CAIRO UNIVERSITY
FACULTY OF ENGINEERING
PUBLIC WORKS DEPARTMENT

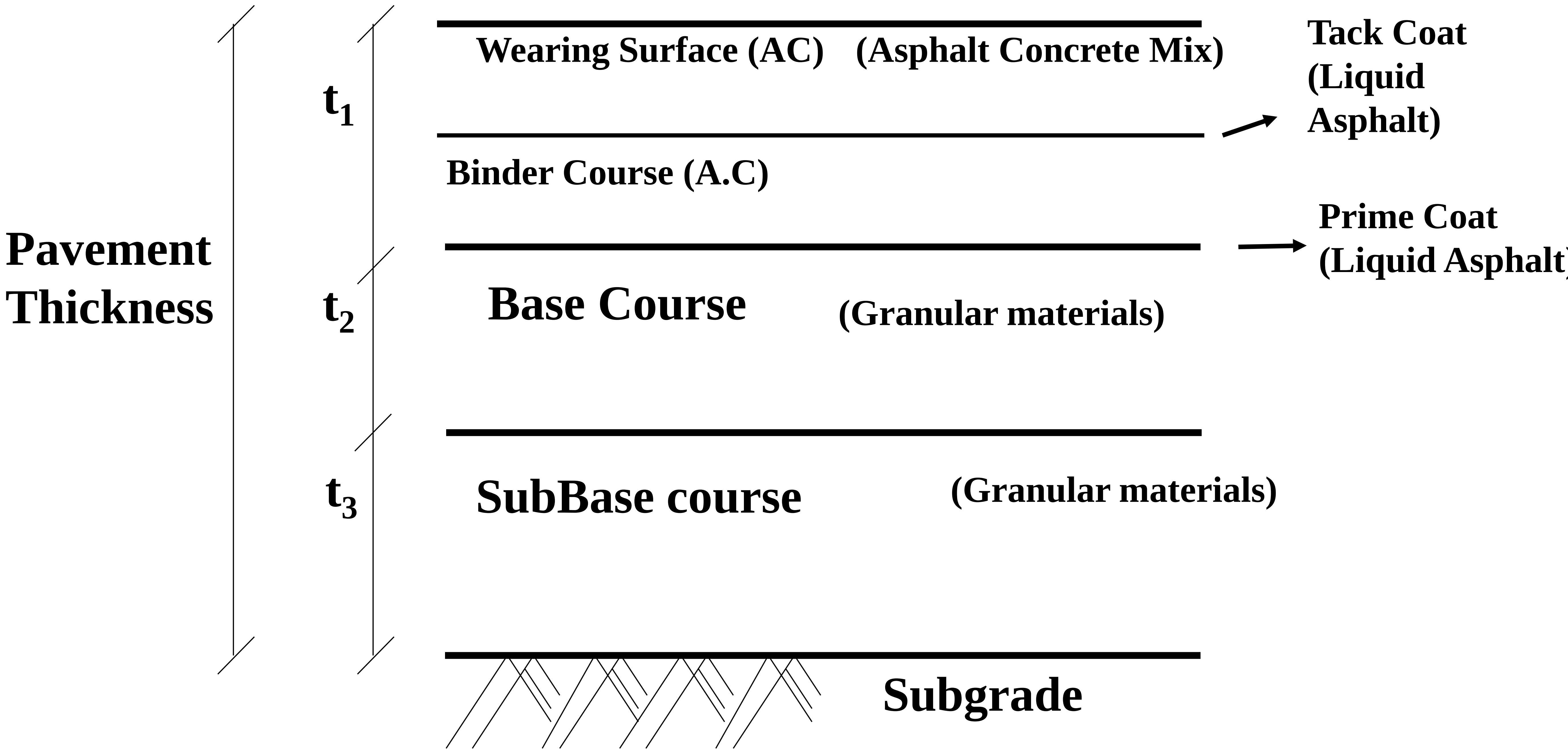
# Structural Design of Highways
# (Part II-A)
# Asphalt Pavement Materials

**Handout (5): <u>Asphalt Cement & Design of Hot mix Asphaltic Concrete</u>**

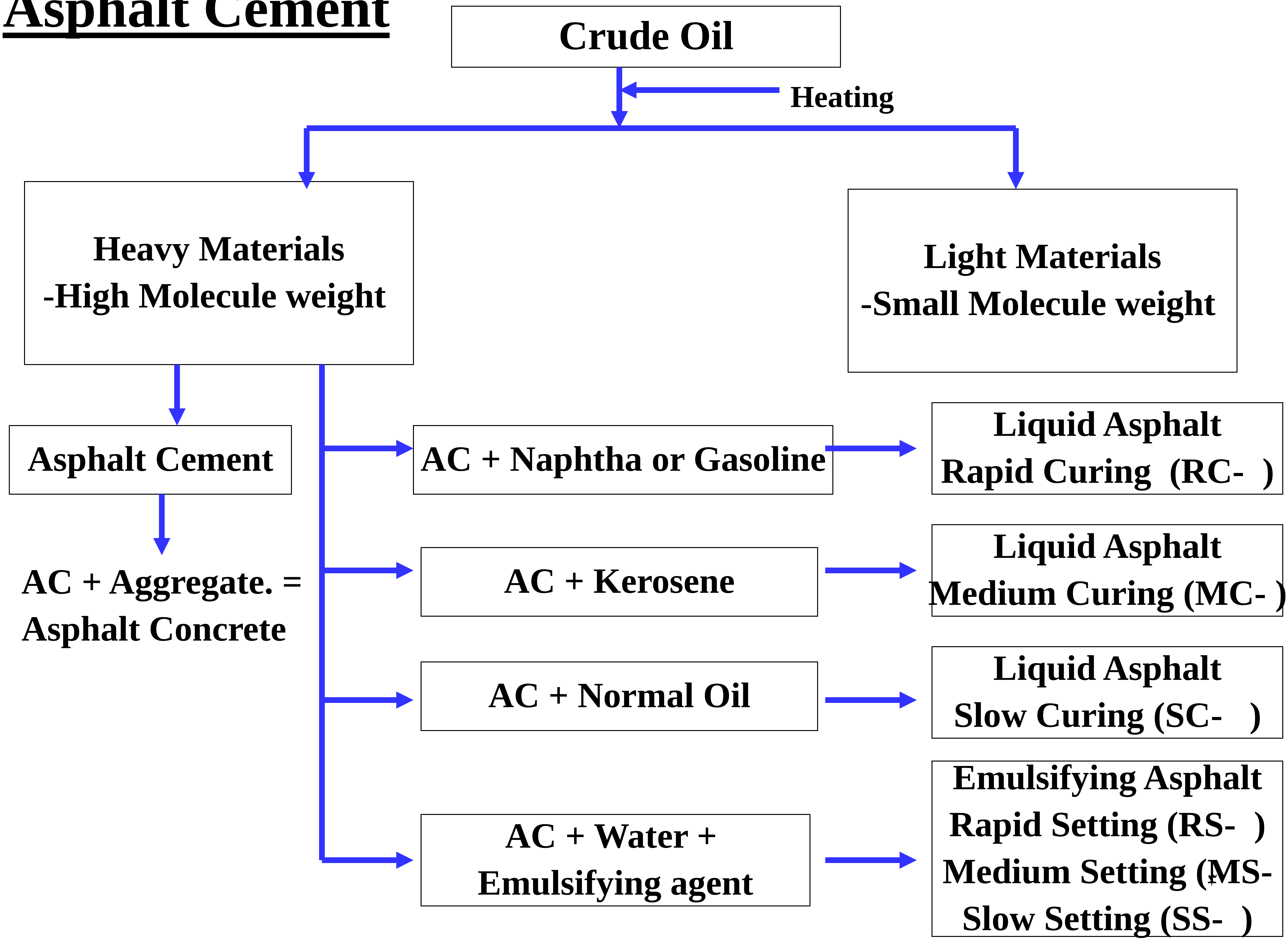
**Lecturer: Dr. Gamal S. Darwish**

# Pavement Structure

## Flexible pavement



# Asphalt Cement



# Asphalt Cement
# (bitumen or asphalt)

- **Paving Asphalt cement is a black, sticky, semisolid and highly viscous material.**
- **Asphalt cement (A.C.) is composed primarily of complex hydrocarbon molecules, but it also contains other atoms such as Oxygen, Nitrogen and Sulfur.**
- **Asphalt cement softens as it is heated and hardens as it is cooled and its properties change dramatically with temperature and rate of loading. It can behave as elastic, visco-elastic or plastic material.**

