General: Pavement Materials

The materials used in the construction of the pavement are:
- Soil
- Aggregate
- Bituminous binders.

The main functions of a paved pavement are:
- To distribute the traffic load over the subgrade soil.
- To provide a good riding surface.
- To protect the subgrade soil from adverse climatic effects.

Subgrade: It is the natural foundation of the pavement which directly receives the loads from the pavement. The subgrade is the supporting structure on which the pavement surface and its special courses rest.

1. Soil

Soil is a complex material produced by the weathering of the solid rock. It is the unconsolidated deposits of mineral and/or organic particles or fragments covering large portions of the earth's crust. It is the foundation material for the highways. In addition, the highway pavement itself is very often composed of compacted soil and stabilized soil.

In order to attain the above objectives of a paved pavement, a soil should have the following desirable properties:

1. Adequate stability or resistance to permanent deformation under traffic loads.
2. Incompressibility to prevent differential settlement.
3. Ease of compaction to attain higher dry densities and strength.
4. Good drainage to avoid excessive water retention and to reduce freezing and thawing action.
5. Permanency of strength to retain the desired subgrade support for the pavement structure. (Stable soil)

**Soil Tests**
- Grain size distribution tests
- L.I. & P.L. (Atterberg Limits)
- Compressive strength
- CBR test (California Bearing Ratio test)
- Plate Bearing test

**Soil Stabilization**
Soil stabilization is the treatment of natural soil to improve its engineering properties. This can be achieved by:
1. Mechanical stabilization
2. Chemical stabilization
3. Electrical
4. Thermal
or a combination of these.

**Mechanical Stabilization**
Mechanical Stabilization is the blending of different grades of soils to obtain a required grade. It is a method of stabilization in soil without adding any chemical material.

Mechanical Stabilization covers two methods for changing soil properties:
1. The arrangement of soil particles
   - blending of the layers
   - remolding of an undisturbed soil
   - the densification of soil
Compaction is a mechanical process of densifying the soil by reducing its voids. It is usually the most economical method. Compaction alone can solve a particular soil problem. It is the oldest and most important method of soil stabilization.

Generally, the properties of the compacted soil is affected by:

1. Moisture content
2. Amount of compaction (Compaction efforts)
3. Type of compaction

The combination of these depends on:
- the parent soil
- the desired properties

So that, varying each of these properties has an effect on:

1. Strength of stress-strain characteristics
2. Permeability
3. Compressibility

Chemical Stabilization

Chemical stabilization is the blending of the natural soil with chemical agents. The most commonly used agents are Portland cement, asphalt binders, lime.

Cement Stabilization

Cement stabilization of soils usually involves addition of 5 percent to 14 percent Portland cement by volume of the compacted mixture to the soil being stabilized. This type of stabilization is used mainly to obtain the required engineering
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The properties of soils that are to be used as base course materials. Although the best results have been obtained when well-graded granular materials were stabilized with cement, nearly all types of soils can be stabilized with cement.

The procedure for stabilizing soils with cement involves:

1. Pulverizing the soil.
2. Mixing the required quantity of cement with the pulverized soil & water.
3. Compacting the soil cement mixture.
4. Curing the compacted layer.

Types of Soil-Cement Mixtures:

1. Soil - cement (for sub-bases, subgrades, parking areas, airport runways, foundations, structures)
2. Cement - modified soil (for road bases, embankments, foundations, structures)
3. Plastic - soil cement (to make soil workable; addition of soil to cement) (used in construction, pavement, levees, embankments)

Factors affecting soil cement properties:

1. Nature of soil
2. Chemical properties
3. Amount & type of cement
4. Soil state
5. Water content (moisture content)
6. Mixing & compacting
7. Environmental conditions
8. Additives

Bituminous Stabilization

Bituminous stabilization is carried out to achieve one or both of the following:

1. Improved bearing capacity
2. Improved drainage characteristics
- Waterproofing of the natural materials
- Binding of natural materials

Waterproofing the natural material through bituminous stabilization aids in maintaining the water content at a required level by providing a membrane that impedes the penetration of water, thereby reducing the effect of any surface water that may enter the soil when it is used as a base course. In addition, surface water is prevented from seeping into the subgrade, which protects the subgrade from failure due to increase in moisture content.

