Highway Pavement

Civil Engineering Department

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8th Lecture: Flexible Pavement Materials

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Flexible Pavement Materials

Asphalt Types:

(1) **Asphalt cement**: used for producing hot mix asphalt concrete for paving works.

(2) **Liquid Asphalt (cut – back asphalt)**: asphalt cement + solvent

→ According to the type of solvent we can find:

(a) Rapid curing (RC): (< 1 hr) يتطاير في

AC (85 – 100) + gasoline or Naphtha

RC 70

RC 250 → Kinematic viscosity @ 60°C (250 – 500 cst)

RC 800

(b) Medium curing (MC): (≈ 24 hr) يتطاير خلال

AC (120 – 150) + Kerosine

MC 30

MC 70 → Kinematic viscosity @ 60°C (70 – 140 cst)

MC 250

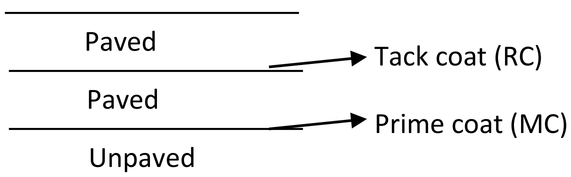
(c) Slow curing (SC): (≈ 7 days) يتطاير خلال

AC (200 – 300) + oil

SC 250

SC 3000

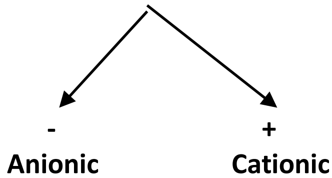
* Uses of liquid asphalt → Tack coat
→ Prime cost



Tack coat	*Prime coat*
1) Thin film of liquid asphalt	Film of liquid asphalt
2) Applied immediately before pavement	Applied before 24hr from paving
3) RC	MC
4) Between two paved layers	Between paved and unpaved
5) 0.25 - 0.5 l/m^2	5) 1 - 1.5 l/m^2
6) for necessary bond	6) for stabilizing loose material and for necessary bond

(3) **Emulsified Asphalt**:

Asphalt cement + water + emulsifying agent



وظيفة هذه المواد هي لشحن الاسفلت ليتحد مع الماء

→ ***<u>According to the type of emulsifying agent</u>***:

(a) Anionic Emulsified Asphalt (-):

(1) Rapid setting (RS)

RS-1

RS-2 → viscosity 2 times viscosity of RS-1

RS-2h → same viscosity of RS-2 but harder AC

(2) Medium setting (MS):

MS-1

MS-2

(3) Slow setting (SS):

SS-1

SS-1h

(b) Cationic Emulsified asphalt (+):

(1) Rapid Setting (CRS):

CRS-1

CRS-2

CRS-2h

(2) Medium setting (CMS):

CMS-1

CMS-2

(3) Slow setting (CSS):

CSS-1

CSS-1h

(*) Uses of emulsified asphalt → cold mix صيانة الطرق الخارجية و كذلك في اعمال التسطيح

Asphalt Mix Design Analysis

Asphalt mix design is a complex issue with a lot of variables involved. It is a mixture of **course aggregate**, **fine aggregate**, **mineral filler** and **bitumen**. Well graded aggregates, mineral filler and optimum quantity of bitumen results a mix with maximum density and very high stability. Marshall Mix design is the most popular method that widely been used in road industry.