# Asphalt Cement (A.C.)

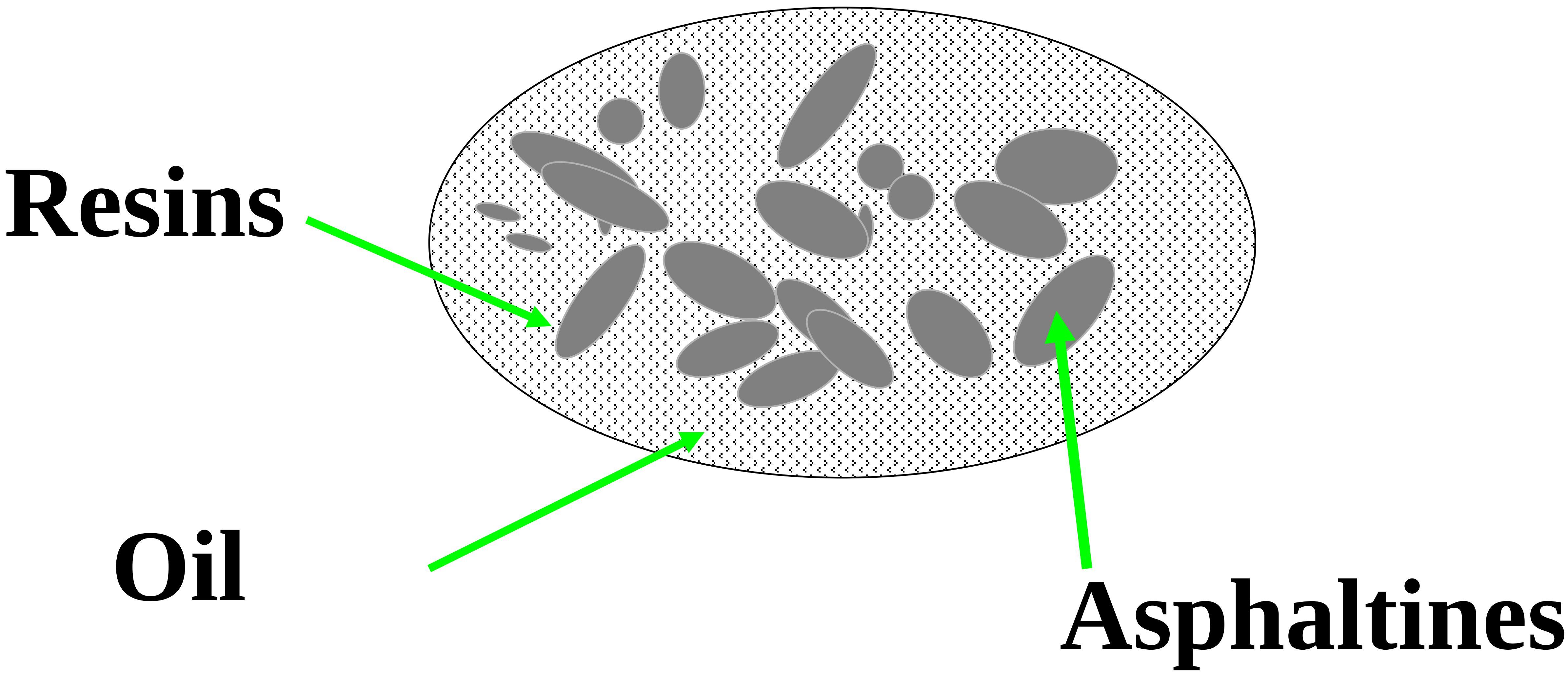
## Asphalt Components:

- Asphaltins : High molecule weight and high portion of Hydrocarbon.
- Resins : Medium Molecule weight , Hydrocarbon + Nitrogen + sulfur.
- Oils : Small Molecule weight like, Naphtha and other oils.

** Asphalt Penetration depends on the portion and properties of Asphaltins.

** The adhesion between Asphalt and Agg., Plasticity of Asphalt and Shear resistance of Asphalt are Affected by the portion and properties of oils.

# *Asphalt Cement*
# *(Bitumen)*



# Tests for Asphalt Cement Evaluation:

**1- Viscosity Test: - To measure the viscosity of A.C. at certain temperatures, 60 and 135 °C.**

**- *Kinamatic viscosity* (135 °C): A.C. Flow time under gravity.**

**Viscosity = Time x Constant = Centistoke**

**(1 stoke = 100 centistoke)**

**- *Saybolt Furol* viscosity (60 °C): A.C. Flow time under vacuum pressure.**

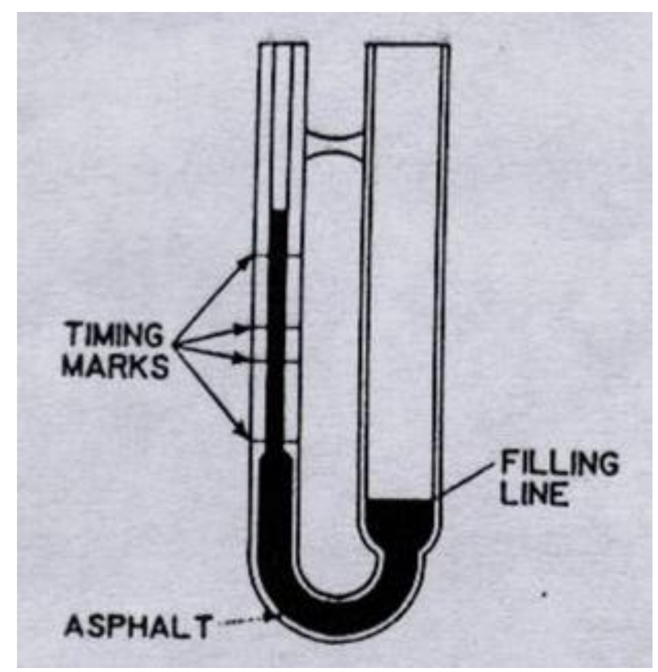
**Viscosity = Time x Constant = Poises**

**Absolute viscosity in Poises = Kinematic viscosity in stokes x specific gravity**

**135 °C simulates mixing and laying down temp.**

**60 °C simulates the max. pavement temp.**

**Vacuum Viscometer**



**2- Penetration Test :** - To measure consistency of A.C.

- The distance a needle penetrates on an A.C. container (at 25 °C)
- Asphalt Grades: pen. 40 – 50 , pen. 60 – 70

  pen. 85 – 100 , pen. 120 – 150

**3- Flash Point Test:** - To indicate safe heating temperature i.e.,the temperature at which volatiles can cause flash under a passing flame.

**4- Thin Film Oven Test:** - To measure resistance of A.C. to changes under hardening (heating – cooling) conditions simulating plant operation.

**5- Ductility Test:** - To measure how much the A.C. can be elongated under certain conditions.

- Higher ductility means higher A.C. adhesion (to aggregates).