Binding improves the durability characteristics of the natural soil by providing an adhesive characteristic, whereby the soil particles adhere to each other, increasing cohesion.

**Types of Bituminous Stabilized Mixtures:**

1. Sand Bitumen (adhesive material binds sand together
   (Asphalt made from refined petroleum distillate or crude oil)
2. Soil Bitumen (used with fine-grained material, having little cohesion)
3. Sand-Gravel-Bitumen (asphalt mixed with crushed stone or gravel)
4. Road Oil (used without asphalt treatment)

**Factors affecting Soil Asphalting:**

1. Nature & type of soil
2. Amount & type of asphalt
3. Mixing
4. Compaction conditions
5. Curing conditions
6. Admixtures
3. **Lime Stabilization**

Lime stabilization is one of the oldest processes of improving the engineering properties of soils & can be used for stabilizing both base & subbase materials. In general, the oxides & hydroxides of calcium & magnesium are considered as lime, but the materials most commonly used for lime stabilization are calcium hydroxide $\text{Ca(OH)}_2$ & dolomite $\text{Ca(OH)}_2 + \text{MgO}$.

**Types of lime used**

1. High-calcium quick lime $\text{CaO}$
2. Dolomitic quick lime $\text{CaO + MgO}$
3. Hydrated high-calcium lime $\text{Ca(OH)}_2$
4. Normal hydrated dolomitic lime $\text{Ca(OH)}_2 + \text{MgO}$
5. Pressure-hydrated dolomitic lime $\text{Ca(OH)}_2 + \text{Mg(OH)}_2$

**Lime uses in soil stabilization**

- As a modifier to improve the soils, especially high plasticity soils, the plasticity index can be reduced when lime is added.
- As an additive with cement to produce lime-cement stabilizer.
- As an additive with bitumen to produce cement-lime-bitumen stabilizer.
- As an additive with fly ash to produce lime-fly ash stabilizer.
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Flexible Pavement

- Surface course (surfacing)
- Base course (u.k.)
- Binder course (u.s.a.)
- Prime coat
- Coarse base (u.k.)
- Base (u.s.a.)
- Subbase
- Subgrade

Rigid Pavement

- Concrete slab
- Subbase
- Subgrade

Asphalt
- Asphalt cement
- Binder
- Bitumen

Asphalt mix
- Bituminous mix
- Asphalt concrete (u.k.)

The black liquid viscous material

Aggregate + Asphalt cement

Asphalt (u.k.)
2. Aggregates

These are the basic materials of highway pavement construction. They not only support the main stresses occurring within the pavement but also resist wear due to abrasion by traffic as well as the effects of weathering agencies. The behaviour of the pavement structure depends on the inherent properties and qualities of the individual particles and on the means by which they are held together, i.e., by interlocking, by cementitious binders, or by both. In general, the aggregates may be classified as:

(a) Natural aggregates
(b) Artificial aggregates.

Characteristics of Good Road Aggregates

The following properties of aggregates are taken into consideration while selecting aggregates for road construction:

1. Hardness: It is the quality of road aggregates which measures its resistance to abrasion of the surface. The road aggregates should possess adequate hardness to resist abrading action between tyres of moving vehicles and the aggregate exposed to the top surface. The presence of foreign materials like sand between the vehicle tyres and the road surface increases the abrasion.

2. Attrition: It is the mutual rubbing of stones caused due to pavement deformation under wheel loads. The pavement deformation results in relative movement of aggregates thereby causing mutual rubbing of stones within the pavement layer.

3. Toughness: It may be defined as the power possessed by an aggregate to resist the fracture under an applied load. In all form of flexible pavement, the aggregate must be tough enough to support...
the weight to the roller during construction & the repeated impact action of traffic. The impact effect increases with the increase of road surface roughness, the speed of vehicle & other vehicular characteristics.

