

UNIT-4

HIGHWAY MATERIALS AND CONSTRUCTION PRACTICES

Sub grade soil

Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation, that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory.

Desirable properties

The desirable properties of sub grade soil as a highway material are

1. Stability
2. Incompressibility
3. Permanency of strength
4. Minimum changes in volume and stability
5. Good drainage
6. Ease of compaction

Soil Classification

Two commonly used systems for soil engineers based on particle distribution and atterberg limits:

- American Association of State Highway and Transportation Officials (AASHTO) System (for state/county highway dept.)
- Unified Soil Classification System (USCS) (preferred by geotechnical engineers).

Soil particles

The description of the grain size distribution of soil particles according to their texture (particle size, shape, and gradation). Major textural classes include, very roughly:

- gravel (>2 mm);
- sand ($0.1 - 2$ mm);
- silt ($0.01 - 0.1$ mm);
- clay (< 0.01 mm).

TEST ON SOILS

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests. The tests used to evaluate the strength properties of soils may be broadly divided into three groups:

1. Shear tests
2. Bearing tests
3. Penetration tests

Shear tests

Shear tests are usually carried out on relatively small soil samples in the laboratory. In order to find out the strength properties of soil, a number of representative samples from different locations are tested. Some of the commonly known shear tests:

- Direct shear test,
- Triaxial compression test,
- Unconfined compression test.

California Bearing Ratio (CBR)

This test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements.

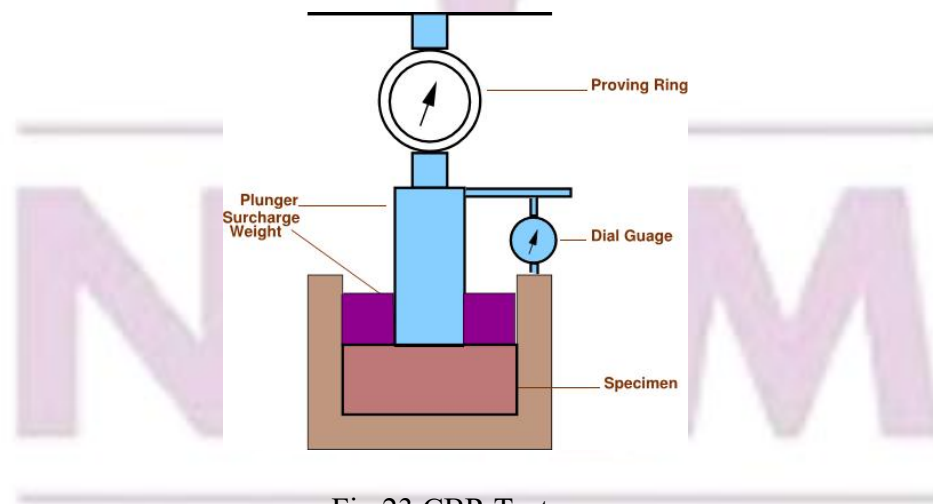


Fig 23 CBR Test

Plate Bearing Test

Plate bearing test is used to evaluate the support capability of sub-grades, bases and in some cases, complete pavement. Data from the tests are applicable for the design of both flexible and rigid pavements. In plate bearing test, a compressive stress is applied to the soil or pavement layer through rigid plates relatively large size and the deflections are measured for various stress values.

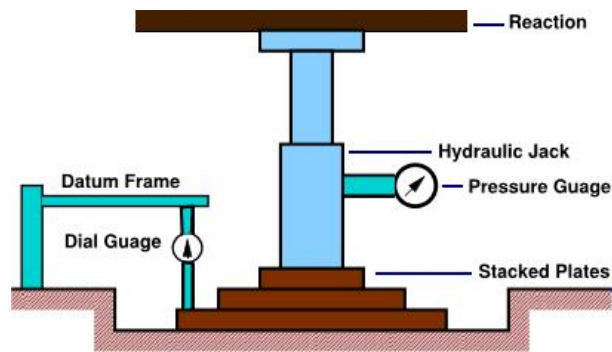


Fig.24 Plate load test

PAVEMENT MATERIALS

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 bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured.

