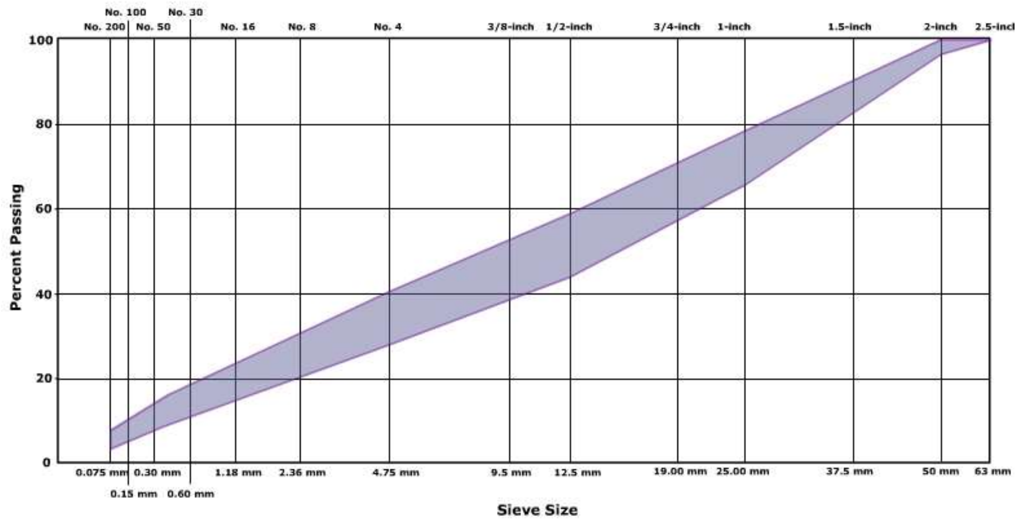
Aggregate

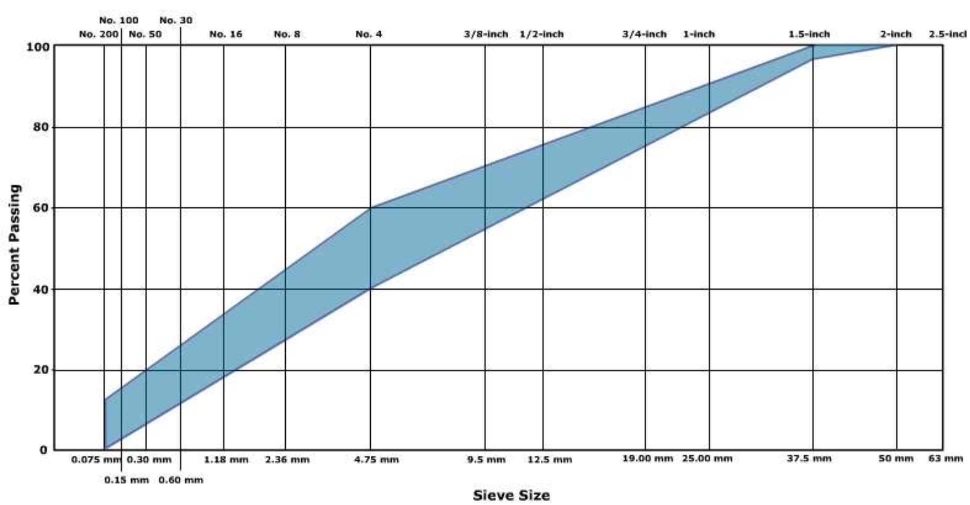
Gradation specifications



Representative Gradation Specifications for Base Course

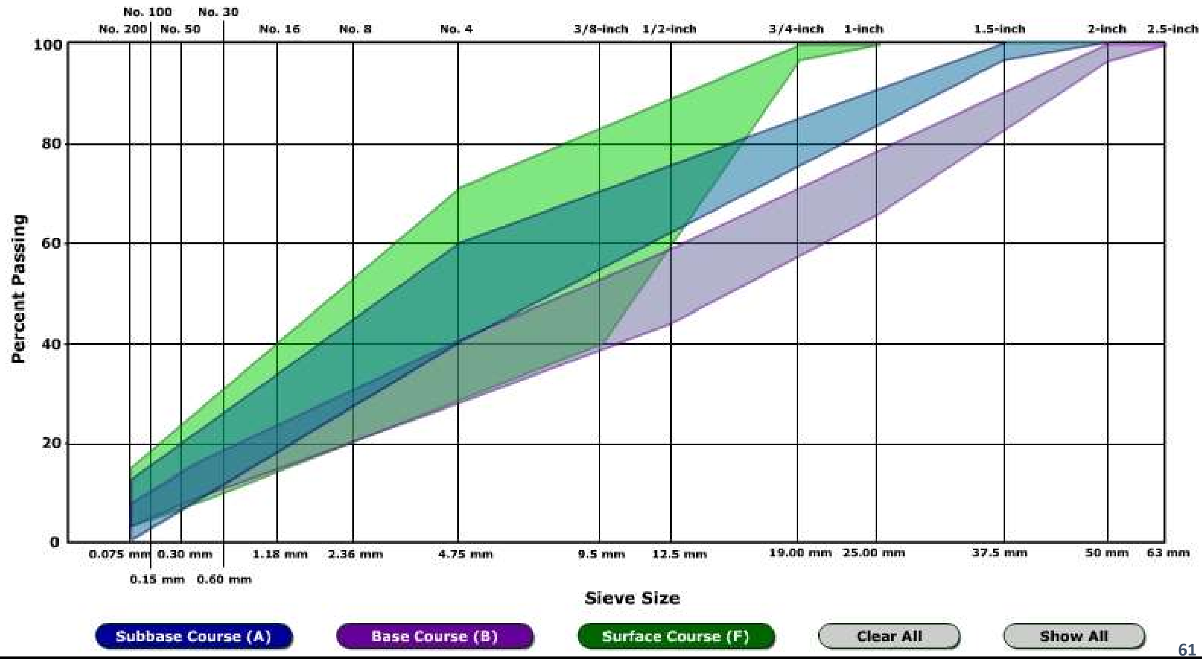
Aggregate

Gradation specifications



Representative Gradation Specifications for Subbase Course

Aggregate



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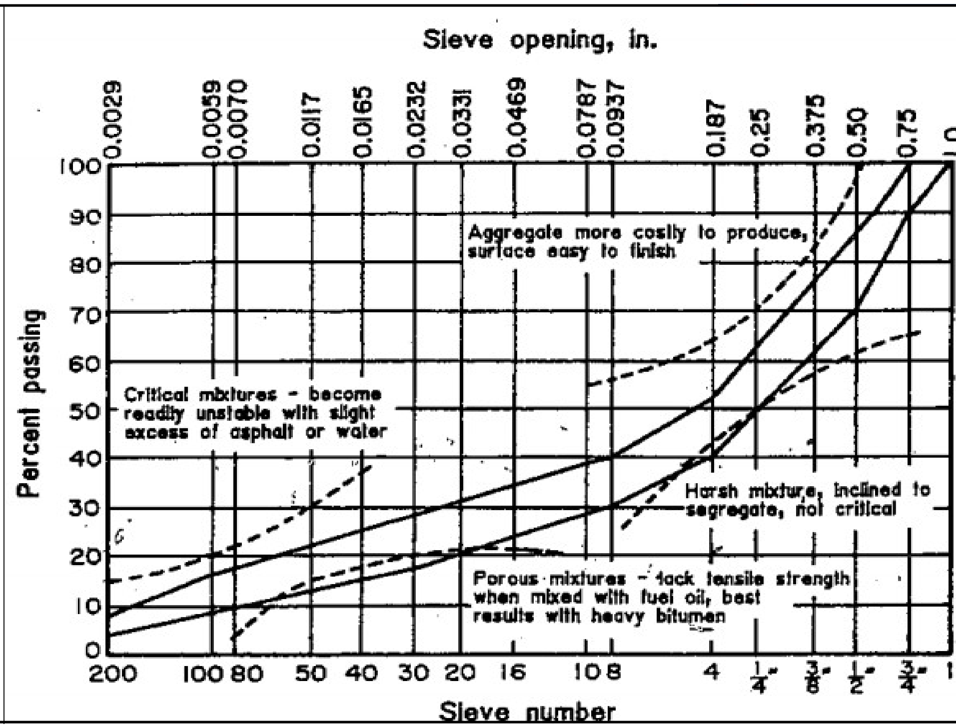
Aggregate

Why Gradation specifications (limits) is needed



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Aggregate

Aggregate blending

- <u>A single aggregate</u> source is generally **unlikely to meet gradation** requirements for Portland cement or asphalt concrete mixes
  - Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.
- A <u>trial and error</u> process is generally used to determine the proportions

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Aggregate

Aggregate blending

- The basic equation for blending is

$$P_i = A_i a + B_i b + C_i c + \dots \quad (5$$

where

P_i = percent blend material passing sieve size i

A_i, B_i, C_i = percent of aggregates A, B, C, … passing sieve i

a, b, c = decimal fractions by weight of aggregates A, B, and C used in the blend, where the total is 1.00

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Aggregate

Aggregate blending

- Steps

1. Selecting critical sieves for the aggregates in the blend;
2. Determining an initial set of proportions a, b, c, etc., which will meet the specification requirements for the critical sieves;
3. Checking the calculated blend using the proportions determined for all sieves in the specification requirements; and
4. Adjusting the proportions, as necessary, to ensure that the percentages for all sieves are within specification limits.