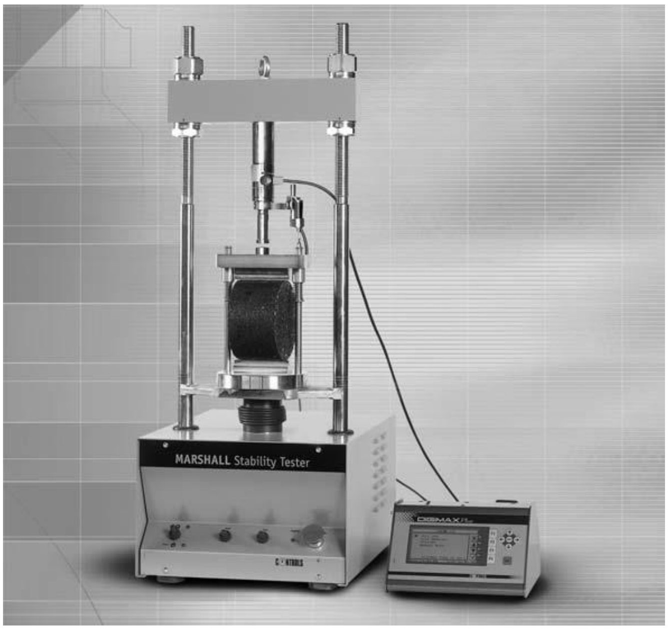
Mix Design Methods

- Marshall Method
- Hveem Method
- Superpave Method

Marshall Mix Design (ASTM D-1559)

Standard test method for resistance to plastic flow of bituminous mixture using Marshall Apparatus.

Purpose: to find O.A.C which is used in pavement to get max stability, min flow, min % voids and max % voids filled with asphalt.



→ Suitable for asphalt cement mixture with the aggregate max size ≤ 1”

→ Analysis of two features:

- Stability – flow
- Density - voids

Marshall Stability: Maximum load resistance of Marshall standard specimen (4" diameter * 2.5" height) at temperature of 60°C.

The stability portion of the test measures the maximum load supported by the test specimen. The specimen is loaded at a constant rate of deformation of 2 in (5 mm) per minute at a standard test temperature of 60 C°. Basically, the load is increased until it reaches a maximum then when the load just begins to decrease, the loading is stopped and the maximum load is recorded.

During the loading, an attached dial gauge measures the specimen’s plastic flow as a result of the loading. The flow value is the deformation that recorded in 0.25 mm (0.01 inch) increments at the same time the maximum load is recorded.

Height of specimen = 2.5" (63.5 mm)

Diameter of specimen = 4" (101.6 mm)

الغرض من تجربة مارشال هو ايجاد نسبة الاسفلت المثالية

If weight of Marshall Specimen (asphalt + aggregate) = 1200 gm and asphalt content (PS) = 5% by weight of mixture.

∴ Asphalt weight = 1200 x (5/100) = 60 gm (asphalt)

(Aggregate + filler) weight = 1200-60 = 1140 gm (aggregate)

In this test we must calculate:

1- Air voids الفراغات الهوائية

2- Voids in Mineral Aggregate الفجوات الداخلية للركام

3- Voids filled with Asphalt (70-85%) الفجوات المملوؤة بالاسفلت

Air voids الفراغات الهوائية = (3-5) % surface layers الطبقات السطحية

(3-7) % non-surface layers

Impact compact method

- Marshall Hammer: 10 lb, 18" drop, 75 blows for each end

≥ 10 KN (1000 kg) wearing course of freeway and bridge approaches.

≥ 8 KN (800 kg) wearing course of highway

≥ 7 KN (700 kg) levelling course (binder)

≥ 5 KN (500 kg) base course

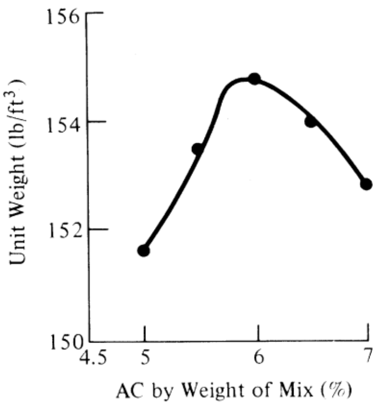
Marshall Flow: Deformation of the standard Marshall specimen @ 60°C corresponding to the max load resistance.

$$Marshall\ Stiffness\left(\frac{kg}{mm}\right) = \frac{Marshall\ Stability\ (kg)}{Marshall\ Flow\ (mm)}$$