Desirable properties

Strength

The aggregates used in top layers are subjected to

- (i) Stress action due to traffic wheel load,
- (ii) Wear and tear,
- (iii) crushing.

Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.

Toughness

Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes severe impact on the aggregates.

Shape of aggregates

Aggregates which happen to fall in a particular size range may have rounded cubical,

angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

Adhesion with bitumen

The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.

Freedom from deleterious particles

Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of flat or elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, chert, silt and other organic impurities.

Crushing test

One of the modes in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load.

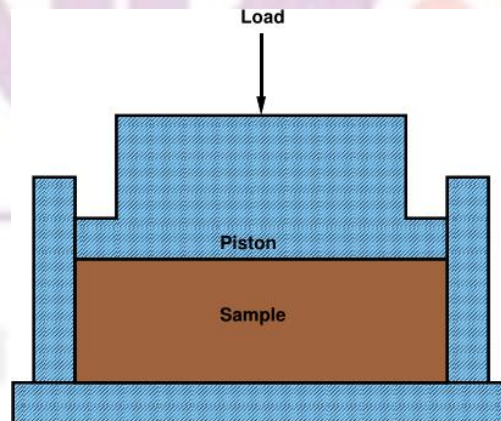


Fig.25 Crushing test setup

Abrasion test

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS:2386 part-IV).

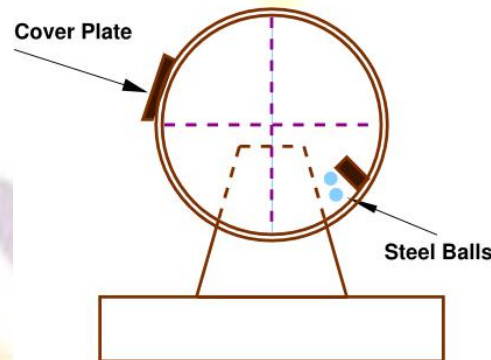


Fig.26 Los Angeles abrasion test setup

Impact test

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows.

Soundness test

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely. To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V.

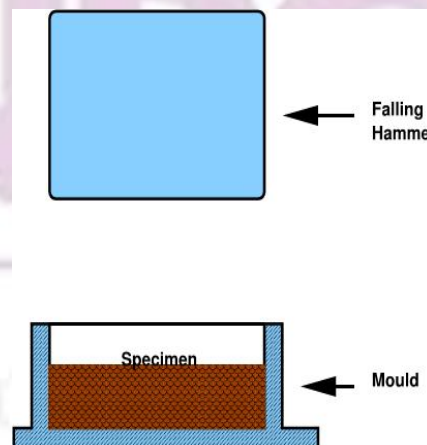


Fig.27 Impact test setup

Shape tests

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes. The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. Test procedure had been standardized in India (IS:2386 part-I).

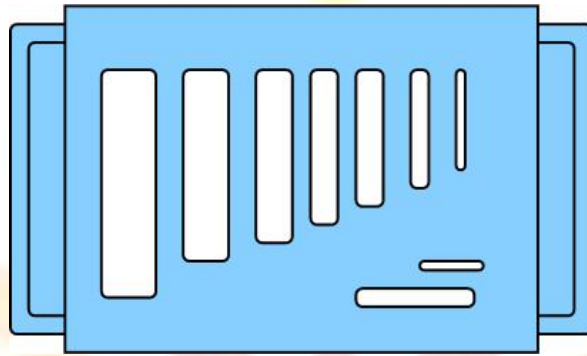


Fig.28 Flakiness gauge

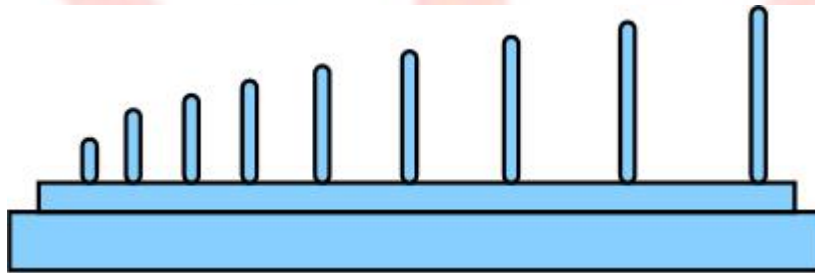


Fig.29 Elongation gauge

Specific Gravity and water absorption

The Specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The Specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature.

