Marshall Mix Design

The objective of Mix Design Method is to determine the amount of various sizes of mineral aggregates to use to get a mix of maximum density or, determines the optimum bitumen content. Two (02) types of mix design are used in the world, these are,

- Dry Mix Design
- Wet Mix Design

Dry Mix Design: Dry Mix Design Method is used to determine the amount of various sizes of mineral aggregates to use to get a mix of maximum density. The Dry Mix Design involves three important steps known as,

- selection of aggregates
- aggregates gradation
- proportion of aggregates

Selection of Aggregates:

The desirable qualities of a bituminous paving mixture are dependent to a considerable degree on the nature of the aggregates used. Aggregates are classified as coarse, fine and filler. The function of the coarse aggregates in contributing to the stability of a bituminous paving mixture is largely due to interlocking and frictional resistance of adjacent particles. Similarly, fines or sand contributes to stability failure function in filling the voids between coarse aggregates. Mineral filler is largely visualized as a void filling agent. Crushed aggregates and sharp sands produce higher stability of the mix when compared with gravel and rounded sands.

Aggregates Gradation:

The properties of the bituminous mix including the density and stability are very much dependent on the aggregates and their grain size distribution. Gradation has a profound effect on mix performance. It might be reasonable to believe that the best gradation is one that produces maximum density. This would involve a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This create more particle-to-particle contact, which in bituminous pavements would increase stability and reduce water infiltration. However, some minimum amount of void space is necessary to,

- Provide adequate volume for the binder to occupy,
- Promote rapid drainage and
- Provide resistance to frost action for base and sub base courses.

A dense mixture may be obtained when this particle size distribution follows Fuller Law. Fuller's model (Asphalt Institute 1992) represents the equations of coarse and fine aggregates gradation.

For Fine Aggregates, Fuller's Law can be expressed as follows,

$$P_i = 100(D_i/D_{max})^n$$

where, D_i = sieve size (diameter in mm),

D_{max} = maximum aggregates size (mm),

n = shape factor of the aggregates (0.5 for perfectly rounded particles),

P_i = amount finer than diameter D_i,

i = sub-index which represents a particular sieve.

For Coarse Aggregates, Fuller's Law can be expressed as follows,

$$P_i = A^*(D_i/D_{max})^{nC} * 100 + B$$

where,

A & B are constant,

nC = coefficient of coarse aggregate gradation,

Proportioning of Aggregates:

After selecting the aggregates and their gradation, proportioning of aggregates has to be done and following are the common methods of proportioning of aggregates:

- Trial and Error Procedure: Vary the proportion of materials until the required aggregate gradation is achieved.
- Graphical Method: Two Graphical Methods in common use for proportioning of aggregates are, Triangular Chart Method and Roch's Method. The former is used when only three materials are to be mixed.
- Analytical Method: In this method a system of equations are developed based on the gradation of each aggregates, required gradation and solved by numerical methods.

Wet Mix Design:

The Wet Mix Design determines the Optimum Bitumen Content. There are many methods available for Wet Mix Design which vary in the size of the test specimen, compaction and other test specifications. Marshall Method of Mix Design is the most popular one and is discussed below,

Marshall Mix Design:

The basic concepts of the Marshall Mix Design method were originally developed by Bruce Marshall of the Mississippi Highway department around 1939 and then refined by the U.S. army. The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values. This section consists of a brief history of the Marshall Mix design method followed by a general outline of the actual method. This outline emphasizes general concepts and rationale over specific procedures.