**6- Solubility Test:** - To measure the purity of A.C.

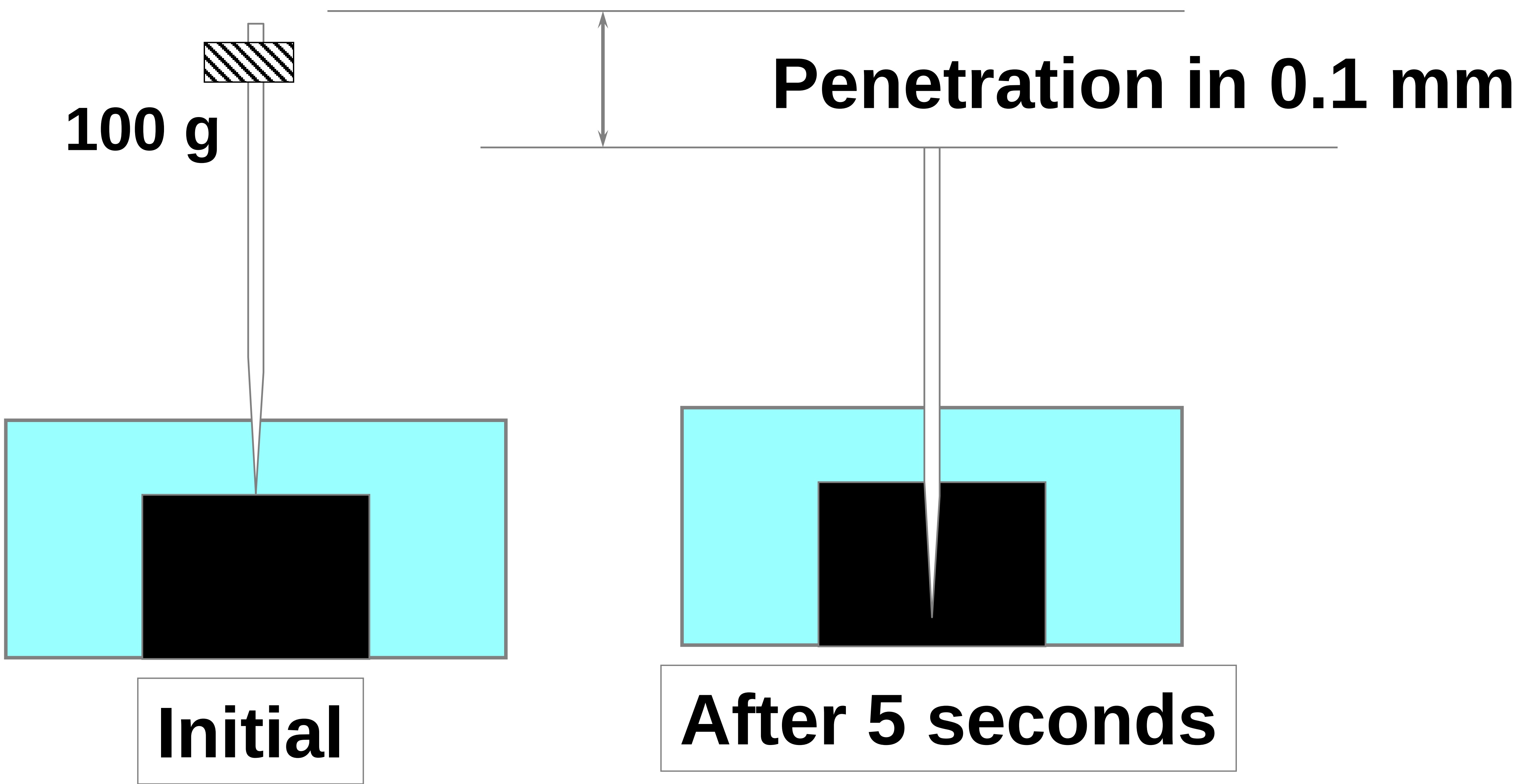
- The soluble portion of A.C. (in carbon disulfide) represents the active cementing constituents. (inert materials are not soluble).

**7- Softening point test:** - To measure the temperature required to reach a certain degree of softening.

- (more important for non-paving applications).

# Penetration Test

- Sewing machine needle
- Specified load, time, temperature (25 °C)



## جدول رقم (١-٣-١) مواصفات الهيئة العامة للطرق والكبارى والنقل البرى للأسفلت الصلب[1] بأنواعه المختلفة

| الخصائص | النوع | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ١٢-٦ | ٢٠-١٠ | ٣٠-٢٠ | ٤٠-٣٠ | ٥٠-٤٠ | ٧٠-٦٠ | ١٠٠-٨٠ | ٢٠٠-١٨٠ |
| – درجة الغرز ( عند ٢٥ $^0$م ، ١٠٠ جم ، ٥ ث ) ٠,١ مم | ١٢-٦ | ٢٠-١٠ | ٣٠-١٠ | ٤٠-٣٠ | ٥٠-٤ | ٧٠-٦٠ | ٠-٨٠ | ٢٠٠-١٨٠ |
| – درجة حرارة التطرية ( بطريقة الكرة والحلقة ) $^0$م [2] | ١٠٠-٨٠ | ٧٥-٦٥ | ٦٨-٥٨ | ٦٤-٥٤ | ٦٠-٥٠ | ٥٥-٤٥ | ٥٢-٤٢ | ٤٥-٣٥ |
| – القابلية للسحب عند ٢٥ $^0$م – سم (حد أدنى) | - | ٥ | ٢٥ | ٦٠ | ٨٠ | ٩٠ | ١٠٠ | ٥٠ |
| – درجة الوميض بجهاز كليفلاند المفتوح – $^0$م (حد أدنى) | ٢٩٠ | ٢٥٠ | ٢٥٠ | ٢٥٠ | ٢٥٠ | ٢٥٠ | ٢٠٠ | ٢٠٠ |
| – الذوبان في رابع كلوريد الكربون وثالث كلوريد الايثيلين – ٪ (حد أدنى) [3] | ٩٩ | ٩٩ | ٩٩ | ٩٩ | ٩٩ | ٩٩ | ٩٩ | ٩٩ |
| – اللزوجة عند ١٣٥ $^0$م (٢٧٥ $^0$ف) – سنتي ستوك – (حد أدنى) | - | - | - | - | ٣٥٠ | ٣٢٠ | ٣٠٠ | ٢٠٠ |
| – اختبار الطبقة الرقيقة ١/٨ بوصة ، ١٦٢,٨ $^0$م (٣٢٥ $^0$ف) وتسخين لمدة خمسة ساعات : (طبقا لما ينص عنه بالشروط الخصوصية للعمليات) | - | - | - | - | - | - | - | - |
| * الفاقد بعد التسخين – نسبة مئوية (حد أقصى) | ٠,٨ | ٠,٨ | ٠,٨ | ٠,٨ | ٠,٨ | ٠,٨ | ١,٠ | ١,٣ |
| * الغرز على المتبقى بعد التسخين – نسبة مئوية من الغرز الاصلي (حد أدنى) | - | - | - | - | - | ٥٤ | ٥٠ | ٤٦ |
| * السحب للمتبقى بعد التسخين عند ٢٥ $^0$م (٧٧ $^0$ف) ، ٥ سم/ دقيقة – حد أدنى | - | - | - | - | - | ٥٠ | ٧٥ | ١٠٠ |
| اختبار البقعة<br>* فى محلول النافثا القياسى<br>* فى محلول النافثازايلين | سالب لجميع الانواع | | | | | | | |

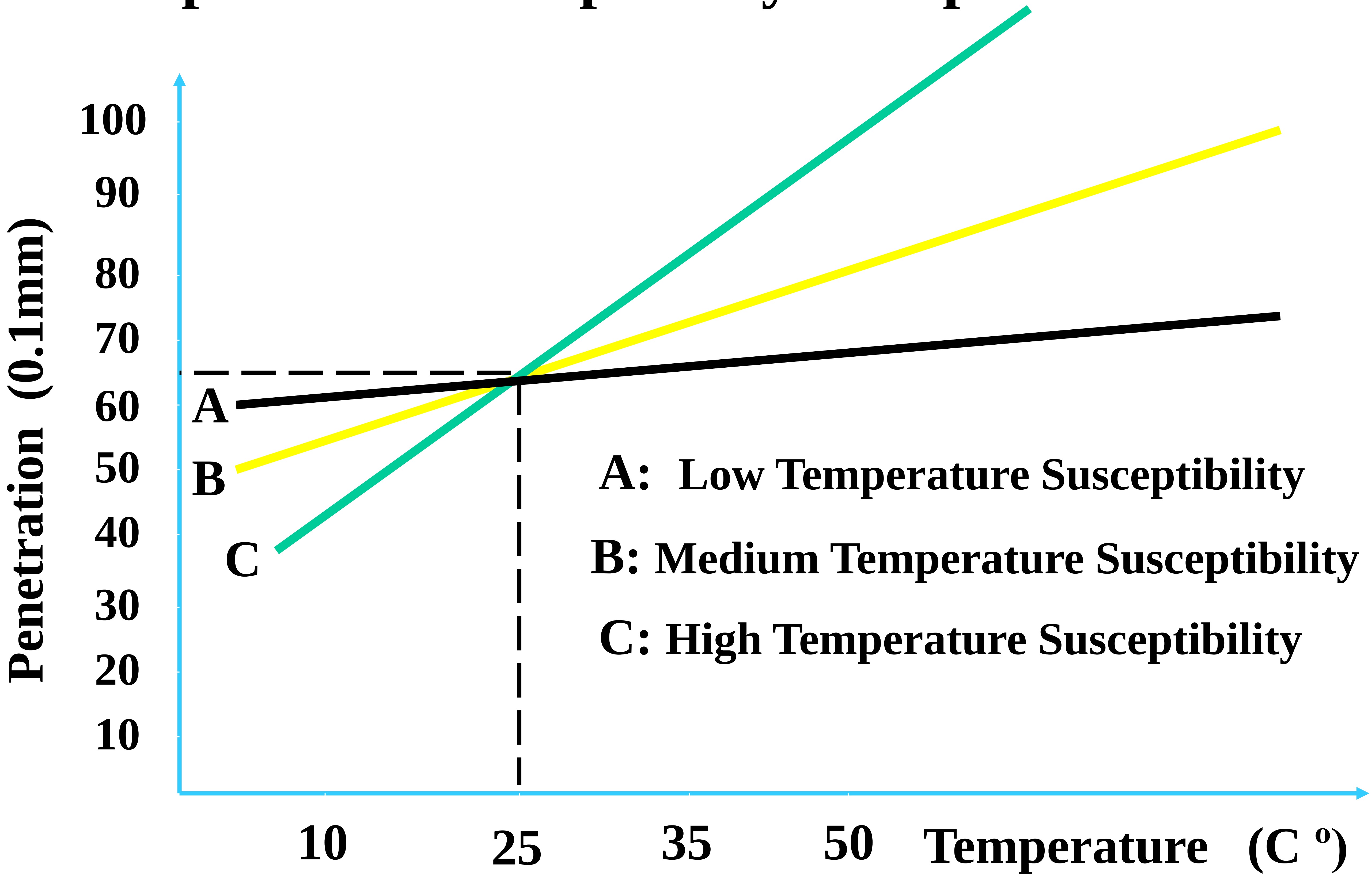
(١) تكون المادة متجانسة تجانسا تاماً وخالياً من الماء

(٢) للاسترشاد .