- Apparent Specific Gravity
- Bulk Specific Gravity

Water absorption, The difference between the apparent and bulk specific gravities is nothing but the water- permeable voids of the aggregates. The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 2.9. Water absorption values ranges from 0.1 to about 2.0 percent for aggregates normally used in road surfacing.

Bitumen adhesion test

Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold.

Table 24.1 Tests for Aggregates with IS codes

Property of aggregate	Type of Test	Test Method
Crushing strength	Crushing test	IS : 2386 (part 4) -1963
Hardness	Los Angeles abrasion test	IS : 2386 (Part 5)-1963
Toughness	Aggregate impact test	IS : 2386 (Part 4)-1963
Durability	Soundness test- accelerated durability test	IS : 2386 (Part 5)-1963
Shape factors	Shape test	IS : 2386 (Part 1)-1963
Specific gravity and porosity	Specific gravity test and water absorption test	IS : 2386 (Part 3)-1963
Adhesion to bitumen	Stripping value of aggregate	IS : 6241-1971

Production of Bitumen

Bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties.

Vacuum steam distillation of petroleum oils

In the vacuum-steam distillation process the crude oil is heated and is introduced into a large cylindrical still. Steam is introduced into the still to aid in the vaporization of the more volatile constituents of the petroleum and to minimize decomposition of the distillates and residues. The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed. The residues from this distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils. The bottom fraction from this unit is the vacuum-steam-refined asphalt cement.

Different forms of bitumen

Cutback bitumen

Normal practice is to heat bitumen to reduce its viscosity. In some situations preference is given to use liquid binders such as cutback bitumen. In cutback bitumen suitable solvent is used to lower the viscosity of the bitumen. From the environmental point of view also cutback bitumen is preferred.

There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC).

Bitumen emulsion

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC). Bitumen emulsions are ideal binders for hill road construction.

Bituminous primers

In bituminous primer the distillate is absorbed by the road surface on which it is spread. The absorption therefore depends on the porosity of the surface. Bitumen primers are useful on the stabilized surfaces and water bound macadam base courses. Bituminous primers are generally prepared on road sites by mixing penetration bitumen with petroleum distillate.

Modified Bitumen

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999.

Requirements of Bitumen

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should possess following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

Tests on bitumen

There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

- Penetration test
- Ductility test
- Softening point test

- Specific gravity test
- Viscosity test
- Flash and Fire point test
- Float test
- Water content test
- Loss on heating test

Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position.

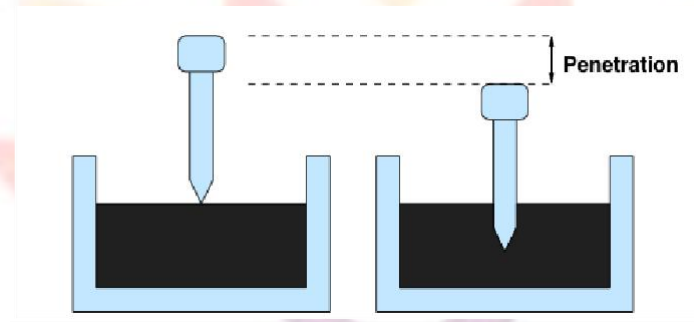


Fig. 30 Penetration Test Setup

Ductility test

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking.

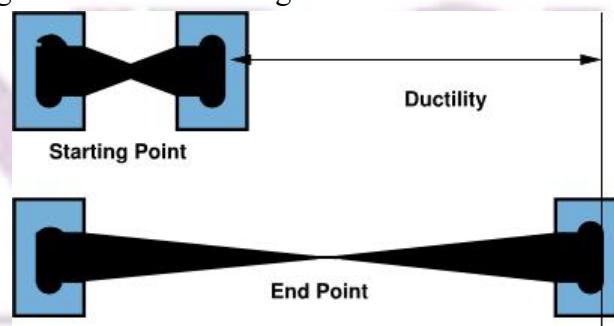


Fig. 31 Ductility Moulds

Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus.