Aggregate

Example -3

- Determine a blend of the two aggregates shown in the table below, which will meet the specifications

Sieve	12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.00 mm (No. 10)	0.425 mm (No. 40)	0.180 mm (No. 80)	0.075 mm (No. 200)
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1

Aggregate

Aggregate blending

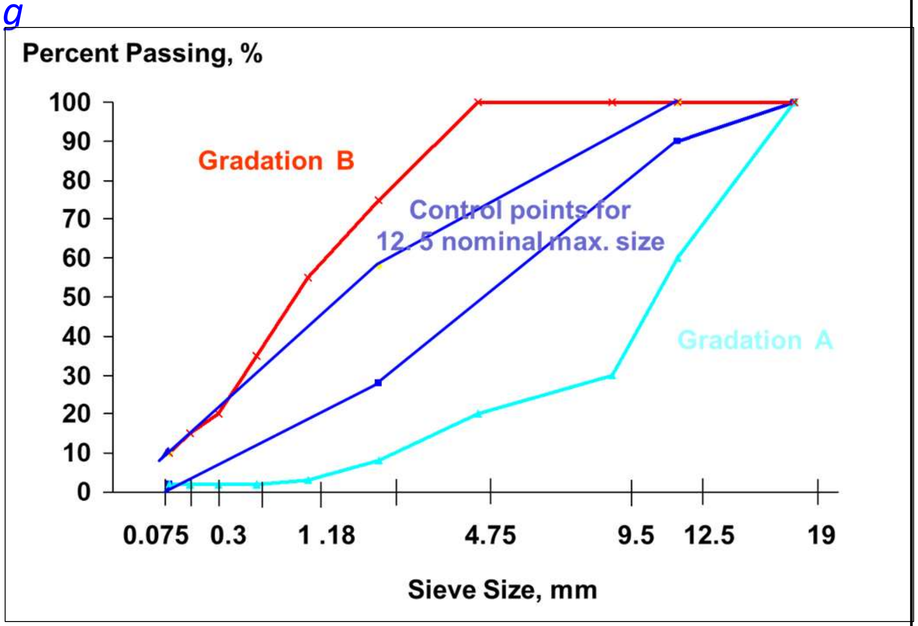
TABLE 5.9 Example of Aggregate Blending Analysis by Iterative Method

Sieve	12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.00 mm (No. 10)	0.425 mm (No. 40)	0.180 mm (No. 80)	0.075 mm (No. 200)
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1
30% A_i ($a.A_i$)	30	30	29.4	27	21.3	12.6	5.7
70% B_i ($b.B_i$)	70	65.8	49	34.3	9.8	1.4	0.7
Blend (P_i)	100	96	78	61	31	14	6.4

Aggregate

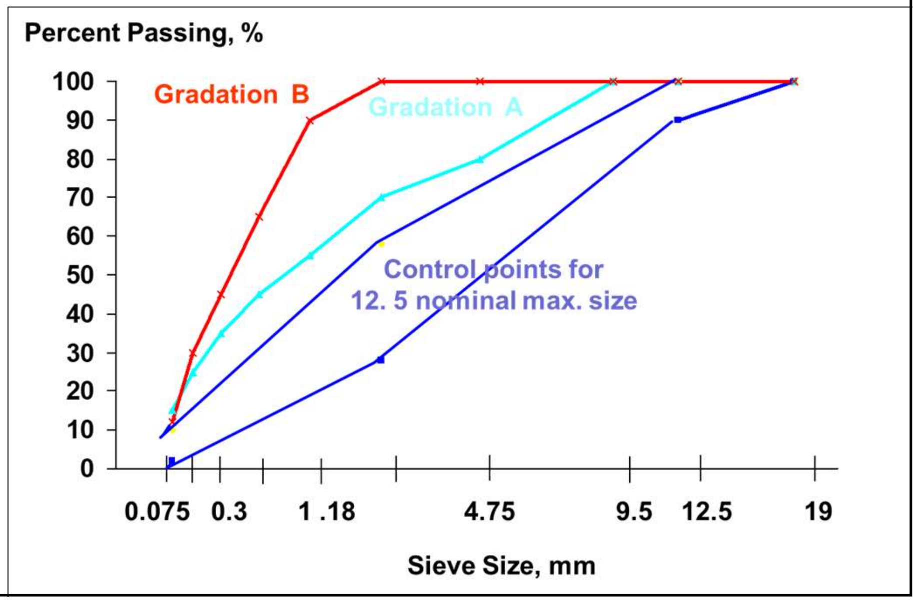
Aggregate blending

All possible combinations fall between A and B



Aggregate

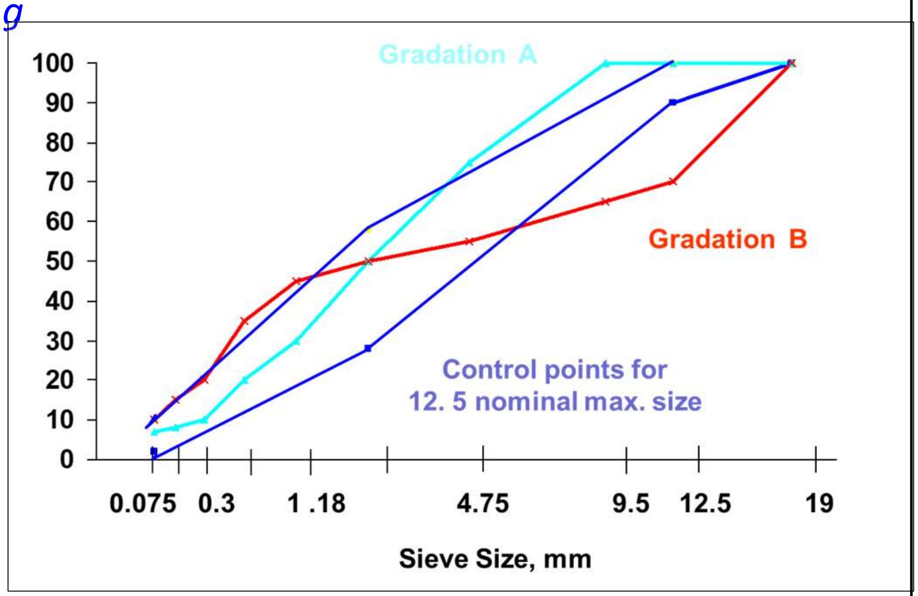
Aggregate blending



No poss. combination of A and B will meet spec.