(٣) يجوز الاكتفاء بأحد الاختبارات.

(٤) تحدد نسبة الزايلين فى الشروط الخصوصية للعمليات .

# Temperature Susceptibility of Asphalt Binders

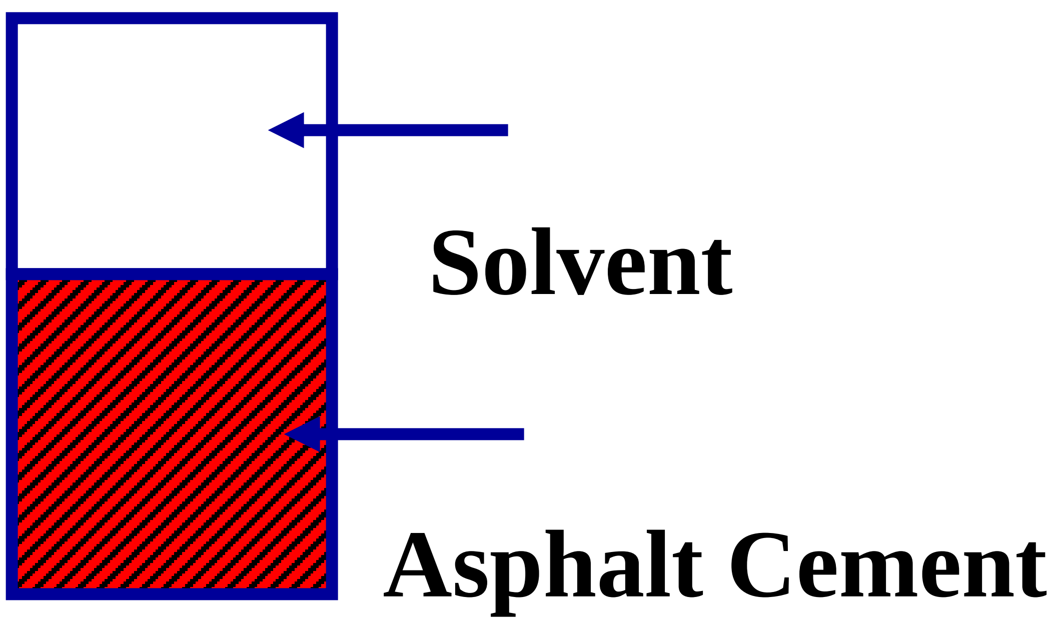


# Liquid Asphalt (L.A.)

**Asphalt Cement + Solvent → Liquid Asphalt (L .A .)**

Asphalt Cement + Solvent: Naphtha, Kerosene, Light Oil

Liquid Asphalt (L .A .): R.C., M.C., S.C.




- **Rapid cure (RC) (Naphtha or Gasoline)**
  - **High volatility of solvent**
  - **Used for Tack coats**
- **Medium cure (MC) (Kerosene)**
  - **Moderate volatility of solvent**
  - **Used for Prime coat**
- **Slow cure (SC) (Low viscosity oil)**
  - **Low volatility of solvent**
  - **Used for dust control**

## Example :

**(MC 0) or (MC 30) means Medium Curing liquid asphalt Degree (0)**

**or Medium Curing liquid asphalt with viscosity (from 15 to 30).**

**Used for prime coat (applied temperature 170 °C)**

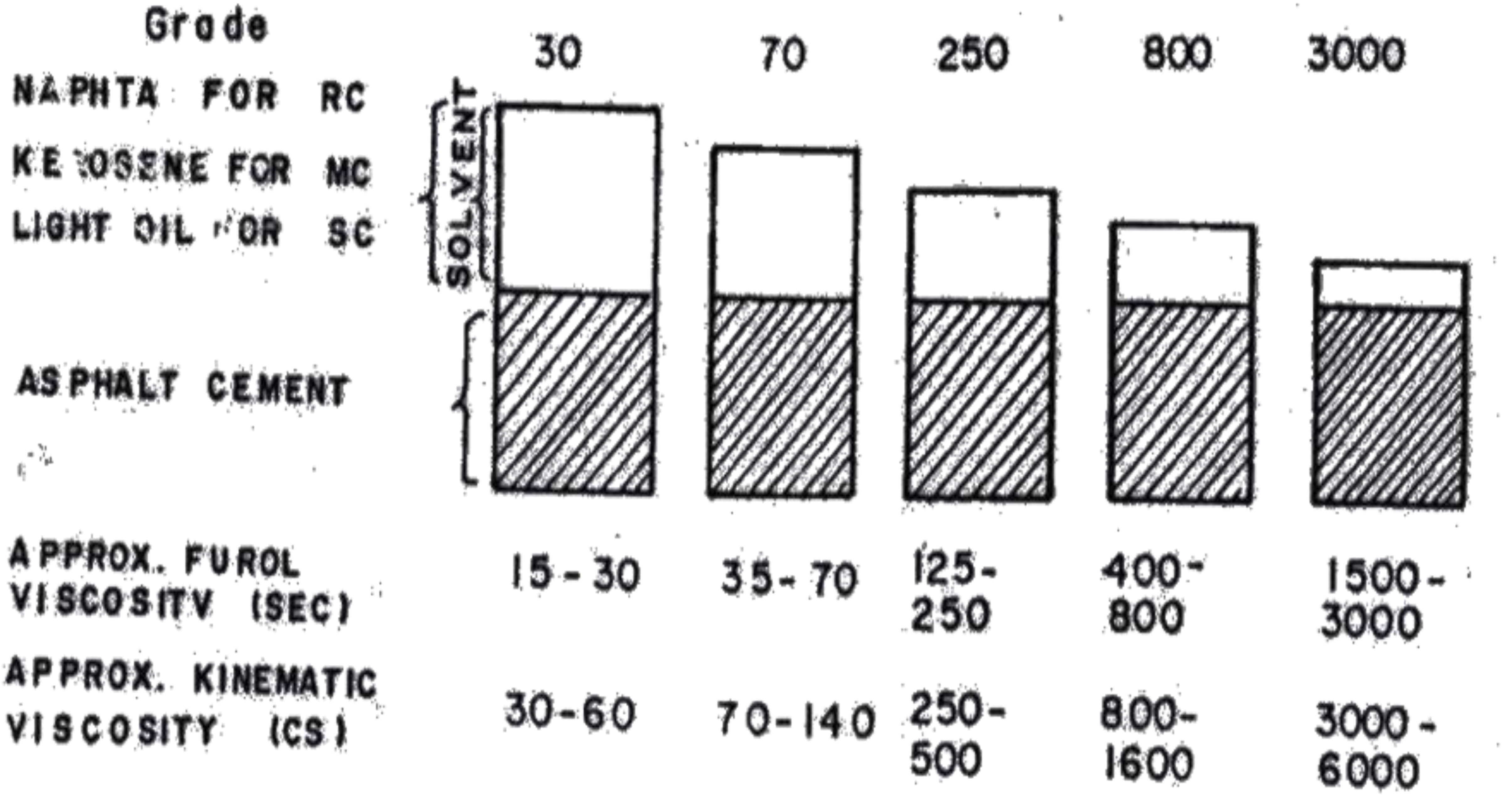



Figure 4.6 Composition and viscosity relations of liquid asphalt

# Asphalt Emulsions

**Asphalt Emulsions consist of Asphalt Cement mixed with water in existence of emulsifying agent to keep asphalt molecules suspended in water.**

**Asphalt**

**Water**

**emulsifying agent**

**Asphalt Emulsion**

**According to type And portion of emulsifying agent**

**Slow Setting (S.S.)**

Mixed with fine materials (sand)

**Medium Setting (M.S.)**

- **M.S.1** — Cold mix In site
- **M.S.2** — Cold mix In mixer

**Rapid Setting (R.S.)**

- **R.S.1** — low Vis.
- **R.S.2** — High Vis.