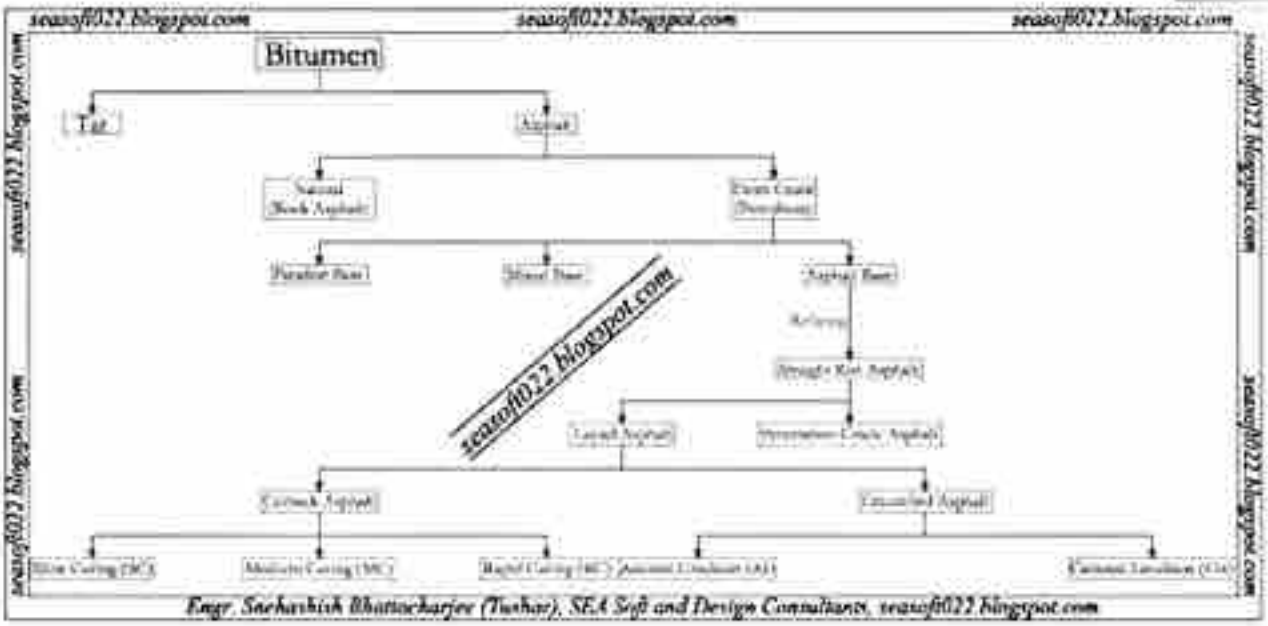

Figure-01: Classification of Bitumen

Specimen Preparation:

Approximately 1200 gm of aggregates and filler is heated to a temperature of 121~125 degree C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154~160 degree C. The mix is placed in a preheated mold and compacted by a hammer with 50 blows on either side at temperature of 138~149 degree C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5 mm. Vary the bitumen content in the next trial by +0.50% and repeat the above procedure. Number of trials are predetermined.

Properties of Mix:

The properties that are of interest include the theoretical specific gravity, G_t , the bulk specific gravity of the mix G_m , percent air voids V_v , percent volume of bitumen V_b , percent void in mixed aggregate VMA and percent void filled with bitumen VFB. These calculations will be discussed next, to understand these calculation a phase diagram is given in the following figure, ***Figure-02***,

- Asphalt Content vs. Air Void
- Asphalt Content vs. Voids in Mineral Aggregate, VMA
- Asphalt Content vs. Voids Filled with Asphalt, VFA
- Asphalt Content vs. Unit Weight
- Asphalt Content vs. Stability
- Asphalt Content vs. Flow 0.01 inch

These above graphical diagram of Marshall Mix Design are shown as follows at Figure-03.