Aggregate

Aggregate blending



All poss. combinations pass through cross-over point Blends containing more A than B will be closer to A

Aggregate blending

Example

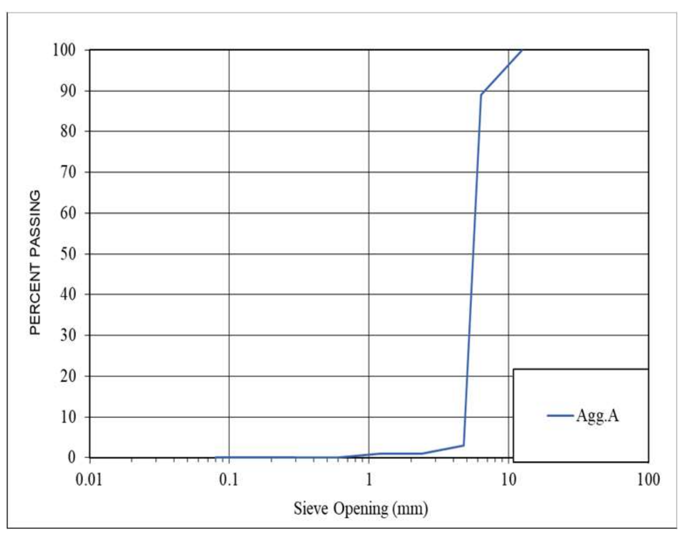
- Determine a blend of the three aggregates shown in the table below, which will meet the specifications

Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg.A	Agg.B	Agg.C	Lower limit	Upper Limit
1/2"	12.5	100	100	100	100	100
1/4"	6.35	89	100	100	70	100
No. 4	4.76	3	58	98	60	77
No. 8	2.38	1	10	81	52	70
No. 16	1.19	1	8	71	46	63
No. 30	0.6	0	5	62	37	57
No. 50	0.3	0	4	48	24	39
No. 100	0.15	0	3	15	8	28
No. 200	0.08	0	2	10	2	8

Aggregate blending

Example

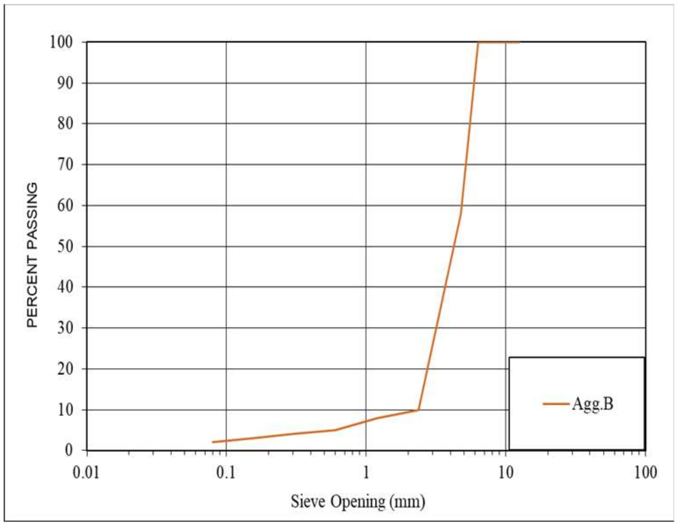
Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg. A	Agg. B	Agg. C	Lower limit	Upper Limit
1/2"	12.5	**100**	100	100	100	100
1/4"	6.35	**89**	100	100	70	100
No. 4	4.76	**3**	58	98	60	77
No. 8	2.38	**1**	10	81	52	70
No. 16	1.19	**1**	8	71	46	63
No. 30	0.6	**0**	5	62	37	57
No. 50	0.3	**0**	4	48	24	39
No. 100	0.15	**0**	3	15	8	28
No. 200	0.08	**0**	2	10	2	8



Aggregate blending

Example

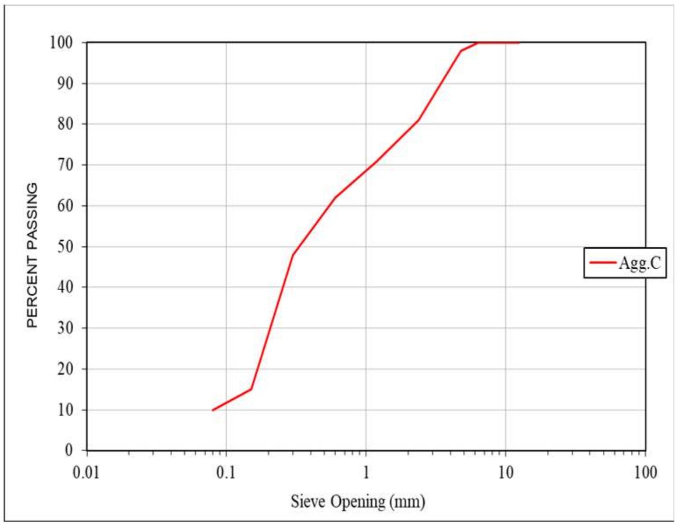
Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg. A	Agg. B	Agg. C	Lower limit	Upper Limit
1/2"	12.5	100	**100**	100	100	100
1/4"	6.35	89	**100**	100	70	100
No. 4	4.76	3	**58**	98	60	77
No. 8	2.38	1	**10**	81	52	70
No. 16	1.19	1	**8**	71	46	63
No. 30	0.6	0	**5**	62	37	57
No. 50	0.3	0	**4**	48	24	39
No. 100	0.15	0	**3**	15	8	28
No. 200	0.08	0	**2**	10	2	8



Aggregate blending

Example

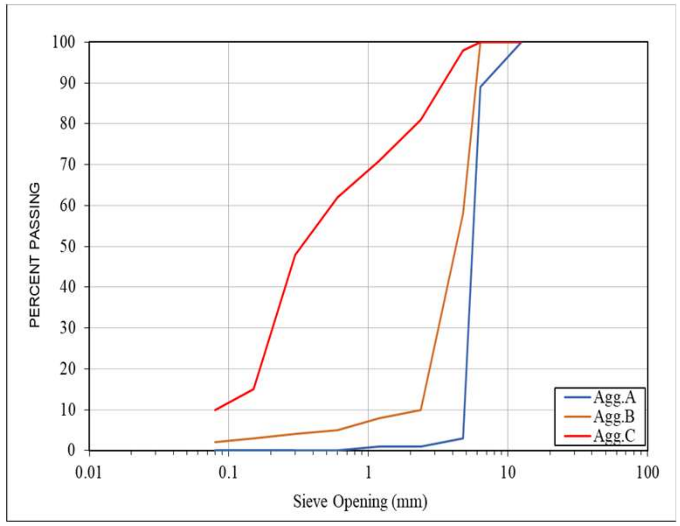
Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg. A	Agg. B	Agg. C	Lower limit	Upper Limit
1/2"	12.5	100	100	**100**	100	100
1/4"	6.35	89	100	**100**	70	100
No. 4	4.76	3	58	**98**	60	77
No. 8	2.38	1	10	**81**	52	70
No. 16	1.19	1	8	**71**	46	63
No. 30	0.6	0	5	**62**	37	57
No. 50	0.3	0	4	**48**	24	39
No. 100	0.15	0	3	**15**	8	28
No. 200	0.08	0	2	**10**	2	8



Aggregate blending

Example

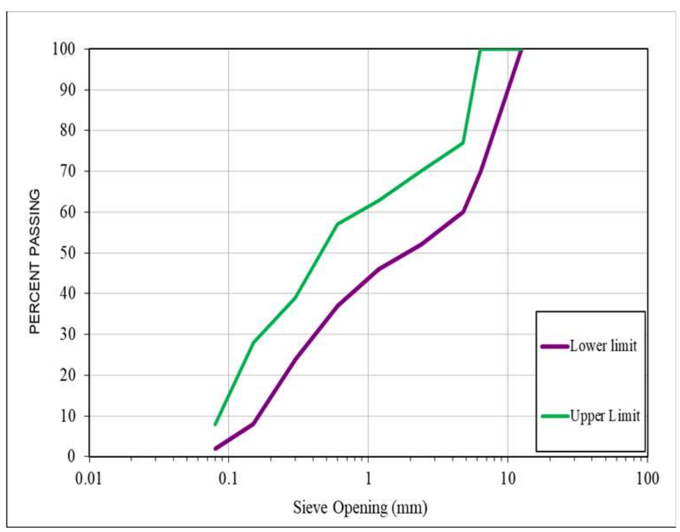
Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg. A	Agg. B	Agg. C	Lower limit	Upper Limit
1/2"	12.5	100	100	100	100	100
1/4"	6.35	89	100	100	70	100
No. 4	4.76	3	58	98	60	77
No. 8	2.38	1	10	81	52	70
No. 16	1.19	1	8	71	46	63
No. 30	0.6	0	5	62	37	57
No. 50	0.3	0	4	48	24	39
No. 100	0.15	0	3	15	8	28
No. 200	0.08	0	2	10	2	8



Aggregate blending

Example

Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
		Agg. A	Agg. B	Agg. C	Lower limit	Upper Limit
1/2"	12.5	100	100	100	100	100
1/4"	6.35	89	100	100	70	100
No. 4	4.76	3	58	98	60	77
No. 8	2.38	1	10	81	52	70
No. 16	1.19	1	8	71	46	63
No. 30	0.6	0	5	62	37	57
No. 50	0.3	0	4	48	24	39
No. 100	0.15	0	3	15	8	28
No. 200	0.08	0	2	10	2	8