5. **Strength**: It is the measure of the resistance of an aggregate to crushing. The aggregates to be used in surfacing course of the pavement structure should be able to withstand the stresses due to traffic wheel loads in addition to wear & tear.

6. **Texture**: It is the measure of degree of roughness or smoothness of the stone. It can be either glossy, smooth, rough or crystalline. Glossy texture gives conchoidal fracture. Gravels are smooth. It depends upon the size, degree of uniformity & arrangement of mineral grains. As a rule an even fine grained rock being highly resistant to wear is most suitable.

6. **Durability**: It may be defined as the resistance of stone to disintegration under the influence of weathering action. The property by virtue of which a stone is able to withstand the adverse weathering action is known as soundness. The composition of stone should be such that it can withstand or resist the action of rain & ground water & that of atmosphere.

7. **Specific Gravity**: The bulk specific gravity is the ratio of the weight in air of a volume of aggregate (including permeable & impermeable voids) to the weight in air of an equal volume of distilled water. The apparent specific gravity is the ratio of the weight in air of a volume of aggregate (including impermeable voids) to the weight in air of an equal volume of distilled water. The specific gravity is of vital importance in determining the proper proportions of road works mixture by weight. Stones having high specific gravity values are generally stronger than those having low specific gravity. Thus a rock of high porosity have a low specific gravity.
8. Shape of Aggregates: The aggregates may either be round or cubical or angular or flaky or elongated. The shape of a cubical aggregate resembles to that of a cube. Angular stones possess well defined edges. Flaky stones have smaller thickness as compared to the sides. Too flaky & too much elongated aggregates have less strength & durability. Therefore, they are avoided for their use in pavement constructions. Rounded particles because of their better workability are preferred for cement concrete pavement construction. In case of flexible pavement where stability is mainly due to interlocking, angular or cubical particles are the best choice.

Cementation: Is the ability of the road stone to form its own binding material under traffic so as to make the rough broken stone pieces grip together imparting resistance to displacement. Lime stone, Konkan & laterite have good cementation properties, particularly in dry weather.

9. Hydrophobic Characteristics: It is the property by virtue of which the stone aggregate resists stripping off of the bitumen in the presence of water. The aggregate used in black top pavements should have less affinity of water when compared with bituminous binders.

Aggregate Tests

Aggregates obtained from different sources may differ considerably in their constitution & properties. Therefore, in order to decide the suitability of the road aggregates the following tests are carried out.

1. Descriptive tests
2. Shape tests
3. Water absorption tests
4. Specific Gravity tests
5. Crushing value tests
6. Impact value tests
7. Abrasion tests
8. Soundness tests

**Los Angeles Abrasion Test**

Los Angeles abrasion test is the most widely used abrasion tests on aggregates. In this test, the abrasion will happen due to the action of the steel balls in the drum as it is rotated. This test is more dependable than other abrasion tests. As a general rule, Los Angeles abrasion value up to 33% is allowed for high quality surfaces & 50% for base courses.
Bitumen:

Bitumen is a viscous liquid or solid material, black or dark brown in color, having adhesive properties, consisting essentially of hydrocarbons. It is substantially non-volatile, non-toxic, and softens gradually when heated. It is soluble in carbon disulphide (CS₂).

There are two main categories of bitumen:

1. Natural bitumen
2. Refinery bitumen

Manufactured (Industrial)

Natural

Residual Fractional Distillation of Crude Petroleum

Grade of Asphalt (Asphaltic Cement)

Liquid Asphalt (Cold backets)
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Lake asphalt (native asphalt):
Lake asphalt is obtained from asphalt lakes in Trinidad & Bermudes. Trinidad asphalt contains about 40% insoluble organic & inorganic materials, and Bermudes asphalt contains about 6% of such materials.

Rock asphalt:
Rock asphalt are natural deposits of sand stone or lime stone rocks filled with asphalt. Deposits have been found in west & south west of U.S.A.. The amount of asphaltic material varies from 45% to 18%. Rock asphalt is not widely used because of its high transportation cost.