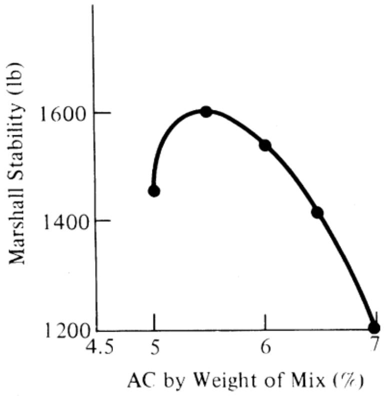
Marshall Flow = (2-4) mm (success)

< 2 mm (semi rigid, no sufficient flexibility)

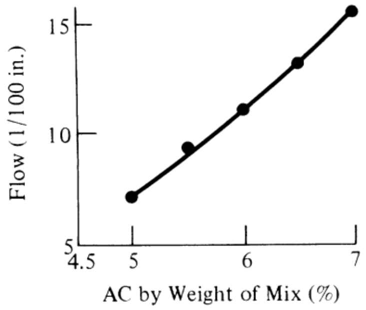
> 4 mm (low resistance to deformation)



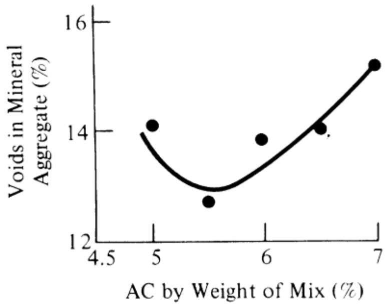
(a) Unit of weight versus asphalt content



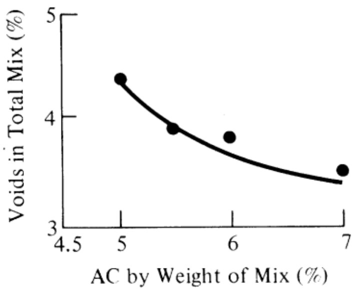
(b) Marshall stability versus asphalt content



(c) Flow versus asphalt content



(d) VMA versus asphalt content



(e) Voids in total mix versus asphalt content

Marshall Test Property Curves

Desirable Properties of Asphalt concrete Mixture:-

An asphalt concrete mixture must be designed, produced and placed in order to obtain the following desirable mix properties:

1. **Stability**: ability to resist permanent deformation under repeated loads.

2. **Durability**: Resistance to weathering effects “temperature, rain water”.

3. **Flexibility**: Ability of pavement to bend repeatedly without fracture “fatigue resistance”.

4. Skid Resistance: ability to provide a suitable coefficient of friction.

- depends on:

- Aggregate surface texture “Rough”

- Dense gradation → Low skid resistance
- Open gradation → High skid resistance

} **Aggregate Gradation**

- Asphalt cement content: high asphalt content → Low Skid Resistance

5. Workability: ability to provide a smooth finishing surface without segregation.

Depends on:

- Construction equipment (paver & roller) and mix plant

- Well proportion of ingredients.

Job mix formula (mix design):

Includes:

1) Selection of proper quality and gradation of aggregate

2) Selection of proper type (grade) of asphalt cement.

3) Selection of proper asphalt cement content (optimum).

→ Aggregate gradation according to the Iraqi General Specification for Roads and Bridge (section R9)

Sieve size		Base course Type I	Binder course Type II	Wearing course Type III A
Inch	mm			
1.5	37.5	100		
1	25	90-100	100	
¾	19	76-90	90-100	100
½	12.5	56-80	70-90	90-100
3/8	9.5	48-74	56-80	76-90
No. 4	4.75	29-59	35-65	44-74
No. 8	2.36	19-45	23-49	28-58
No. 50	0.3	5-17	5-19	5-21
No. 200	0.075	2-8	3-9	4-10

Example 1: In order to make a mixture from 3 types of aggregate. The sieve analysis for these types shown in the table below. Determine the percent that can be used from each type?