Aggregate blending

Example

Sieve Size	Sieve opening (mm)	% Passing			Gradation Limits Range	
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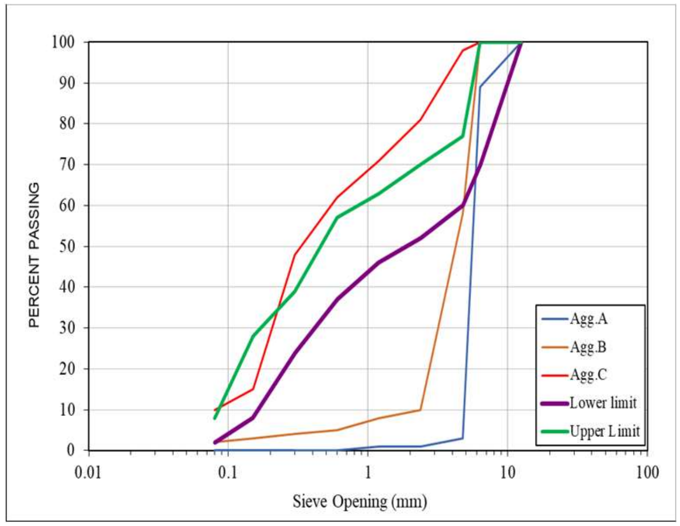
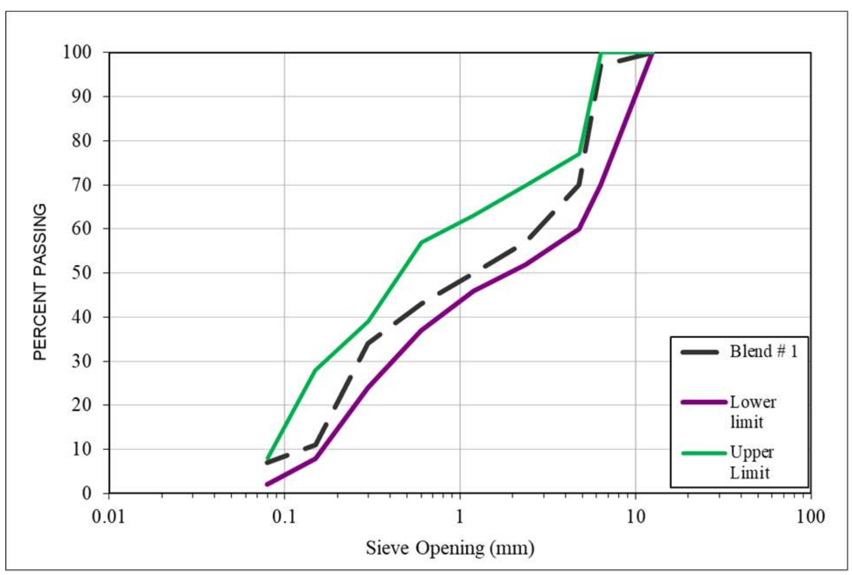
No. 100	0.15	0	3	15	8	28
No. 200	0.08	0	2	10	2	8



Aggregate blending

Example – trial and error



Aggregate

Properties of aggregate

1. Particle size and gradation.
2. Hardness or resistance to wear.
3. Durability or resistance to weathering.
4. Specific gravity & absorption.
5. Chemical stability
6. Particle shape and surface texture.
7. Freedom from deleterious particles or substances.

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Aggregate

Resistance to Wear

- Material should be hard & resist wear due to:
  - *The loading from compaction equipments.*
  - *The polishing effect of traffic.*
  - *Internal abrasive effects of repeated loading.*
- Measure used for hardness of aggregate is
  - *Los Angelos (LA) abrasion test.*
  - Micro Deval Abrasion test

Aggregate

Los Angelos (LA) abrasion test

- Approx. 10% loss for extremely hard igneous rocks
- Approx. 60% loss for soft limestones and sandstones

Aggregate

Los Angelos (LA) abrasion test

https://www.youtube.com/watch?v=trOVxg9GYIs

Aggregate

Los Angelos (LA) abrasion test – Procedures

- Insert aggregate sample in a drum that rotates 30 – 33 rpm for 500 revolutions with steel spheres inside as an abrasive charge.
- Sample removed & sieved @ #12 sieve.
- Retained material are washed and dried.
- Difference between original mass and final mass expressed as percentage of original mass is reported as %wear.
  - *%wear = [(Original – Final)/ Original] 100%*

Aggregate

Micro Deval Abrasion test

Aggregate

Durability & Resistance to Weathering (Soundness Test)

- Soundness Test (AASHTO T104 and ASTM C88)
  - *It simulates the weathering of aggregates that occur in nature.*
  - *It measures resistance to breakdown due to crystal growth.*
- Procedures
  - *Measures the resistance of aggregate to disintegration in a saturated solution of sodium or magnesium sulfate (Na2SO4, MgSO4).*
  - *specify max % loss after X cycles*
  - *typical 10-20% after 5 cycles*

Aggregate

Durability & Resistance to Weathering (Soundness Test)

Before

After

Aggregate

Chemical Stability

- Aggregate surface chemistry affects bonding to cement.
  - *Aggregates that have affinity to water are not desirable in the asphalt mixes (Stripping)*
- Aggregate types

1. Hydrophobic Agg.
   - *Water-hating such as limestone and dolomites have a positive surface charge.*
   - *Work well in asphalt concrete (show little or no strength reduction)*
2. Hydrophilic Agg
   - *Water-loving such as gravels and silicates (acidic) have a negative surface charge (show reduce strength).*

- Gravels may tend to create a weaker interfacial zone in concrete than lime-stone aggregates.

Aggregate

Chemical Stability

- Gravels may tend to create a weaker interfacial zone in concrete than lime-stone aggregates.
- Surface coating (dust of clay, silt, gypsum)
  - *tend to reduce bond strength.*
- Immersion stripping test

Aggregate

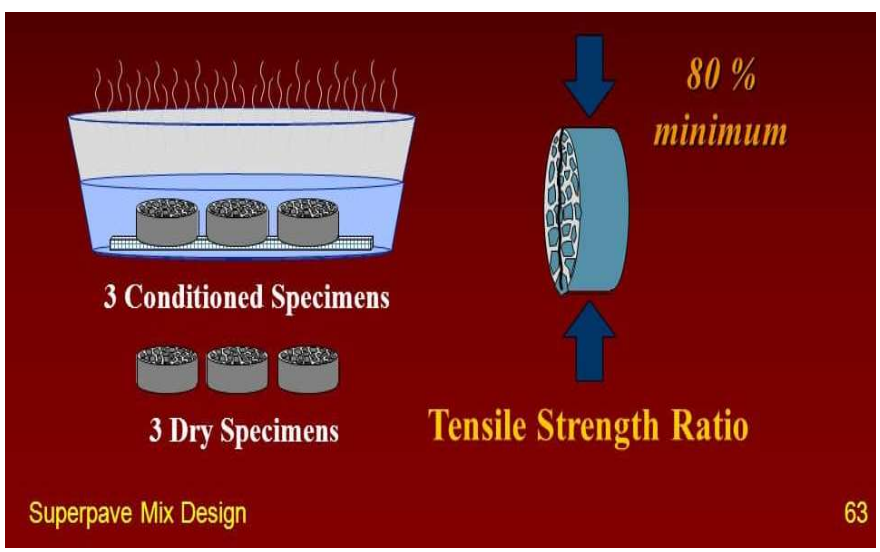
Stripping

https://pavementinteractive.org/reference-desk/pavement-management/pavement-distresses/stripping/

Aggregate

Chemical Stability

- It can be measured using
  - ➢ *Immersion stripping test*



Aggregate

Chemical Stability

- Aggregates used in Portland cement concrete can also cause chemical stability problems.
- Aggregates containing deleterious substances (clay lumbs, chert, silt, organic impurities) which **react** harmfully with the alkalis present in the cement.
- Alkali Silicate Reaction (ASR) results in abnormal expansion of the concrete.