Used in Macadam and surface treatment

**Asphalt Emulsions**

RS-----RS-0 to RS-5

MS----MS-0 to MS-5

SS----SS-0 to SS-5

# Design of Asphalt Mixtures

**Aggregate + Cementing Material**

**(bitumen) (Asphalt cement)**

**% bit or %A.C.**

## Aggregate:

| | Percentage | Sp. Gr. (S) |
|---|---|---|
| Coarse Agg. | % C.A. | $S_{C.A.}$ |
| Fine Agg. | % F.A. | $S_{F.A.}$ |
| Mineral Filler | %M.F. | $S_{M.F.}$ |

$S_{A.V.}$

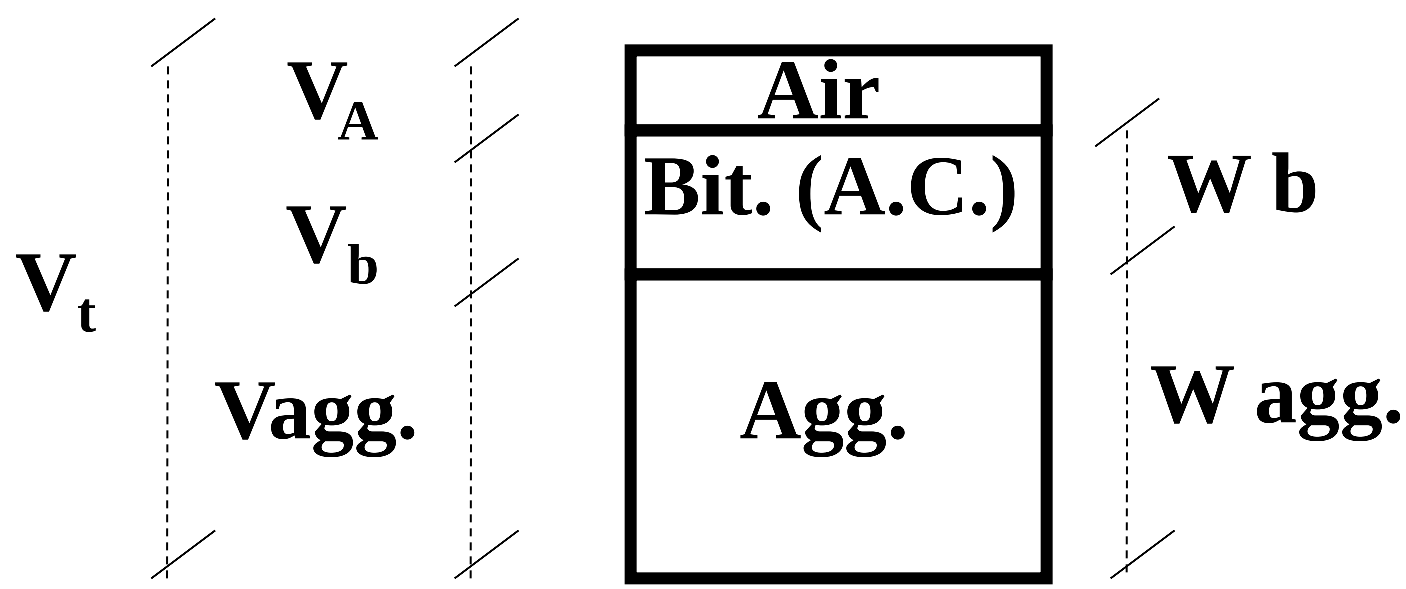
$$S_{A.V.} = \frac{100 \text{ or } (\Sigma \text{ percentages})}{\frac{\%\ C.A.}{S_{C.A.}} + \frac{\%\ F.A.}{S_{f.A.}} + \frac{\%\ M.F.}{S_{M.F.}}} =$$

$$S = \frac{\gamma}{\gamma\, w} \quad \text{Or} \quad \gamma = S \,.\, \gamma\, w$$

$$w_b = v_b \,.\, \gamma_b = vb\,(S_b .\, \gamma_w)$$

$$\gamma_w = 1 \quad gm/cm^3$$

$$= 62.4 \quad Ib/ft^3$$



# Asphalt Cement

$$\%A.C. = \frac{W\ bit}{Wt} * 100$$ (T.W.B.) total weight basis or (by weight of mix)

$$\%A.C. = \frac{W\ bit}{W\ agg.} * 100$$ (A.W.B.) Agg. weight basis or (by weight of agg.)

## General Relationships

$$\gamma\ m = \gamma\ bulk = \frac{W\ t}{V\ t}$$

$W_{S.A.}$ Weight of sample in air (Wt)

$W_{S.W.}$ Weight of sample in water

$$V\ t = \frac{W_{S.A} - W_{S.W}}{\gamma\ w} \quad , \quad \gamma\ m = \frac{W_{S.A}}{W_{S.A} - W_{S.W}} * \gamma\ w$$

$$\gamma_{theoretical} = \gamma_{max} = \frac{W\ t}{V\ t - V\ air} \quad , \quad \%\ Air\ voids = \frac{V_{Air}}{V\ t} * 100$$

$$\frac{\gamma\ bulk}{\gamma_{theoretical}} = 1 - \%A.V. \quad \text{or} \quad \frac{\gamma\ bulk}{\gamma_{theoretical}} = 1 - \frac{V_{Air}}{V\ t}$$

**Volume of voids in Aggregate Mass = VAM**

**Or Voids of Mineral Aggregate = VMA**

$$VAM = V\,air + V\,bit = V\,t - V\,agg$$

$$\%VAM = \frac{V\,air + V\,bit}{V\,t} * 100$$

Or (%VMA)

**% of Voids Filled with Bitumen = %VFB**

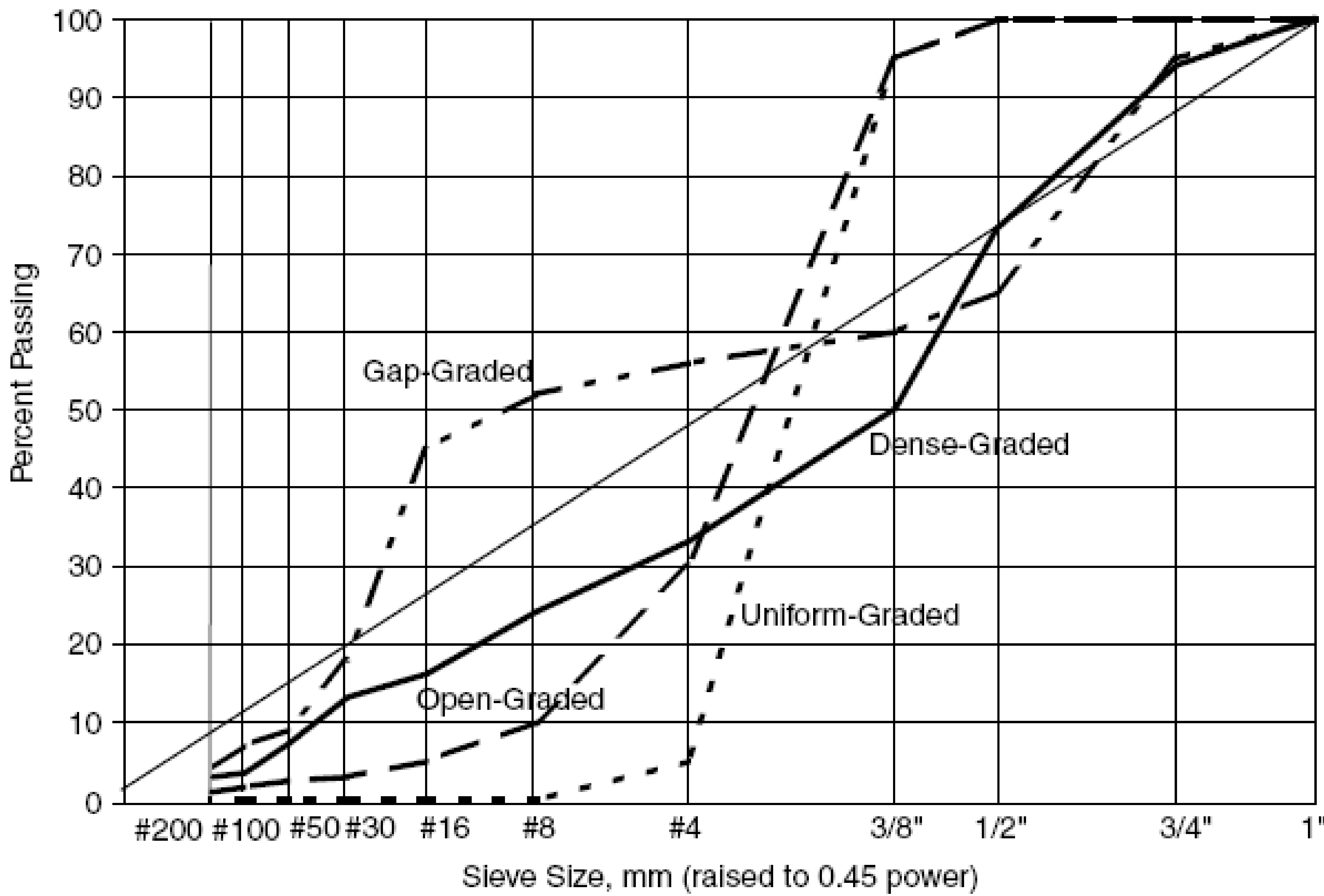
$$\%VFB = \frac{V\,bit}{V\,air + V\,bit} * 100 = \frac{V\,bit}{VAM} * 100$$