Sieve size (mm)	**% passing**			**Specification**
	A	**B**	**C**	
25	100	100	100	100
19	100	100	94	90-100
4.75	100	100	54	60-75
1.18	100	66.4	31.3	40-55
0.3	100	26	22.8	20-35
0.15	73.6	17.6	9	12-22
0.075	40.1	5	3.1	5-10

Solution:

Take sieve size 4.75

P= A*a + B*b + C*c

% passing 100*a + 100*b + 54*c = 67.5 67.5 = (60 + 75)/2

% retained 0*a + 0*b + 46*c = 32.5 32.5 = 100 – 67.5

46 c = 32.5

∴ c = 0.706

Take sieve sizes 1.18 and 0.3

P= A*a + B*b + C*c

% passing (for sieve size 1.18) 100*a + 66.4*b + 31.3*c = 47.5 47.5 = (40+55)/2

% passing (for sieve size 0.3) 100*a + 26*b + 22.8*c = 27.5 27.5 = (20 +35)/2

يتم الان تعويض قيمة ال C في المعادلتين

100 a + 66.4 b = 25.4

$\pm$ 100 a $\pm 26\,b = \pm 11.4$ بالطرح

∴ 40.4 b = 14

b = 0.346

∵ a + b + c =1 ⟶ a= 1 – (b + c)

= 1 – (0.346 + 0.706)

قيمة غير مقبولة لذا علينا ان نعيد المحاولة باختيار قيم اقرب a = - 0.052

و لاعادة الحل ناخذ او نغير في نسب حدود المواصفة

Take sieve size 4.75

% passing 100*a + 100*b + 54*c = 70 ………….. (1)

% retained 0*a + 0*b + 46*c = 30 ………………. (2)

من معادلة 2

46 * c = 30 ⟶ c = 0.652

% passing (for sieve size 1.18) 100 a + 66.4 b + 31.3= 45

(For sieve size 0.3) $\pm 100\ a \pm 26\ b \pm 22.8 * c = -27.5$ بالطرح

∴ 40.4 b + 8.5 c= 17.5

الان تعوض قيمة ال c

b = 0.3

∵ a + b + c =1 ⟶ a= 1 – (b + c)

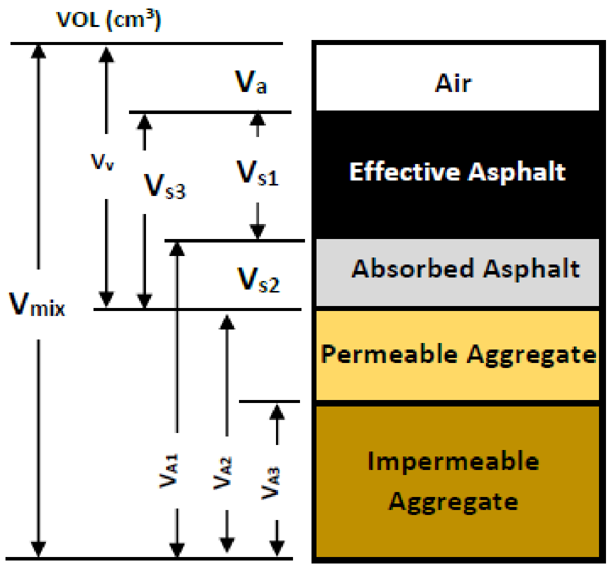
= 1 – (0.3 + 0.65) ∴ a = 0.05

الان اصبحت جميع القيم موجبة و مجموعها 1

الان نعمل الجدول و حسب القيم الجديدة للنسب

Sieve size (mm)	% passing			Combination	Mid-point of Specification
	a *A	b * B	c * C		
25	5	30	65	100	100
19	5	30	61.1	96.1	95
4.75	5	30	35.1	70.1	67.5
1.18	5	19.92	20.34	45.26	47.5
0.3	5	7.8	14.82	27.62	27.5
0.15	3.68	5.28	5.85	14.81	17
0.075	2.005	1.5	2.015	5.52	7.5