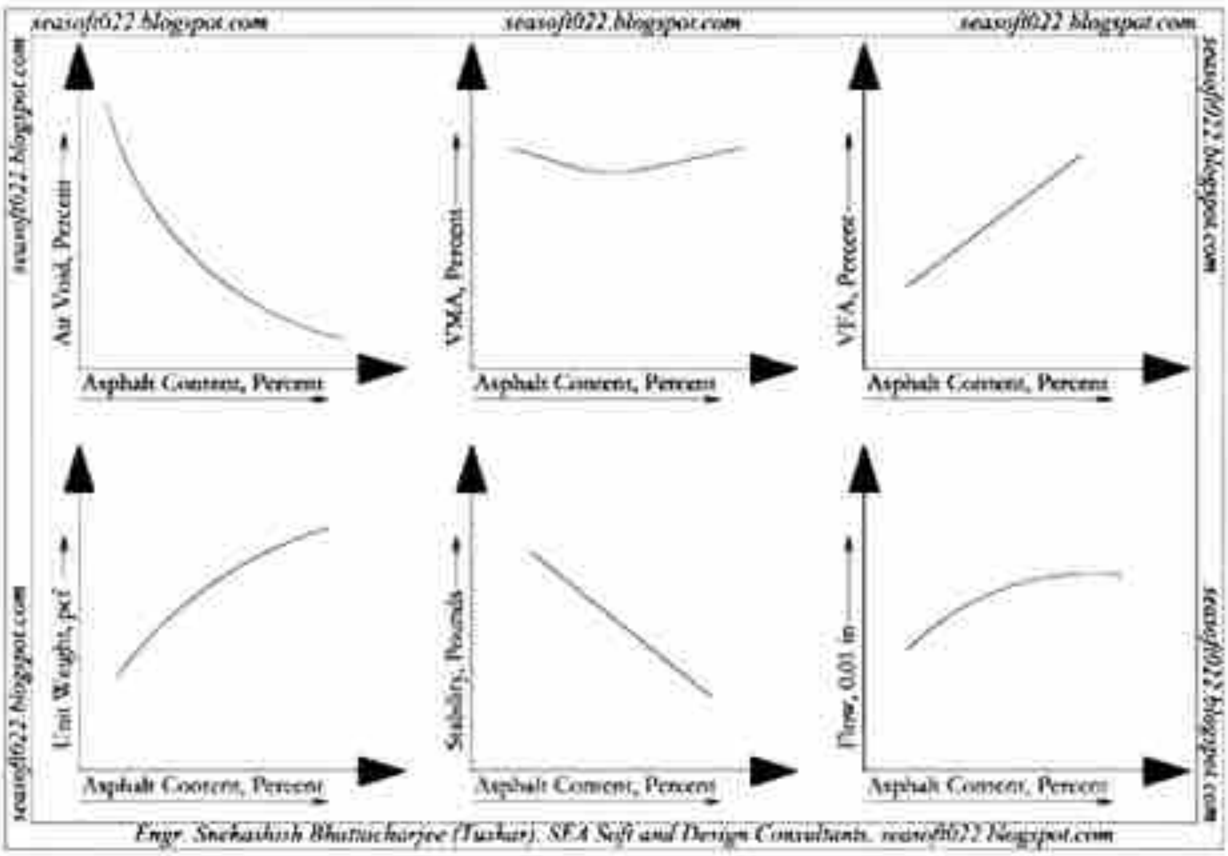

Figure-03: Design Graphs for Marshall Mix Design

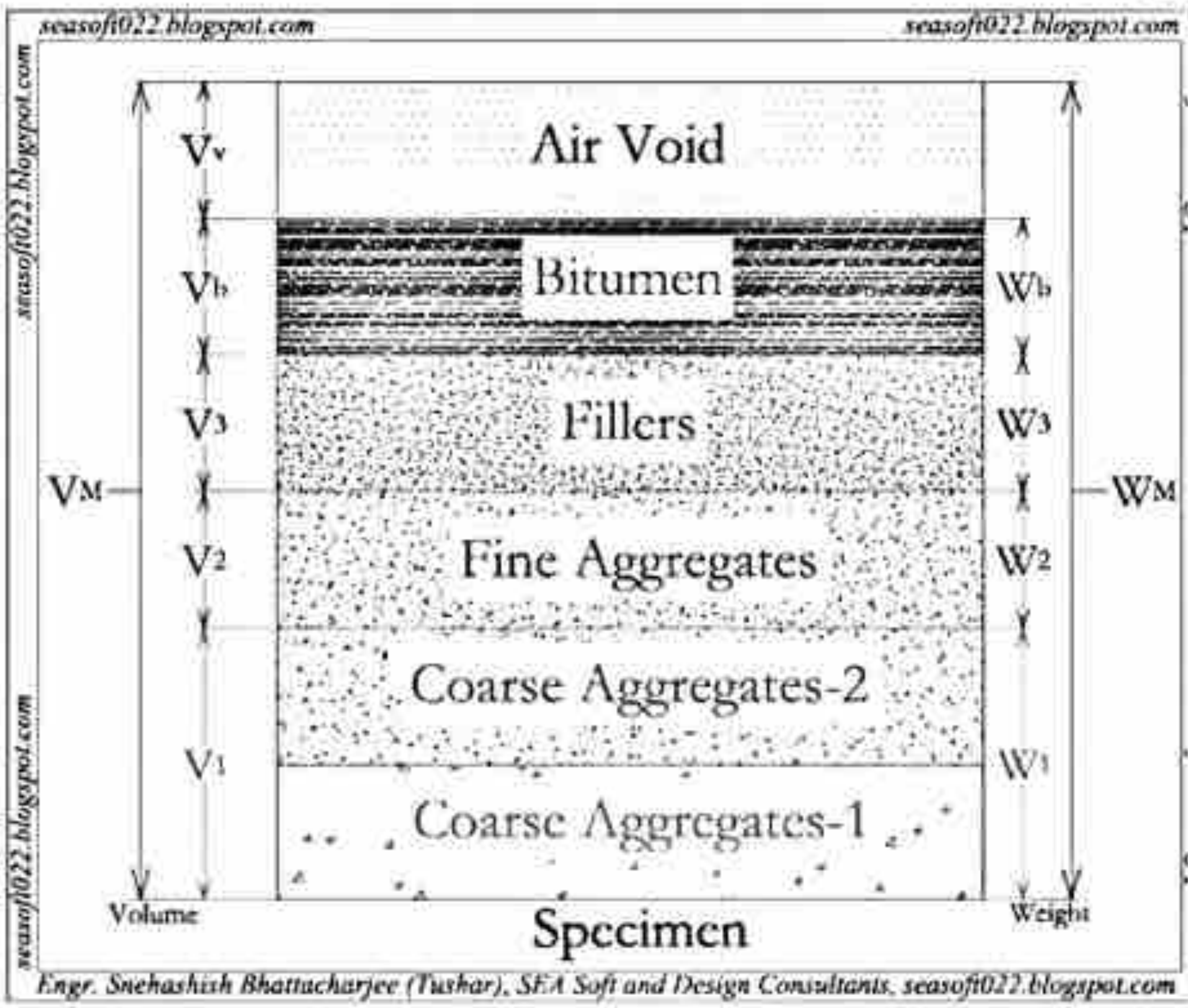

Figure-02: Phase Diagram for Properties of Mix

Theoretical Specific Gravity of the mix, G_t :

Theoretical specific gravity G_t is the specific gravity without considering air voids, and is given by as follows,

$$\text{Theoretical Specific Gravity of the Mix, } G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W1}{G1} + \frac{W2}{G2} + \frac{W3}{G3} + \frac{Wb}{Gb}}$$

Where,

W_1 = Weight of Coarse Aggregates in the total mix,

W_2 = Weight of Fine Aggregates in the total mix,

W_3 = Weight of Filler in the total mix,

W_b = Weight of Bitumen in the total mix,

G_1 = Apparent Specific Gravity of Coarse Aggregates,

G_2 = Apparent Specific Gravity of Fine Aggregates,

G_3 = Apparent Specific Gravity of Filler,

G_b = Apparent Specific Gravity of Bitumen,

Bulk Specific Gravity of mix G_M :

The Bulk Specific Gravity or the actual specific gravity of the mix G_M is the specific gravity considering air voids and is found out by,

$$\text{Bulk Specific Gravity of the Mix, } G_M = \frac{W_M}{W_M - W_W}$$

Where,

W_M = Weight of mix in the air,

W_W = Weight of mix in water,

The term (W_M -W_W) will indicate the volume of the mix.

Sometimes to get accurate Bulk Specific Gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water.