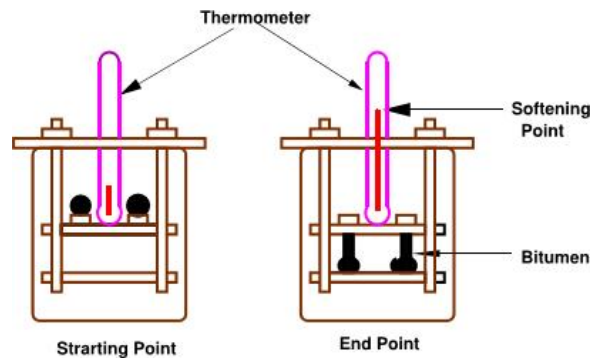


Fig. 32 Softening Point Test Setup

Specific gravity test

In paving jobs, to classify a binder, density property is of great use. In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly influenced by its chemical composition. Increase in aromatic type mineral impurities cause an increase in specific gravity.

Viscosity test

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resists the compactive effort and thereby resulting mix is heterogeneous, hence low stability values.

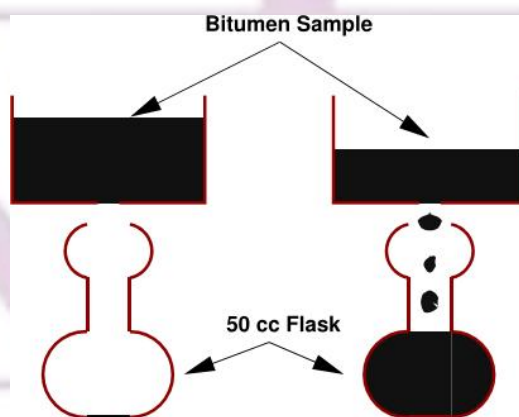


Fig.33 Viscosity apparatus

Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catch fire which is very hazardous and therefore it is essential to qualify

this temperature for each bitumen grade.

Float test

Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used.

Water content test

It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water in a bitumen is determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling off the water.

Loss on heating test

When the bitumen is heated it loses the volatility and gets hardened. About 50gm of the sample is weighed and then heated to a temperature of 163°C for 5 hours in a specified oven designed for this test.

Objectives of mix design

1. Sufficient bitumen to ensure a durable pavement,
2. Sufficient strength to resist shear deformation under traffic at higher temperature,
3. Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic,
4. Sufficient workability to permit easy placement without segregation,
5. Sufficient flexibility to avoid premature cracking due to repeated bending by traffic, and
6. Sufficient flexibility at low temperature to prevent shrinkage cracks.

Constituents of a mix

- Coarse aggregates
- Fine aggregates
- Filler
- Binder

Types of mix

- Well-graded mix
- Gap-graded mix

- Open-graded mix
- Unbounded

Different layers in a pavement

- Bituminous base course
- Bituminous binder course
- Asphaltic/Bituminous concrete.

Stability

Stability is defined as the resistance of the paving mix to deformation under traffic load. Two examples of failure are

- (i) shoving - a transverse rigid deformation which occurs at areas subject to severe acceleration
- (ii) grooving - longitudinal ridging due to channelization of traffic. Stability depend on the inter-particle friction, primarily of the aggregates and the cohesion offered by the bitumen.

Durability

Durability is defined as the resistance of the mix against weathering and abrasive actions.

- (i) pot-holes, - deterioration of pavements locally and
- (ii) stripping, lost of binder from the aggregates and aggregates are exposed.

Flexibility

Flexibility is a measure of the level of bending strength needed to counteract traffic load and prevent cracking of surface. Fracture is the cracks formed on the surface (hairline-cracks, alligator cracks), main reasons are shrinkage and brittleness of the binder.

Skid resistance

It is the resistance of the finished pavement against skidding which depends on the surface texture and bitumen content. It is an important factor in high speed traffic.