Asphalt Mixture Volumetric Properties



Presentation of volumes in compacted asphalt mixture

Vm= volume of compacted mixture

Va= volume of air voids

V_{A1}= Bulk Volume of Aggregate

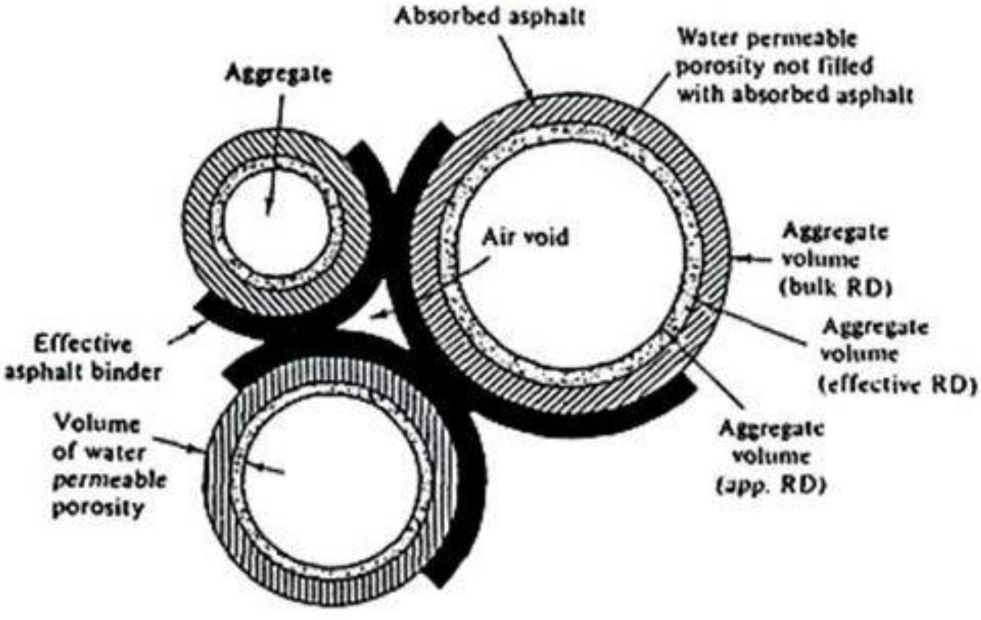
V_{A2}= Effective Volume of Aggregate

V_{A3}= Apparent Volume of Aggregate

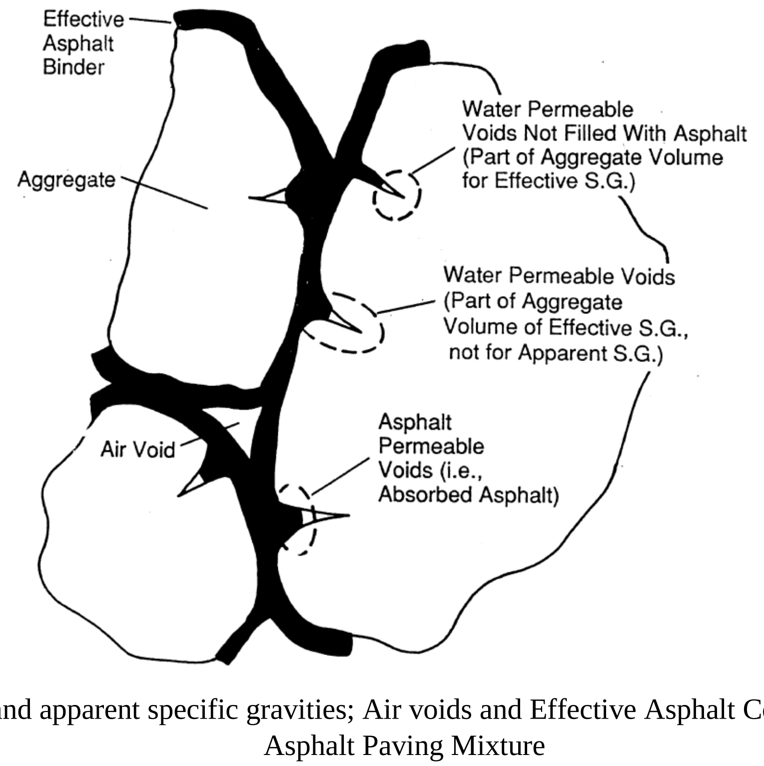
V_{S1}= Volume of Effective Asphalt

V_{S2}= Volume of Absorbed Asphalt

V_{S3}= Volume of Bulk Asphalt



Asphalt mixture showing net or effective asphalt, absorbed asphalt, and air voids.



Bulk, effective and apparent specific gravities; Air voids and Effective Asphalt Content in compacted Asphalt Paving Mixture

Specific Gravity and density of mixture (ASTM D2726):

$$Sp.gr = \frac{A}{B - C}$$

Where:

A: wt. of specimen in air

B: wt. of specimen (SSD) (saturated surface dry sample)

C: wt of specimen in water

قانون من تجارب العملي (حفظ)

Density = Sp. Gr * 0.9974

- Maximum (Theoretical) Specific Gravity of the Mix (G_{mm})

$$G_{mm} = \frac{W_m}{V_m - V_o} = \frac{100}{\frac{P_S}{G_S} + \frac{P_A}{G_{Ae}}}$$

الوزن النوعي الاعظم للمزيج و هو على فرض عدم وجود فراغات

Where:

$G_{mm} = Maximum\ Specific\ Gravity\ of\ Paving\ Mixture\ (no\ air\ voids)$

$W_m = weight\ of\ compacted\ mix\ in\ percent,$ وزن المزيج المرصوص

$V_m = Volume\ of\ compacted\ mix,$ حجم المزيج المرصوص

$V_o = Volume\ of\ air\ voids\ in\ the\ mix,$ حجم الفراغات في الخلطة

$P_S = Asphalt\ content, percent\ by\ weight\ of\ the\ mix,$