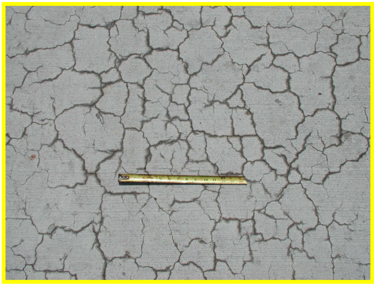
Aggregate

ASR

- Needs three factors:
  - *Source of alkali - Internal and external*
  - *Reactive silica (aggregate)*
  - *Water (humidity) > 80 %*
- ASR results in formation of expansive gels which produce internal stresses which may cause cracking of concrete.
- Environmental factors such as freeze-thaw cycles, wetting/drying cycles, and traffic loading propagate cracking.
- Deicing salts, marine environments, can **accelerate** ASR expansion and deterioration processes.
- ASR can accelerate corrosion deterioration

Aggregate

ASR



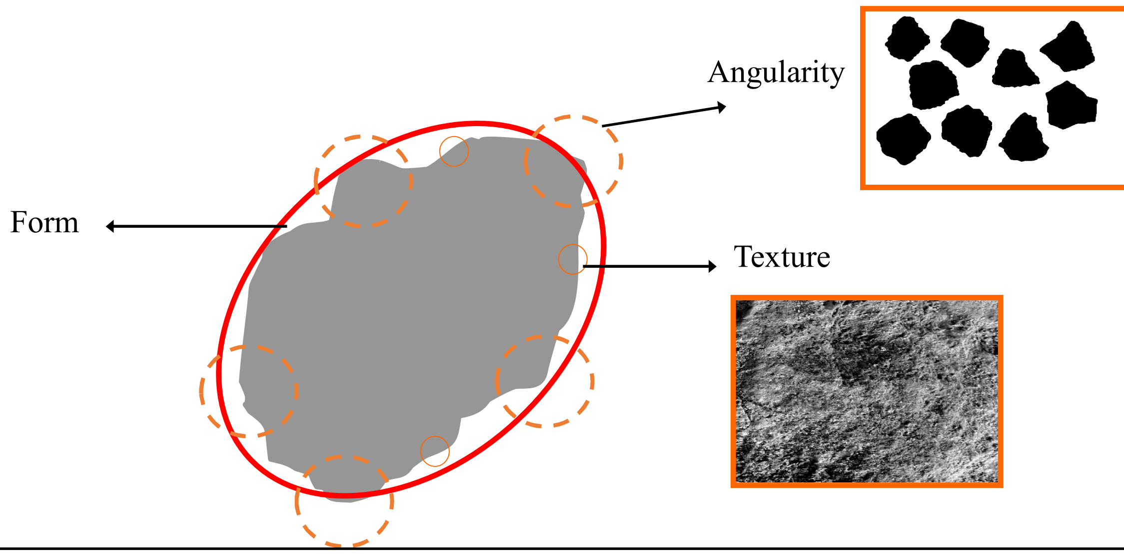
Aggregate

Aggregate Shape & Surface Texture

- Particles shape and surface texture are of great importance to the properties of fresh & hardened concretes.
  - *Form*
    - Reflects variations in the proportions of a particle.
  - *Angularity*
    - Reflects variations at the corners, that is, variations superimposed on shape.
  - *Surface texture*
    - Used to describe the surface irregularity at a scale that is too small to affect the overall shape

Aggregate

Aggregate Shape & Surface Texture



Aggregate

Aggregate Shape & Surface Texture

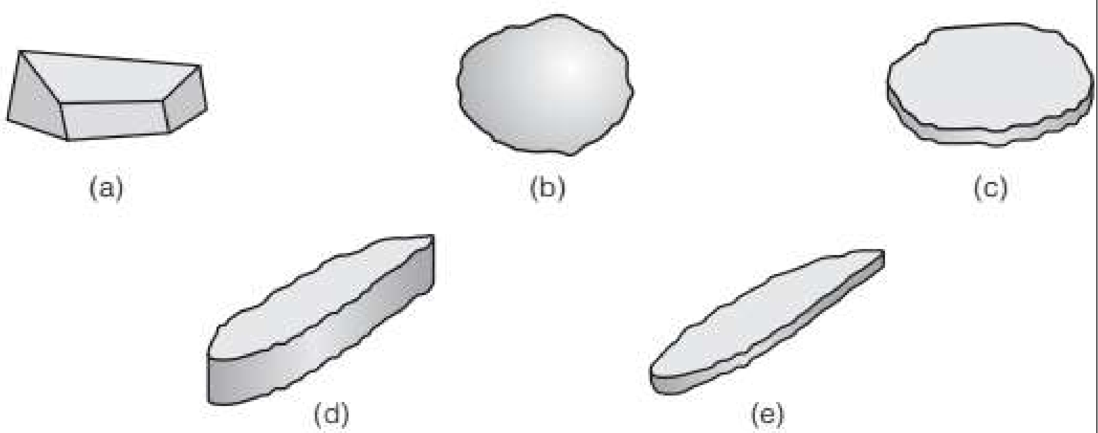


FIGURE 5.3 Particle shapes: (a) angular, (b) rounded, (c) flaky, (d) elongated, and (e) flaky and elongated.

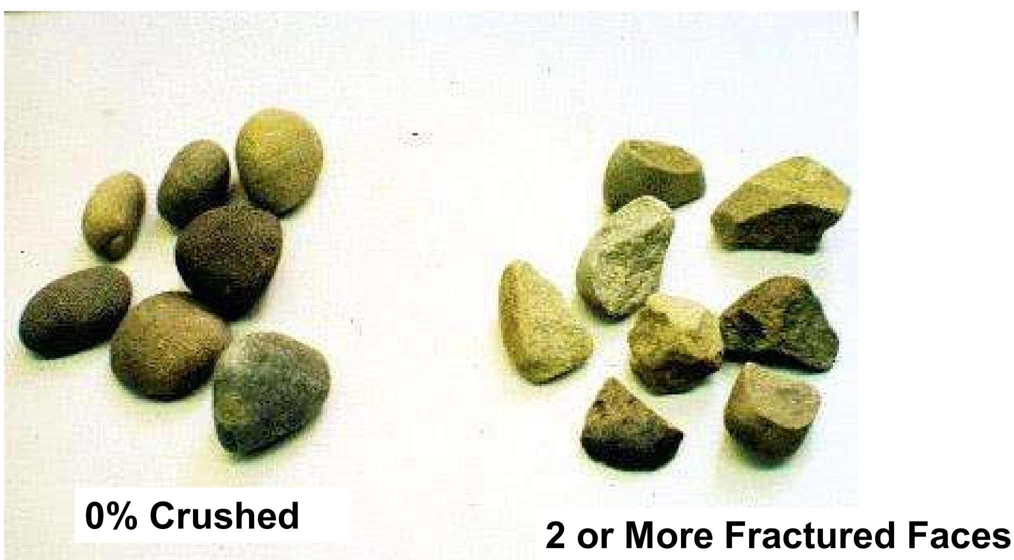
Aggregate

Coarse Aggregate Angularity & Roughness

- Coarse aggregate angularity is important to
  - *Ensure adequate aggregate interlock*
  - *Prevent excessive HMA deformation under load (rutting)*
- It measured using
  - Percent crushed/fractured faces
  - Flat and elongated particles
  - Uncompacted void content

Aggregate

Percent crushed/fractured faces



Aggregate

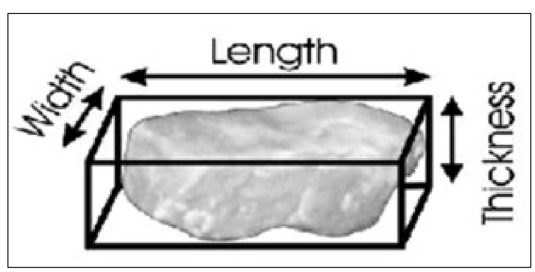
Flat and Elongated Coarse Aggregates

- It provide the percentage by number or weight of flat, elongated, or both flat and elongated particles in a given sample of coarse aggregate.
- Procedures
  - *A proportional caliper device is used to measure the dimensional ratio of aggregates.*
  - *Aggregates are classified according to the undesirable ratios of*
    - width to thickness
    - length to width