## Volumetric properties: % A.V. , %VMA

## Mechanical properties: Stability , Flow

# Types of Hot Asphalt Concrete Mixes

| Type | Application |
|---|---|
| 1-1 Dense Graded Mix | Wearing Course, A.V. 3-5% |
| 1-2 Gap Graded Mix | To Resist Fatigue |
| 1-3 Stone-Mastic Asphalt | Wearing Course, A.V. 3-5% |
| 1-4 Open Graded Friction Course (OGFC) | - To Reduce Accidents.<br>- High drainage properties.<br>- Air Voids = (10 to 12)%. |
| 1-5 Porous Asphalt Mix | - To Reduce Accidents.<br>- High drainage properties.<br>- Air Voids = (15 to 20)%. |
| 1-6 Open Graded Mixes | Binder Course 5-8% |


100
90
80
70
60
50
40
30
20
10
0
Percent Passing
Gap-Graded
Dense-Graded
Uniform-Graded
Open-Graded
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
Sieve Size, mm (raised to 0.45 power)

# Marshall Method of Mix Design

**Objective :** To determine optimum Asphalt Content for a given agg. Blend.

## Test Procedure:

1- Heat aggregate to 170°C for a period of 6 hrs.

2- Heat asphalt cement (A.C.)to about 150°C.

3- Mix Agg. And A.C. at mixing temperature >140°C.

4- Fabricate cylindrical samples D = 4” , h = 2.5”  by applying hummer compaction at compaction temperature>130°C.

** No. of blows 35(low Traffic volume) or 50 (medium Traffic ) or 75 (high Traffic).

## Testing conditions:

- Test temperature  = 60°C

- Rate of loading      = 2”/min

## Test Results:

1- Stability Ib or Newton  (load at failure).

2- Flow 0.01 inch

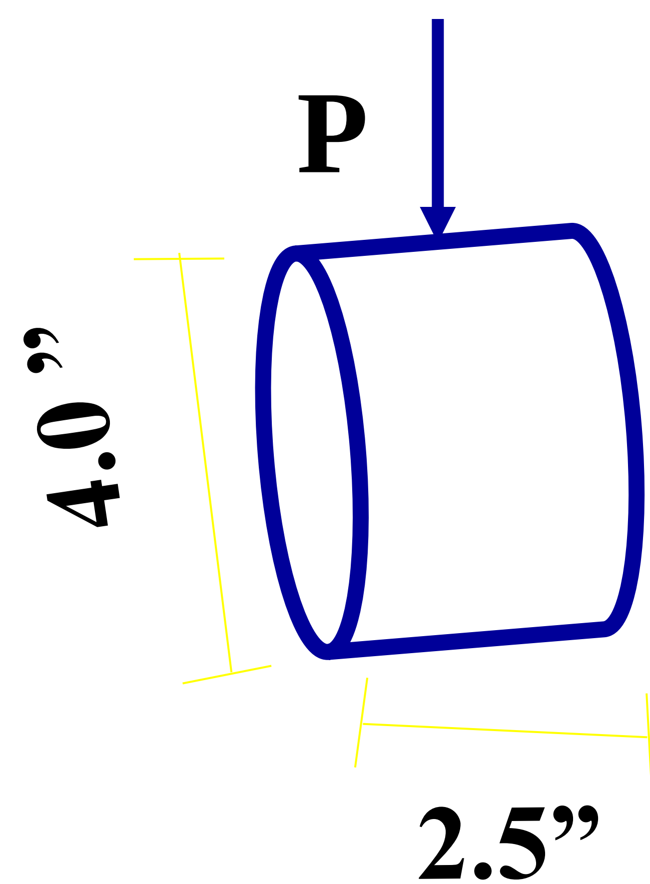
3- %Air Voids  (A.V.).

4- % VMA.

5- Bulk relative density  (γ m).

6- Repeat Test Results at (5) or more A.C. values.

7- Determine Optimum A.C.