$P_A = Aggregate\ content, percent\ by\ weight\ of\ the\ mix,$

$G_S = Specific\ gravity\ of\ asphalt\ cement,$

$G_{Ae} = Effective\ specific\ gravity\ of\ aggregate.$

Specific Gravity of the Aggregate:

- Effective Specific Gravity of Aggregate (G_{Ae})

$$G_{Ae} = \frac{W_A}{V_{Ae}} = \frac{100 - P_S}{\frac{100}{G_{mm}} - \frac{P_S}{G_S}}$$

$G_{mm} = Maximum\ Specific\ Gravity\ of\ Paving\ Mixture\ (no\ air\ voids)$

$P_S = Asphalt\ content, percent\ by\ weight\ of\ the\ mix,$ نسبة الاسفلت

$G_S = Specific\ gravity\ of\ asphalt\ cement,$ الوزن النوعي للاسفلت (يعطى بالسؤال)

• Bulk Specific Gravity of Aggregate (G_{Ab}) الوزن النوعي الحقيقي للركام

The bulk specific gravity is defined as the weight in air of a unit volume (including all normal voids) of a permeable material at a selected temperature, divided by the weight in air of the same volume of gas-free distilled water at the same selected temperature.

$$G_{Ab} = \frac{W_A}{V_{Ab}} = \frac{W_1 + W_2 + W_3}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3}} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}}$$

$G_{Ab} = Bulk\ specific\ gravity\ of\ aggregates\ in\ the\ paving\ mixture,$

$W_1, W_2, W_3 = Weight\ of\ coarse, fine\ aggregate\ and\ mineral\ filler, respectively.$

P_1, P_2, P_3
$= Percent\ by\ weight\ of\ coarse\ aggregate, fine\ aggregate\ and\ mineral\ filler, respectively.$

G_1, G_2, G_3
$= Bulk\ specific\ gravities\ of\ coarse, fine\ aggregate\ and\ mineral\ filler, respectively.$