Aggregate

Flat and Elongated Coarse Aggregates

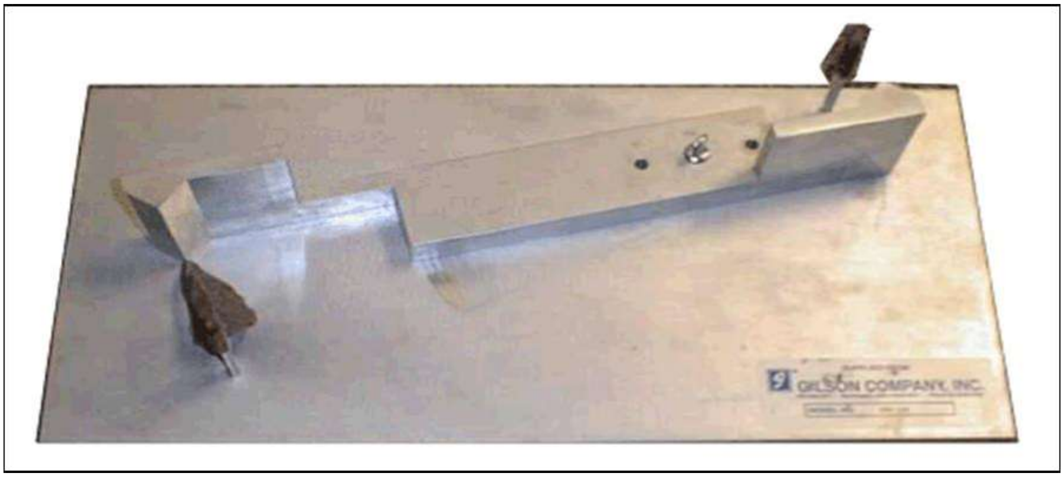
- Aggregates are classified according to the undesirable ratios of
  - *width to thickness to measure flatness*
  - *length to width to measure elongation*



- Aggregate is elongated if
  - *Length > 5 times larger than width*
- Aggregate is flat if
  - *Length or width > 5 times larger than thickness*

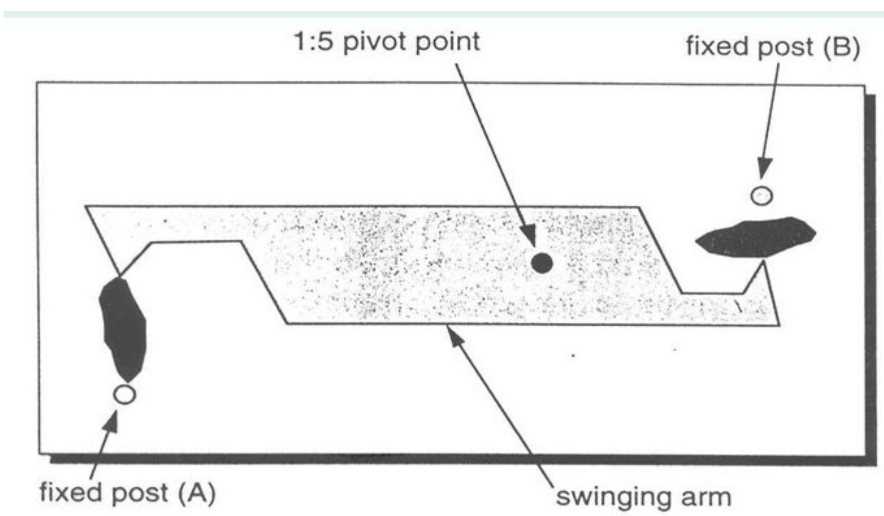
Aggregate

Flat and Elongated Coarse Aggregates



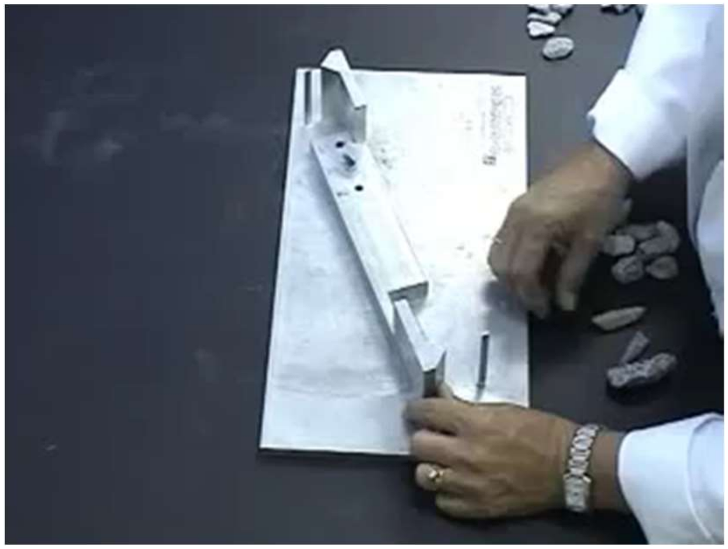
Aggregate

Flat and Elongated Coarse Aggregates



Aggregate

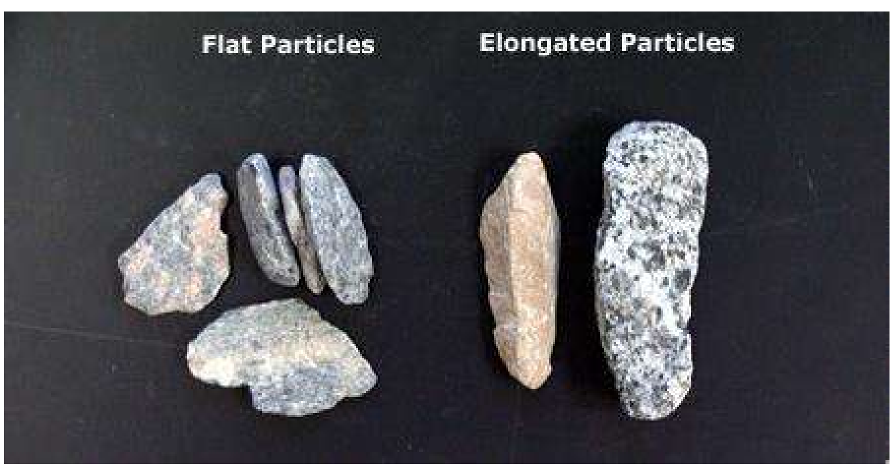
Flat and Elongated Coarse Aggregates



https://www.youtube.com/watch?v=z-FRkiJ4DLc

Aggregate

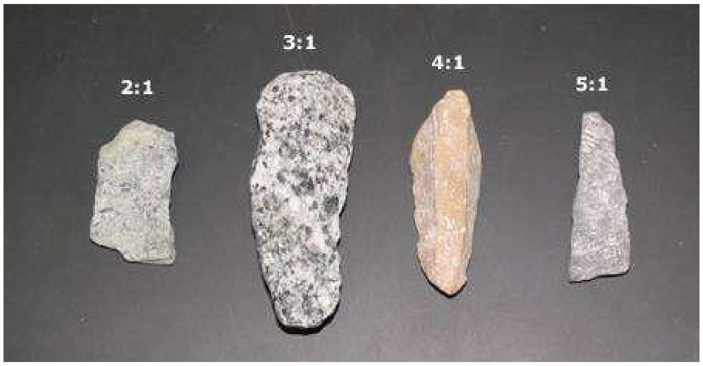
Flat and Elongated Coarse Aggregates



Aggregate

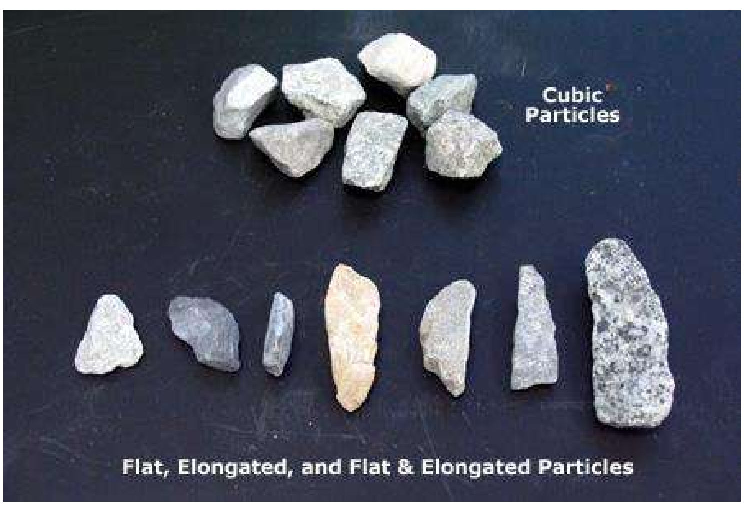
Flat and Elongated Coarse Aggregates

- Typical ratios are 2:1, 3:1, 4:1 and 5:1
- Superpave mix design specifies a ratio of 5:1 and tests particles for flatness and elongation.