Tar:
Tar is a viscous liquid, black in color, with adhesive properties, obtained by the destructive distillation of coal. It is not used in Iraq.

Petroleum Asphaltic Materials:

1. Asphalt cement (Grade asphalt):
These asphalt produced by fractional distillation of crude petroleum. The residual material after separation of light oils is contain the asphalt which is refined into specific grades & called penetration grades, i.e., 40-50, 50-60, 60-70, 85-100, 120-150, & 200-300.

2. Cut back (Liquid asphalt):
In producing cutback bitumen for asphalt, a cutter & sometimes a flux oil are used. The processes are defined as follows:
Cutting:—The addition of a volatile oil which produces a temporary reduction in binder viscosity.
Fluxing:—The addition of an oil which has a long term effect on binder viscosity.

Figure 14-33 p.570
Ogden
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Cut back bitumens can be divided into three main types, depending upon the type of solvent used to dilute the bitumen, these are:

a. Slow-Curing asphalt (SC): Can be obtained directly through the distillation process or by cutting back or fluxing asphalt cement with a heavy distillate such as diesel oil. It is used onto the surfaces of soil-aggregate roads in warm climates in order to keep the dry soil particles from creating a dust under traffic.

b. Medium-Curing asphalt (MC): MC asphalts are produced by cutting back the residual asphalt (usually 120-150) with naphtha. The fluidity of MC asphalts depend on the amount of solvent by volume in the material. MC asphalt can be used for the construction of pavement stabilized bases and surfaces, also used as a prime coat between the stabilized base & binder course in flexible pavement construction.

c. Rapid-Curing asphalt (RC): RC asphalts are produced by blending asphalt cement with a petroleum distillate that will easily evaporate, such as Gasoline or naphtha. RC's are used as a tack coat between the binder & wearing course.

3. Bitumen Emulsions

An emulsion is a relatively stable suspension of one liquid in another, a state of minute subdivision dispersed throughout and then liquid in which it is not soluble. The liquid which is dispersed is called the internal phase, while the surrounding liquid is called the continuous or external phase.

Emulsified asphalt are produced by breaking asphalt cement usually of 100-250 penetration range into minute particles and dispersing these in water with an emulsifier. These minute
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Particles have like electrical charges. Emulsion containing negatively charged particles of asphalt are classified as anionic, and other having positively charged particles of asphalt are classified as cationic. The anionic & cationic asphalt are generally used in highway maintenance & construction. Nonions type is exist but so far, has no applications & may be used in the future as emulsion technology advances.

Emulsions are also divided into three subgroups namely:

a. Rapid setting (RS)

b. Medium setting (MS)

(continued...)

Blown Asphalt:

Blown asphalt is obtained by blowing air through the semisolid residue obtained during the latter stages of the distillation process. It is relatively stiff when compared with other types of asphalts. Blown asphalt is not used as paving material, however, it is useful as a sealing material & as a joint filler for concrete pavements.
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Properties of Asphalitic Materials

The properties of asphalitic materials pertinent to pavement construction can be classified into four main categories:

- Consistency
- Durability
- Rate of curing
- Resistance to water action

1. Consistency

The consistency of any asphalitic material changes as the temperature changes. The consistency of a bituminous binder will vary from solid to liquid depending on the temperature. Therefore, it is essential that when the consistency of the asphalitic material is given, the associated temperature also must be given. The effect of temperature on the consistency of the given asphalt is known as temperature susceptibility and depends on the crude oil from which the asphalt is obtained.

2. Durability

When asphalitic materials are exposed to environmental elements, natural deterioration gradually takes place, and eventually, the materials lose their plasticity and become brittle. This change is caused primarily by chemical and physical reactions that take place in the material. This natural deterioration of the asphalitic material is known as weathering. The weathering for paving asphalt must be minimized as much as possible. The ability of an asphalitic material to resist weathering is known as durability. Some of the factors that influence weathering are oxidation, volatilization, temperature, exposed surface area, and age hardening.
Oxidation: Is the chemical reaction that takes place when the asphaltic material is attacked by the oxygen in the air. This chemical reaction causes gradual hardening & eventually permanent hardening & considerable loss of the plastic characteristics of the material.