= 2.6, 2.65 and 2.85

- Apparent Specific Gravity of Aggregates

The apparent specific gravity is defined as the ratio of the weight in air of an impermeable material to the weight of an equal volume of distilled water at a specified temperature.

$$G_{AA} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_{1A}} + \frac{P_2}{G_{2A}} + \frac{P_3}{G_{3A}}}$$

G_{1A}, G_{2A}, G_{3A}
$= Apperant\ specific\ gravities\ of\ coarse, fine\ aggregate\ and\ mineral\ filler, respectively.$

- Bulk Specific Gravity of the Compacted Mix (G_{mb}) الوزن النوعي الحقيقي او المؤثر للخليط (المزيج) (فلر + ركام + اسفلت)

$$G_{mb} = \frac{W_m}{V_m} = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{P_S}{G_S}}$$

Bulk density of the mix = G_{mb} * ρw

Air Voids:

- % Air Voids in total mix (VTM) الفجوات الهوائية في الخلطة الكلية

$$VTM = \frac{V_o}{V_m} * 100 = \left[1 - \frac{bulk\ G_m}{\max G_m}\right] * 100 = \left[1 - \frac{Vm - Vo}{V_m}\right] * 100$$

Where:

$W_m = weight\ of\ the\ mix\ in\ percent,$

$V_m = Volume\ of\ the\ mix,$

$V_o = Volume\ of\ air\ voids\ in\ the\ mix,$

- Voids in Mineral Aggregate (VMA) الفجوات الهوائية داخل الركام

$$VMA = 100 - \frac{G_{mb} * P_A}{G_{Ab}}$$

Where:

$G_{mb} = Bulk\ specific\ gravity\ of\ compacted\ mixture$

$P_A = Aggregate\ percent\ by\ weight\ of\ total\ paving\ mixture$

$G_{Ab} = Bulk\ specific\ gravity\ of\ aggregate$

Voids in Mineral Aggregate is the volume of intergranular voids space between the aggregate particles of a compacted paving mixture that occupies by asphalt and air. In a component diagram, it is the sum of the volume of air and the volume of effective asphalt.

VMA ≥ 15%

- Voids Filled with Asphalt (VFA) الفجوات الهوائية المملوؤة بالاسفلت

$$VFA = \frac{1}{1 + \frac{G_s * \%VTM}{G_{mb} * P_{Se}}} * 100$$

$$P_{Se} = P_S - P_{S(ab)}$$

$$P_{S(ab)} = P'_{S(ab)} * \frac{P_A}{100}$$

$$P'_{S(ab)} = \left[\frac{1}{G_{Ab}} - \frac{1}{G_{Ae}}\right] * G_S * 100$$

Where:

P_{Se} = % Effective asphalt content by the weight of total mix

P_S = % asphalt by weight of total mixture

P_A = % aggregate by weight of total mixture

$P_{S(ab)}$= % absorbed asphalt by weight of total mix

$P'_{S(ab)}$ = % absorbed asphalt by weight of aggregate

Absorbed Asphalt: it is the percent by weight of the asphalt that is absorbed by the aggregate based on the total weight of the aggregate.

Effective Asphalt content: it is the difference between the total amount of asphalt in the mixture and that absorbed into the aggregate particles.

مع ملاحظة ما يلي:

VMA ≥ 15%

VFA = (70-85) %

ان تحققهما يوفر سمك الاسفلت المطلوب من خلال توفير حيز من الفراغ لاحتواء الاسفلت و حيز مناسب من الفراغات

$$Relative\ Compaction = \frac{G_{mb}\ in\ field}{G_{mb}\ in\ lab} * 100$$

$$Density = \frac{W_t\ of\ Marshall\ specimen\ (lb)}{Volume\ of\ standard\ Marshall\ specimen\ (in^3)} = \frac{W_t}{\frac{\pi}{4}(4)^2 * 2.5}$$