Aggregate

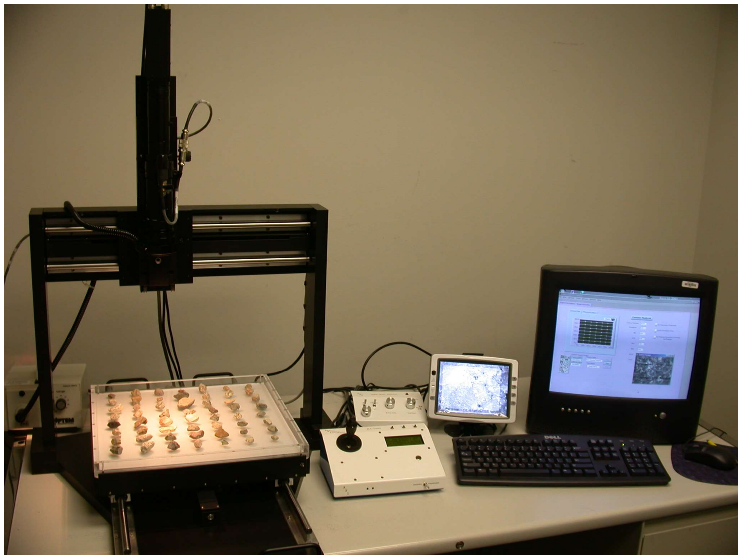
Flat and Elongated Coarse Aggregates

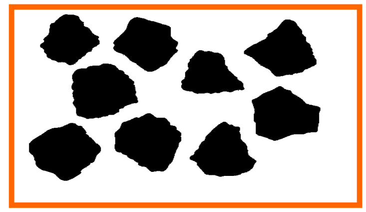


Aggregate

Flat and Elongated Coarse Aggregates

Angularity





Aggregate

Flat and Elongated Coarse Aggregates

Texture

Aggregate

Uncompacted Voids in Coarse Aggregate

- The void content of coarse aggregate measurement provides an indication of angularity, sphericity and surface texture compared to other aggregates of the same grading
- Test procedures
  - *The test aggregate is allowed to free fall 115 mm from the funnel bottom of a cylindrical hopper into a 154 mm diameter by 160 mm high cylindrical measure.*
  - *Excess heaped aggregate is struck off using a bar, and the miss is measured*
  - *Uncompacted void content is computed as the difference between the volume of the cylindrical measure and the absolute volume of coarse aggregate collected in the measure (Based on bulk dry specific gravity as determined by AASHTO T85)*
- Higher void content in samples of equal size gradation indicate
  - *a combination of greater angularity, less sphericity. or rougher surface texture.*

Aggregate

Uncompacted Voids in Coarse Aggregate

- Voids ratio = 1- (bulk density/(S.G x U.Wt. water))

Aggregate

Uncompacted Voids in Coarse Aggregate

- $U = (V - F/G) \sim x\ 100$
- Where:
  - *V = volume of cylindrical measure, ml*
  - *F = net mass of coarse aggregate in measure, g*
  - *G = bulk dry specific gravity of coarse aggregate (by AASHTO T85 procedure)*
  - *U = uncompacted voids, percent in the material*

Aggregate

Freedom from deleterious particles or substances.

- A deleterious substance is any material that adversely affects the quality of Portland cement or asphalt concrete made with the aggregate
- For asphalt mixes
  - Deleterious substances are clay lumps, soft or friable particles, and coatings.
  - These substances decrease the adhesion between asphalt and aggregate particles

Aggregate

Freedom from deleterious particles or substances.

TABLE 5.10 Main Deleterious Substances and Their Effects on Portland Cement Concrete

Substance	Harmful Effect
Organic impurities	Delay settling and hardening, may reduce strength gain, may cause deterioration
Minus 0.075 mm (No. 200)	Weaken bond, may increase water materials requirements
Coal, lignite or other low-density materials	Reduce durability, may cause popouts or stains
Clay lumps and friable particles	Popouts, reduce durability and wear resistance
Soft particles	Reduce durability and wear resistance, popouts

Aggregate

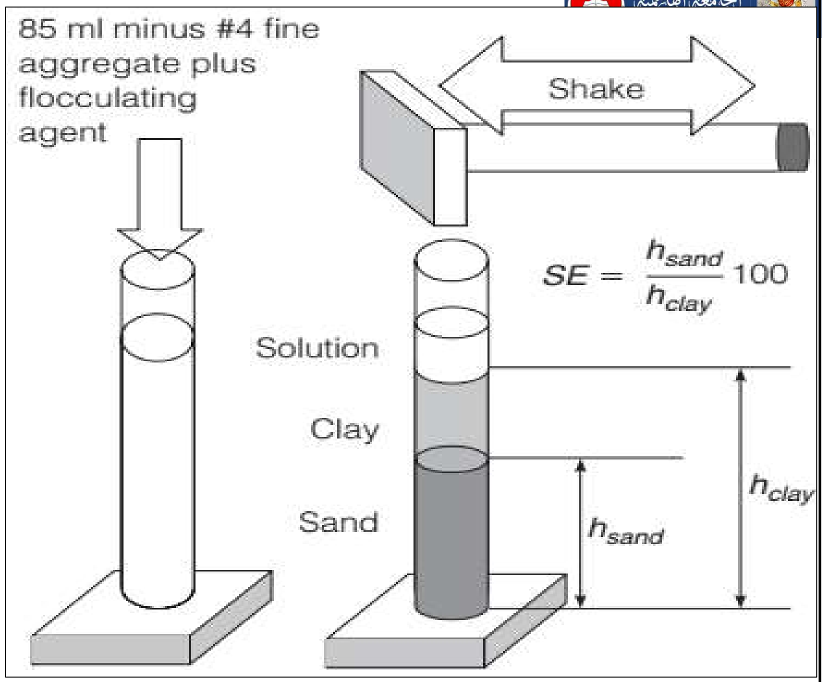
Freedom from deleterious particles or substances.

- The Sand Equivalency test (SE) is used to measure the cleanness of materials
  - *Superpave use the SE test to limit the* clay content of fine aggregates used in asphalt concrete

Aggregate

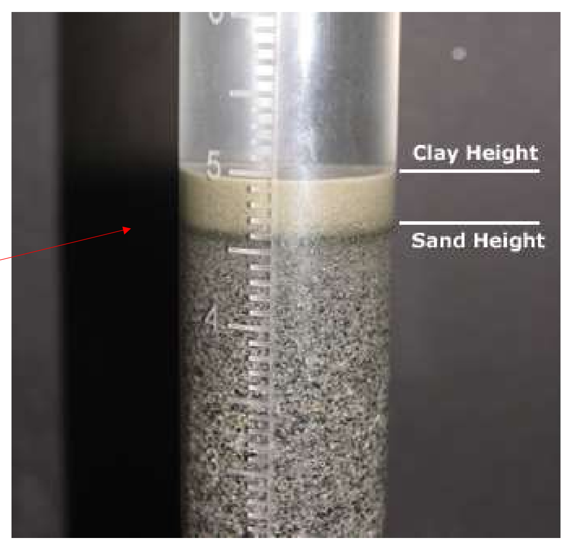
SE test concept

- Specification for aggregate in HMA specify
  - *a minimum sand equivalent in the range of 25 to 35*



Aggregate

SE test



https://pavementinteractive.org/reference-desk/testing/aggregate-tests/sand-equivalent/

Aggregate

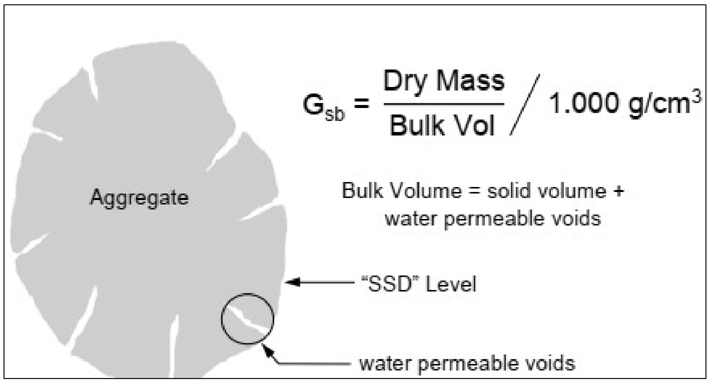
Specific Gravity & Absorption

- Required for the design of concrete & bituminous mixes.
- S.G. :
  - *The ratio of the mass of a unit volume of a material to the mass of the same volume of water at stated temperatures*
    - Conveniently, at 25°C the density of water is 1.000 g/cm3
- Due to permeable voids in aggregates, three types of S. G. are defined
  - *Apparent (Gsa)*
  - *Bulk (oven-dry) (Gsb)*
  - *effective (Gse)*
  - *Gsb < Gse< Gsa*