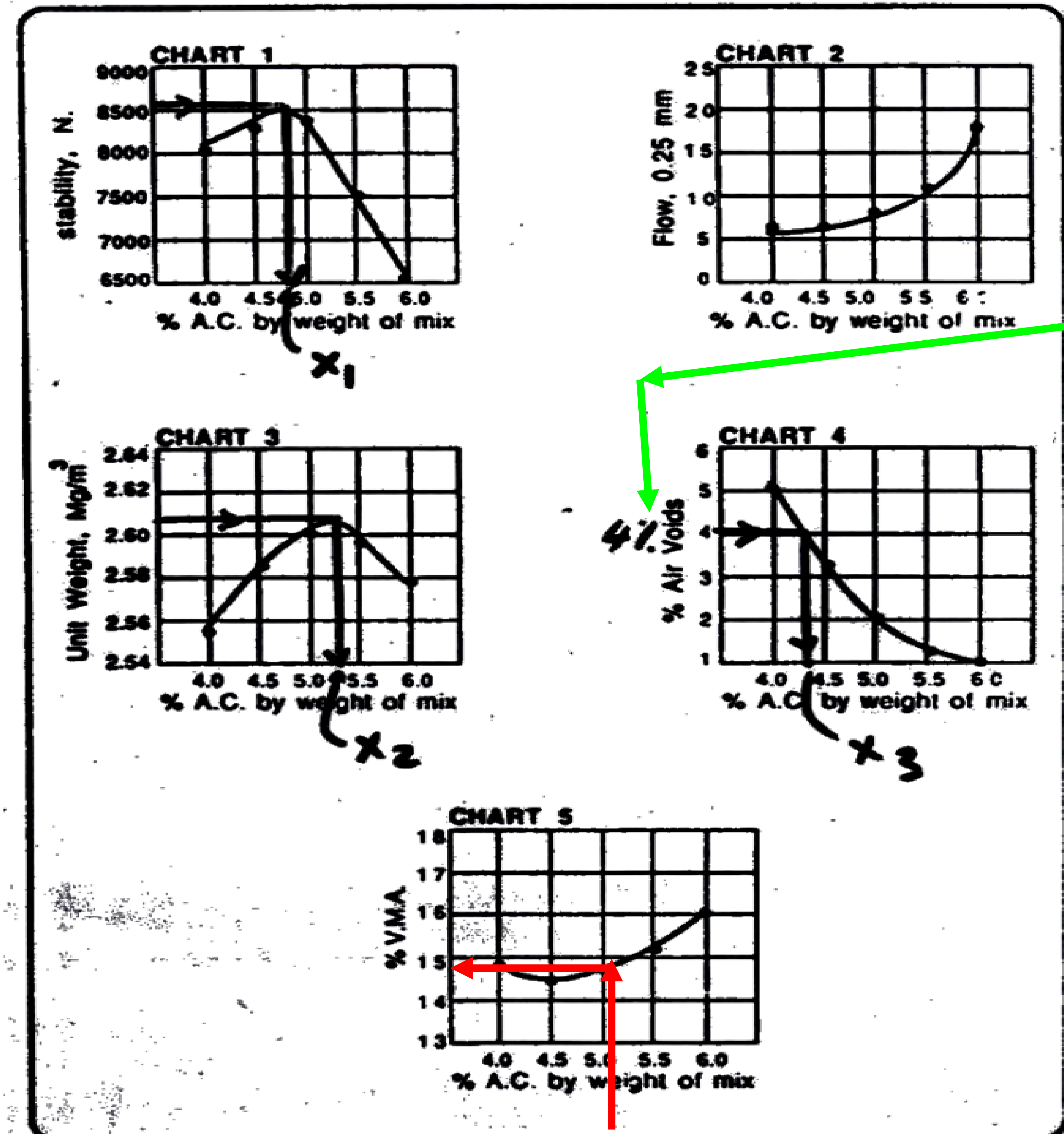


# Marshall Test Apparatus

## **Example

**A.C. Content, %**

| Variable | 5 | 5.5 | 6 | 6.5 | 7 |
|---|---|---|---|---|---|
| Weight of sample in air = Wt | 1211.9 | 1214.2 | 1221.4 | | |
| Weight of sample in water =Ws | 718.9 | 726.4 | 737.3 | | |
| $V\ t = (W_{sA} - W_{sw}) / \gamma_w$ | | | | | |
| $W_{bit} = (\%A.C.) * Wt$ | | | | | |
| $V_{bit} = (W_{bit}) / (S\ bit * \gamma_w)$ | | | | | |
| $W_{agg} = W_t - W_{bit}$ | | | | | |
| $V_{agg} = W_{agg} / (S_{agg} * 1)$ | | | | | |
| $V\ air = V_t - V_{bit} - V_{agg}$ | | | | | |
| $\%A.V. = (V\ air / V\ t) * 100$ | | | | | |
| $VMA = V_{bit} + V_{air}$ | | | | | |
| $\%VMA. = (VAM / V_t) * 100$ | | | | | |
| $\gamma_{bulk} = (W_t / V_t)$ | | | | | |
| Stability (Ib) | 1646 | 1755 | | | |
| Flow 0.01” | 10 | 12 | 13 | ---- | ----- |




Example Plotted Curves Showing Test Results for Marshall Method of Mix Design

**Mid rang for A.V.**

**Surface Mix**
**3 < A.V. < 5**
**4**

**Binder Mix**
**3 < A.V. < 8**
**5.5**

**OGFC Mix**
**10 < A.V. < 12**

**Porous Asph. Mix**
**15 < A.V. < 20**

# Determining Optimum A.C.

- Obtain x1 , x2 ,x3 as shown in the graph
- Optimum A.C. = X = (x1 + x2 + x3) /3 =      %
- Determine mix properties at selected A.C. content (X) : Stability, Flow, A.V., VMA., $\gamma_m$ at (X).
- Check design criteria (Specifications):

Stability > $S_{min}$

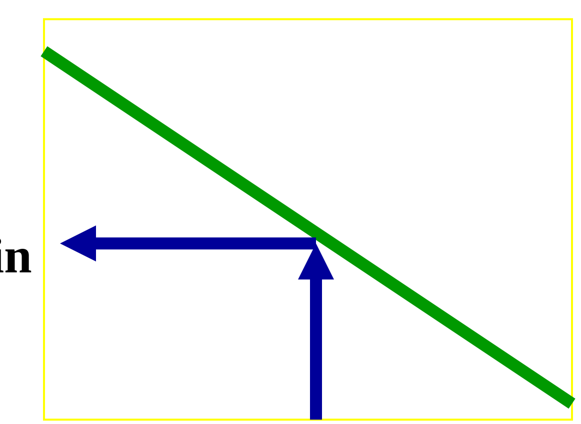
$f_{min}$ < Flow < $f_{max}$

3 < A.V. < 5 for Surface mix ,

3 < A.V. < 8 for Binder mix. *Note; For OGFC or PA*

VMA > VMA min

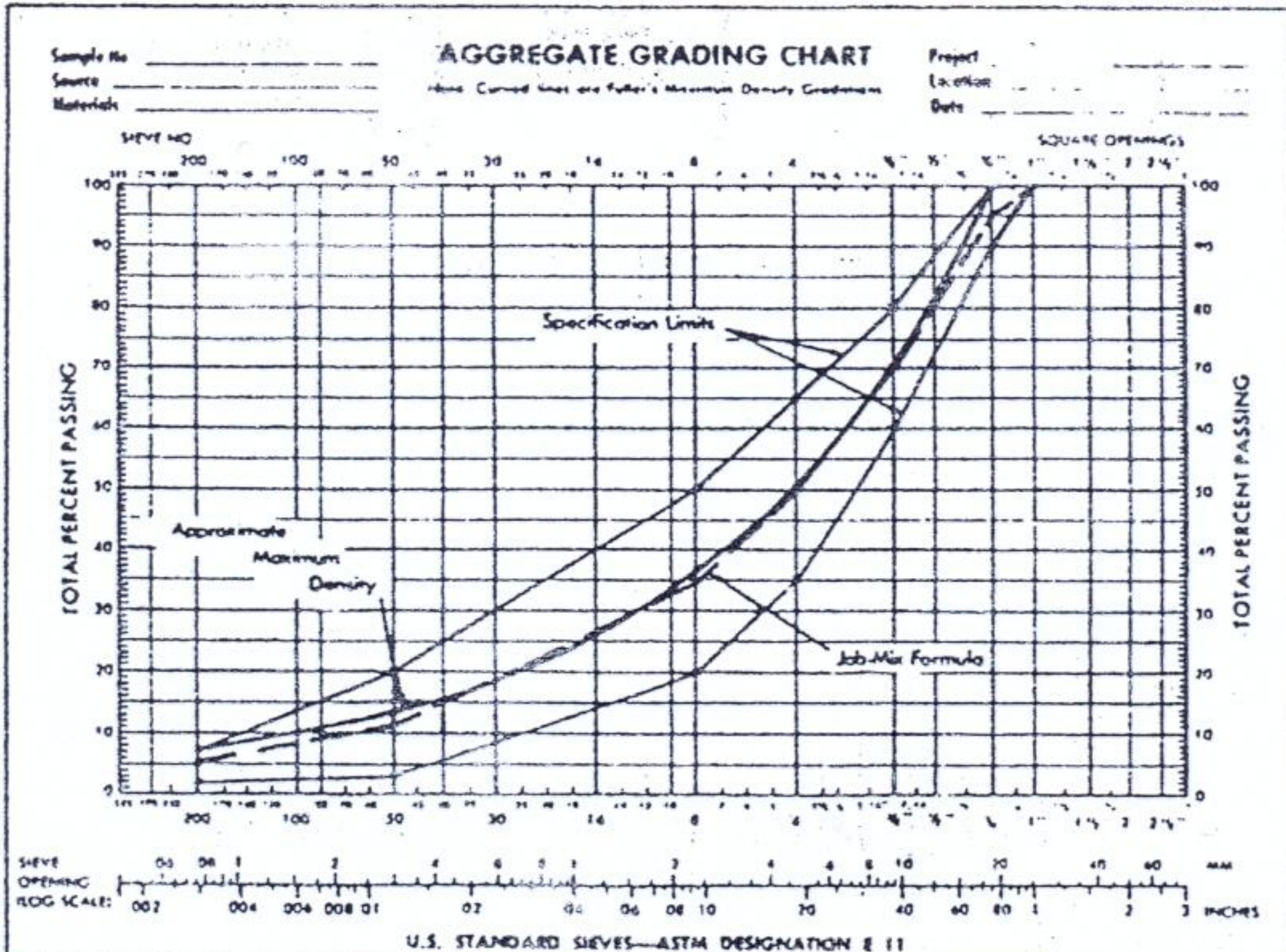
VMA $_{min}$



Max. agg. Size
(¾) or 1”

# Mix Design Alternatives

| Sieve Size or No. | Percent Passing by Weight | | | | |
|---|---|---|---|---|---|
| | Mix A | Mix B | Mix C | Job mix formula Tolerances | Specs. limits |
| 1 –in. | 100 | 100 | 100 | ± 5 | 100 |
| 3/4-in | 83.6 | 82.1 | 83.6 | ± 5 | 80-100 |
| 1/2-in | 68.1 | 67.6 | 68.1 | ± 4 | 65-100 |
| No. 4 | 48.4 | 42 | 48.4 | ± 4 | 40- 60 |
| No. 8 | 39.7 | 38.0 | 39.7 | ± 3 | 25- 50 |
| No. 40 | 22.5 | 23 | 22.5 | ± 3 | 15- 25 |
| No. 200 | 9.5 | 5 | 9.5 | ± 2 | 5- 10 |
| Agg. Type | Limestone | Limestone | **Dolomite** | | |
| Stability | | | | | |
| Flow | | | | | |
| A.V. | | | | | |
| A.C. | | | | | |




Aggregate grading plotted on semilogarithmic chart

Table 3.3 Marshall design criteria

| Traffic category<br>No. of compaction blows each end of specimen | Heavy& very heavy<br>75 | | Medium<br>50 | | Light<br>35 | |
|---|---|---|---|---|---|---|
| Test property | Min | Max | Min | Max | Min | Max |
| Stability (all mixture) | 750 | | 500 | | 500 | |
| Flow (all mixture) | 8 | 16 | 8 | 18 | 8 | 20 |
| % air voids | | | | | | |
| - surfacing or leveling | 3 | 5 | 3 | 5 | 3 | 5 |
| - sand or stone sheet | 3 | 5 | 3 | 5 | 3 | 5 |
| - sand asphalt | 5 | 8 | 5 | 8 | 5 | 8 |
| - binder or base | 3 | 8 | 3 | 8 | 3 | 8 |
| % voids in mineral agg. | see Figure 3.5 | | | | | |