Air Void Percent V_V :

Air Void V_V is the percent of air voids by volume in the specimen and is given by,

$$\text{Air Void Percent, } V_V = \frac{(G_t - G_M)*100}{G_t}$$

Where,

G_t = Theoretical Specific Gravity of the mix,

G_M = Bulk or Actual Specific Gravity of the mix,

Percent Volume of Bitumen V_b :

The volume of bitumen V_b is the percent of volume of bitumen to the total volume and given by as follows,

$$\text{Percent Volume of Bitumen, } V_b = \frac{\left(\frac{Wb}{Gb}\right)}{\frac{(W1 + W2 + W3 + Wb)}{GM}}$$

Marshall Method history:

During World War II, the U.S Army Crops of Engineers (USCOE) began evaluating various Hot Mix Asphalt (HMA) Mix Design Methods for use in airfield pavement design. Most for this search came from the ever-increasing wheel loads and tire pressures produced by larger and larger military aircraft.

The most promising method eventually proved to be the Marshall Stability method developed by Bruce G. Marshall at the Mississippi Highway Department in 1939. U.S Army Waterways Experiment Station (WES) took the original Marshall Stability Test and added a deformation measurement (using a flow meter) that was reasoned to assist in detecting excessively high asphalt contents. This appended test was eventually recommended for adoption by the U.S. Army because,

1. It was designed to stress the entire sample rather than just a portion of it,
2. It facilitated rapid testing with minimal effort,
3. It was compact, light and portable,
4. It produced densities reasonably close to field densities,

WES continued to refine the Marshall Method through the 1950's with various test on materials, traffic loading, and weather variables. Today the Marshall Method, despite its shortcomings, is probably the most widely used Mix Design Method in the world. It has probably become so widely used because it was adopted and used by the U.S. Military all over the world during and after WW II, it is simple, compact and inexpensive.

Marshall Mix Design Procedure:

The Marshall Mix Design Method consists of 6 basic steps:

1. Aggregates Selection,
2. Asphalt Selection,
3. Sample Preparation (including compaction),
4. Stability Determination using the Stabilometer
5. Density and Voids Calculations,
6. Optimum asphalt binder content selection

Classification of Bitumen:

Liquid Asphalt is commonly used over the Existing Road Level, Liquid Asphalt can be classified as follows,

a) Cutback Asphalt,

b) Emulsified Asphalt.

Where,

W_1 = Weight of Coarse Aggregates in the total mix,

W_2 = Weight of Fine Aggregates in the total mix,

W_3 = Weight of Filler in the total mix,

W_b = Weight of Bitumen in the total mix,

G_b = Apparent Specific Gravity of Bitumen,

G_M = Bulk or Actual Specific Gravity of the mix,

Voids in Mineral Aggregate, VMA :

Voids in mineral aggregate VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen and is calculated from,

$$VMA = V_V + V_b ,$$

Where,

V_V = percent air voids in the mix,

V_b = percent bitumen content in the mix,

Voids Filled with Asphalt, VFA :

Void filled with bitumen VFA is the voids in the mineral aggregate frame work filled with the bitumen and is calculated as,

$$VFA = (V_b * 100)/VMA ,$$

Where,

V_b = percent bitumen content in the mix,

VMA = percent voids in the mineral aggregate,

Determine Marshall Stability and Flow:

Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5 cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall Flow Value of the Specimen.

Design Graphs for Marshall Mix Design:

There are ***06 (Six) Graphs for Marshall Mix Design*** which is known as "Design Graphs for Marshall Mix Design".

Cutback Asphalt:

When volatile solvents are mixed with asphalt cement to make a liquid product, the mixture is called "Cutback Asphalt". When a Cutback Asphalt are exposed to air, the volatile solvent evaporates and the asphalt in the mixture regain its original characteristics. Depending on the volatility of the solvent used, the rate of curing of cutback asphalt can vary from a few minutes to several days. Three type of cutback asphalts are,

a) Slow-Curing (SC): Road Oils,

b) Medium-curing (MC): Kerosene,

c) Rapid-curing (RC): Gasoline.

Emulsified Asphalt:

A mixture of asphalt cement, water and an emulsifying agent. Two types of emulsified are,

a) Anionic Emulsion (AI): Anionic Emulsion are effective in coating electro-positive aggregates like limestone and Anionic Emulsion can carry negative charges.
b) Cationic Emulsion (CIs): Cationic Emulsion are effective in coating electro-negative aggregates like siliceous and Cationic Emulsion can carry positive charges.

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix Design Method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. The important steps involved in Marshall Mix Design are summarized next,