Aggregate

Bulk Specific Gravity, Gsb

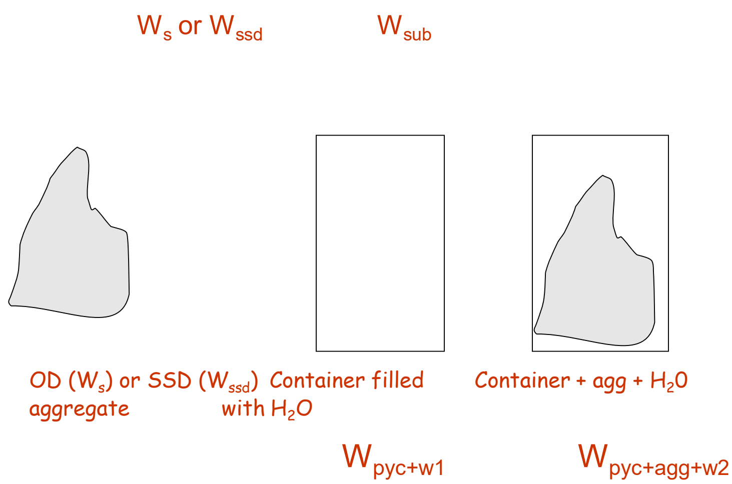
- *The ratio of the mass in air of a unit volume of a permeable material to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.*



Aggregate

Effective Specific Gravity, Gse

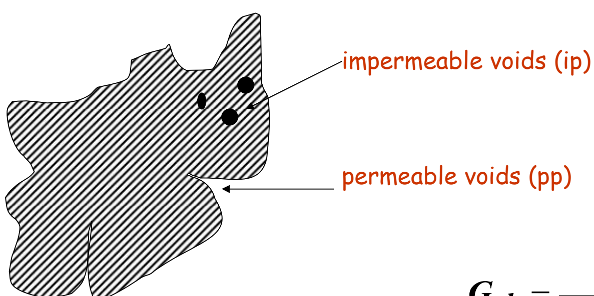
Coarse Aggregate



Fine Aggregate

Aggregate

Bulk Specific Gravity (Gsb)



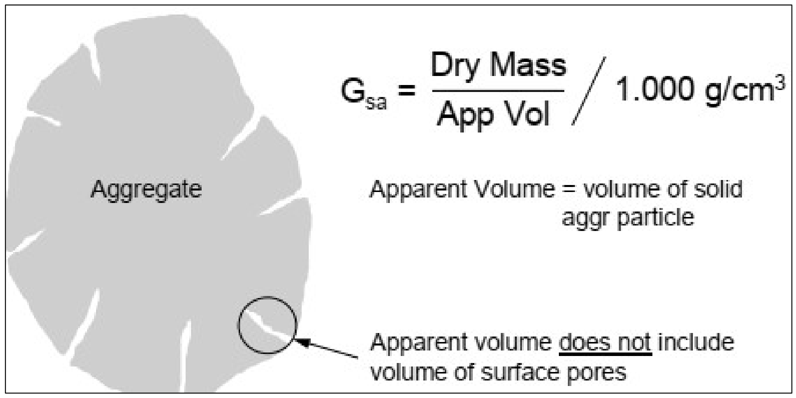
$$G_{sb} = \frac{W_s}{(V_s + V_{ip} + V_{pp})\gamma_w}$$

$$G_{sb} = \frac{W_s}{W_{ssd} - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_{ssd} - W_{pyc+agg+w2}}$$

Aggregate

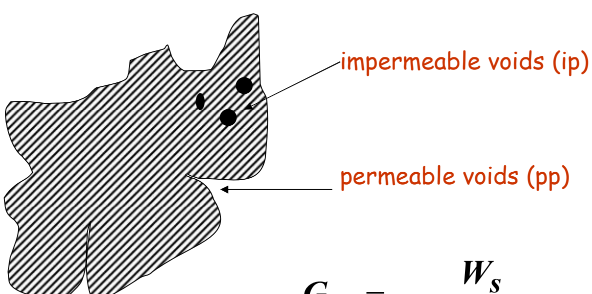
Apparent Specific Gravity, Gsa

- *The ratio of the mass in air of a unit volume of an impermeable material at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature*



Aggregate

Apparent Specific Gravity (Gsa)



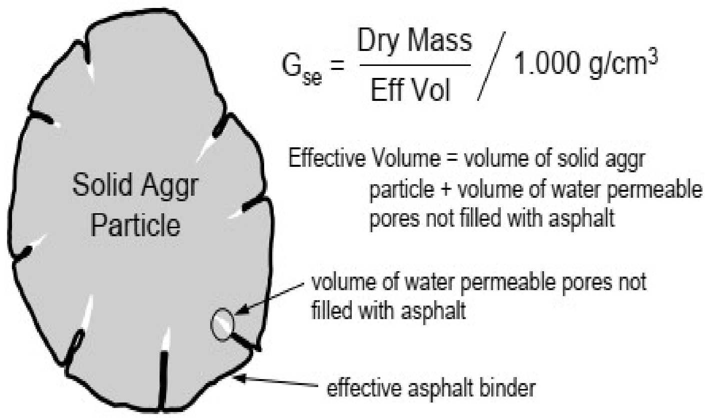
$$G_{sa} = \frac{W_s}{(V_s + V_{ip})\gamma_w}$$

$$G_{sa} = \frac{W_s}{W_s - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_s - W_{pyc+agg+w2}}$$

Aggregate

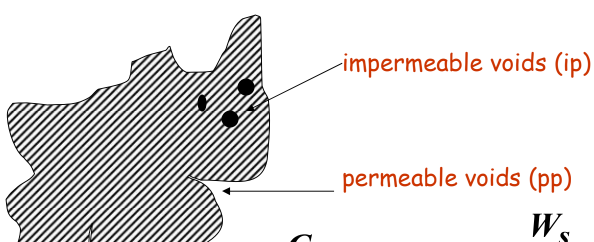
Effective Specific Gravity, Gse

- Apparent Specific Gravity, Gsa
  - *The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.*



Aggregate

Effective Specific Gravity (Gse),



$$G_{se} = \frac{W_s}{(V_s + V_{ip} + V_{pp} - V_{ap})\gamma_w}$$

Calculated from mixture information

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \text{ for } P_b = \text{by wt mix}$$

Aggregate

*V = Very important; M = Moderately important; U = Unimportant or importance unknown

Property	Portland Cement Concrete	Asphalt Concrete	Base
	Relative Importance for End Use*		
PHYSICAL			
Particle shape (angularity)	M	V	V
Particle shape (flakiness, elongation)	M	M	M
Particle size—maximum	M	M	M
Particle size—distribution	M	M	M
Particle surface texture	M	V	V
Pore structure, porosity	V	M	U
Specific gravity, absorption	V	M	M
Soundness—weatherability	V	M	M
Unit weight, voids—loose, compacted	V	M	M
Volumetric stability—thermal	M	U	U
Volumetric stability—wet/dry	M	U	M
Volumetric stability—freeze/thaw	V	M	M
Integrity during heating	U	M	U
Deleterious constituents	V	M	M

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Aggregate

*V = Very important; M = Moderately important; U = Unimportant or importance unknown

Property	Portland Cement Concrete	Asphalt Concrete	Base
	Relative Importance for End Use*		
Solubility	M	U	U
Surface charge	U	V	U
Asphalt affinity	U	V	M
Reactivity to chemicals	V	U	U
Volume stability—chemical	V	M	M
Coatings	M	M	U
MECHANICAL			
Compressive strength	M	U	U
Toughness (impact resistance)	M	M	U
Abrasion resistance	M	M	M
Character of products of abrasion	M	M	U
Mass stability (stiffness, resilience)	U	V	V
Polishability	M	M	U

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