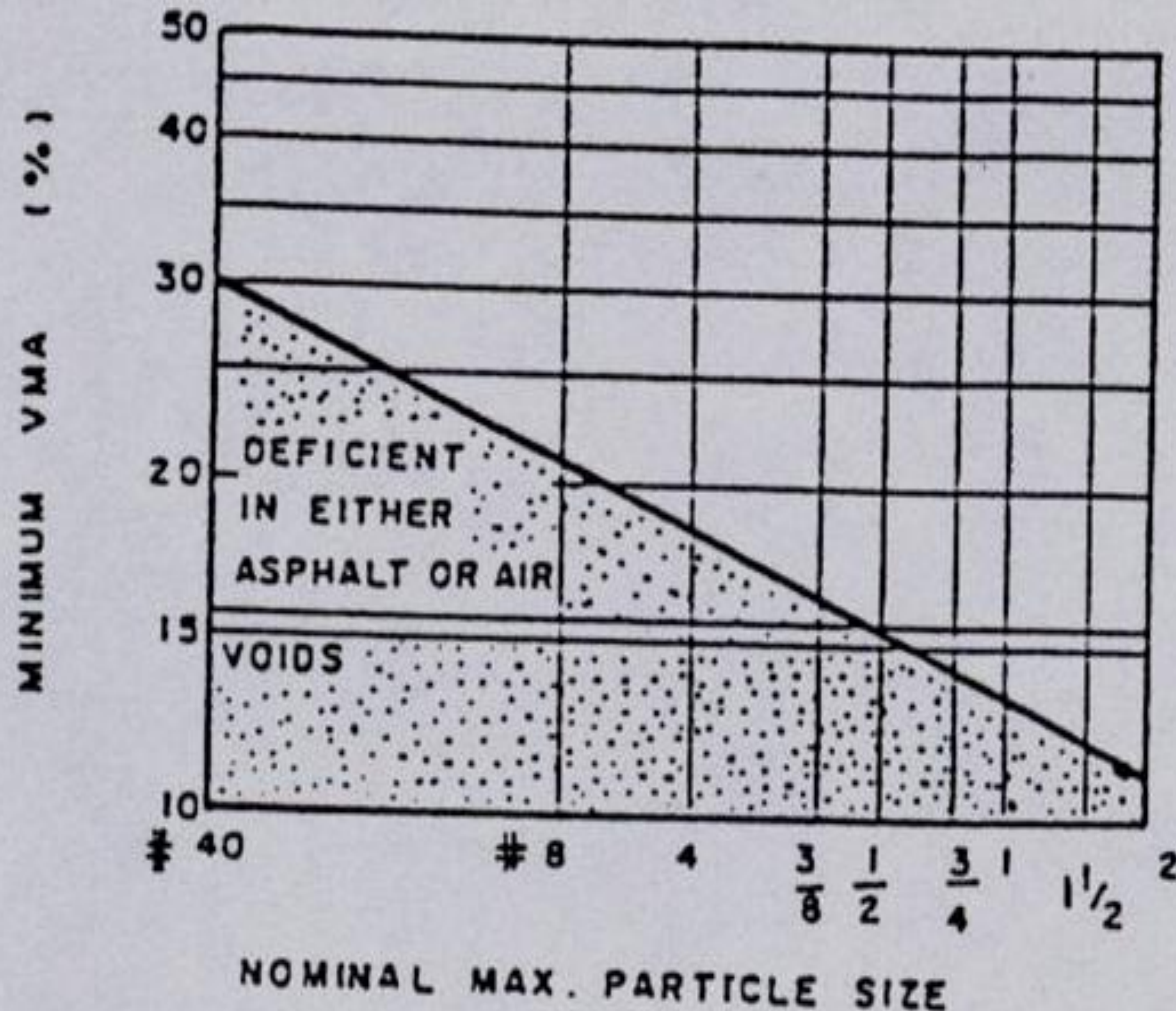



Figure 3.5 Relationship between minimum allowable voids in mineral aggregate (VMA) and nominal particle size of aggregate for compacted dense graded paving mixtures

# Adjust mix properties if necessary

- Low Stability -------- increase coarse aggregate.
- Low Voids -------- decrease mineral filler , use clean sand.
- High Voids ---------- increase fine Agg. Or filler.
- Low Flow ---------- use absorptive agg. (Dolomite agg.)

| Mix Property | | Distress |
|---|---|---|
| Low Stability | $\longrightarrow$ | Deformation, Rutting |
| Low A.V. | $\longrightarrow$ | Bleeding, low skid resistance, Rutting |
| High A.V. | $\longrightarrow$ | Densification under traffic,moisture damage |
| Low Flow | $\longrightarrow$ | Difficult to Compact (harsh mix) |
| High Flow | $\longrightarrow$ | Difficult to Compact (Tender mix) |
| Low VMA | $\longrightarrow$ | Less Durable mix |

# Pavement Rutting ?

- **Permanent deformation on the Wheel Path**
  - **Vehicle Turnover**

**Pavement Surface**

**Asphalt Layer**

## Quality Control Tests

- **For Soil, Agg. Layers:**

**1-Sand cone test ($\gamma d$ )**
**2- Core-Cutter test ($\gamma d$ )**
**3- Volumenometer test ($\gamma d$ )**
**4- Aggregate Gradation**
**5- Core samples (for thickness)**
**6- Straight Edge**

- **For Asphalt mix layers:**

**1- Extraction Test (%A.C.)**
**2- Aggregate Gradation**
**3- Core samples (for thickness)**
**4- Bulk density ($\gamma m$ )**
**5- Straight Edge**

**During Construction to ensure quality**

## Material Characterization Tests

**1- California Bearing Ratio (CBR) (strength)**
**2- Proctor test ($\gamma_{lab.}$ )**
**2- Aggregate Evaluation Tests**
**3- Plate Bearing Test**
**Elastic modulus of a layer (E) and Modulus of Subgrade Reaction (K)**

**Before construction to provide design data**

# Extraction Test

- **A quality Control Test used to separate asphalt cement from an asphalt mix and to determine :**

  **- A.C. content**

  **- Aggregate gradation**

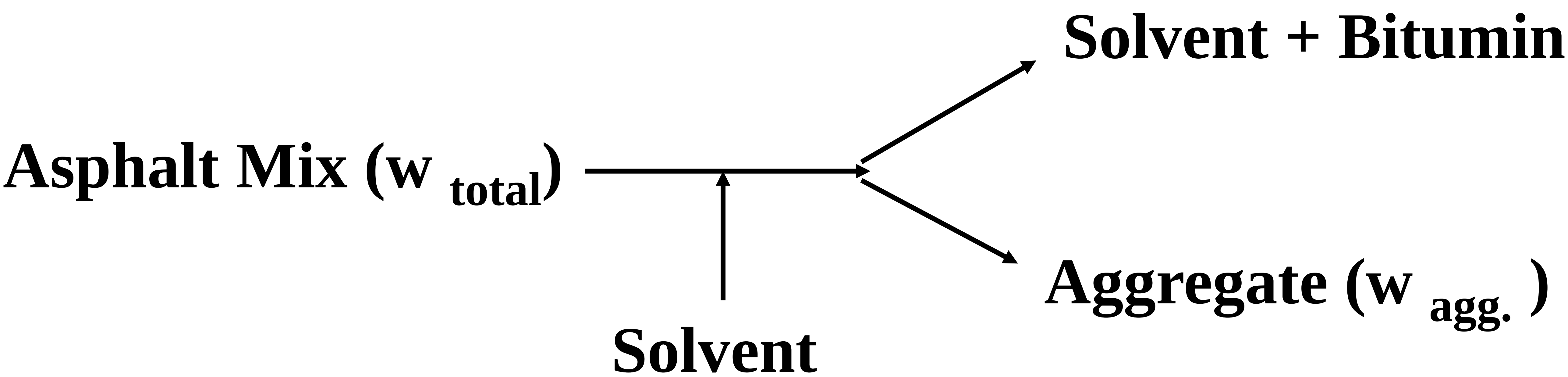
- **Samples are taken as :**

  **1- Core Samples after construction.**

  **2- Loose mix during construction.**

  **3- Loose mix from asphalt mix plant.**

# Extraction Test




$$W_{bit} = W_{total} - W_{agg}$$

$$\%\ A.C. = (W_{bit} / W_{total})* 100$$