Workability

Workability is the ease with which the mix can be laid and compacted, and formed to the required condition and shape.

Desirable properties

From the above discussion, the desirable properties of a bituminous mix can be summarized as follows:

- ✓ Stability to meet traffic demand
- ✓ Bitumen content to ensure proper binding and water proofing

- ✓ Voids to accommodate compaction due to traffic
- ✓ Flexibility to meet traffic loads, esp. in cold season
- ✓ Sufficient workability for construction • Economical mix

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.

Aggregate gradation

The properties of the bituminous mix including the density and stability are very much dependent on the aggregates and their grain size distribution.

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.

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:
- Graphical Methods:
- Analytical Method:

Marshall mix design

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.

Specimen preparation

Determine the properties of the mix

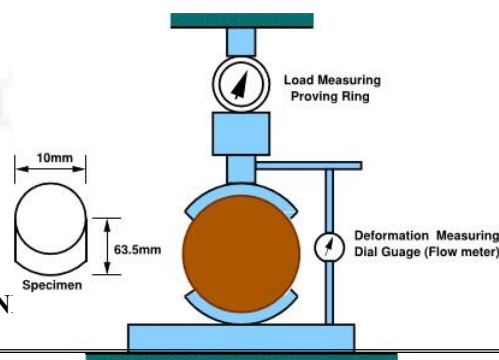


Fig. 34 Marshall Mould

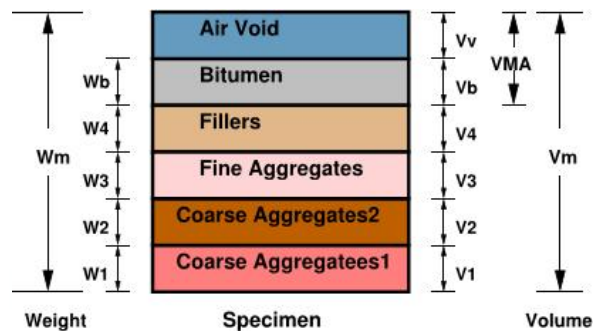


Fig. 35 Marshall Mould

Theoretical specific gravity of the mix G_t

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

Bulk specific gravity of mix G_m

$$G_m = \frac{W_m}{W_m - W_w}$$

Air voids percent V_v

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_b}{G_m}}$$

Voids in mineral aggregate $VMA = V_v + V_b$

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).

Apply stability correction

Volume of specimen (cm ³)	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.19
471 - 482	68.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 - 559	68.3	0.89
560 - 573	69.9	0.86

Prepare graphical plots

The average value of the above properties are determined for each mix with different bitumen content and the following graphical plots are prepared:

1. Binder content versus corrected Marshall stability
2. Binder content versus Marshall flow
3. Binder content versus percentage of void in the total mix v
4. Binder content versus voids filled with bitumen (V F B)
5. Binder content versus unit weight or bulk specific gravity

Determine optimum bitumen content

Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found from the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity
3. Binder content corresponding to the median of designed limits of percent air voids in the total mix v (i.e. 4%)

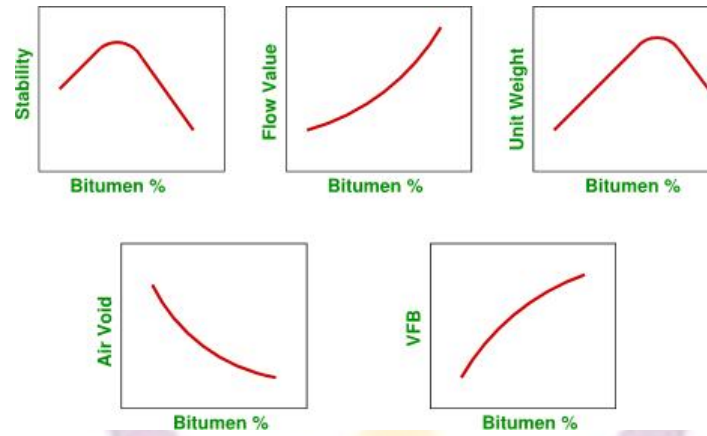


Fig. 36 Marshal graphical plots



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