Volatileization: Is the evaporation of the lighter hydrocarbons from the asphaltic material. The loss of these lighter hydrocarbons also causes loss of the plastic characteristics of the asphaltic material.

Temperature: The temperature has a significant effect on the rate of oxidation & volatileization. The higher the temperature, the higher the rates of oxidation & volatileization. The relationship between temperature increase & increases in rates of oxidation & volatileization is not linear; however, the percentage increase in rate of oxidation & volatileization is usually much greater than the percentage increase in temperature that causes the increase in oxidation & volatileization. It has been postulated that the rate of organic & physical reactions in the asphaltic material approximately doubles for each 10°C (50°F) increase in temperature.

Surface Area:
The exposed surface of the material also influences its rate of oxidation & volatileization. There is a direct relationship between surface area & rate of oxygen absorption & loss due to evaporation in grams per cubic centimeter per minute. An inverse relationship, however, exists between volume & rate of oxidation & volatileization. This means that the rate of hardening is directly proportional to the ratio of the surface area to the volume.

This fact is taken into consideration when asphalt concrete mixes are designed for pavement construction in
that the air voids are kept to the practicable minimum required for stability to reduce the area exposed to oxidation.

Age Hardening: If a sample of asphalt is heated & then allowed to cool, its molecules will be rearranged to form a gel-like structure. This will cause continuous hardening of the asphalt over time, even though it is protected from other factors such as oxidation & volatilization that cause hardening. This process of hardening with time is known as age hardening. The rate at which age hardening occurs is relatively high during the first few hours after cooling, but it gradually decreases & becomes almost negligible after about a year. Age hardening does not seem to have significant effect on pavements except when they are laid as a thin mat.

3. Rate of Curing
Curing is defined as the process through which an asphaltic material increases its consistency as it loses solvent by evaporation.

Rate of Curing & Cutbacks: The rate of curing of any cutback asphaltic material depends on the distillate used in the cutback process. This is an important characteristic of cutback materials, since the rate of curing indicates the time that should elapse before a cutback will attain a consistency that is thick enough for the binder to perform satisfactorily. The rate of curing is affected by both inherent & external factors. The important inherent factors are:
- Volatility of the solvent
- Quantity of solvent in the cutback
- Consistency of the base material.
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The more volatile the solvent is, the faster it can evaporate from the asphaltic material, and therefore the higher the curing rate of the material. This is why Gasoline & naphtha are used for rapid-curing cutbacks, whereas light fuel oil & kerosene are used for medium-curing cutbacks.

For any given type of solvent, the smaller the quantity used, the less time is required for it to evaporate, and therefore the faster the asphalt material will cure. Also, the higher the penetration of the base asphalt is, the longer it takes for the asphalt cutback to cure.

The important external factors that affect curing rate are:

- Temperature
- Ratio of surface area to volume
- Wind velocity across exposed surface

These three external forces are directly related to the rate of curing in that the higher any of these factors is, the higher the rate of curing. Unfortunately these factors cannot be controlled or predicted in the field, which makes it extremely difficult to predict the expected curing time. The curing rates of different asphaltic materials are therefore usually compared with the assumption that the external factors are held constant.

Rate of Curing for Asphalt Emulsions: The curing & adhesion characteristics of emulsions used for pavement construction (anionic & cationic) depend on the rate at which the water evaporates from the mixture. When weather conditions are favorable, the water is relatively rapidly displaced, so curing progresses rapidly. When weather conditions include high humidity, low temperature, or rainfall immediately following
the application of the emulsion, its ability to properly cure is adversely affected. Although the effect of surface & weather conditions on proper curing is more critical for anionic emulsions, favorable weather conditions are required to obtain optimum results for cationic emulsions also. A major advantage of cationic emulsions is that they release their water more readily.

4b. Resistance to Water Action

When asphaltic materials are used in pavement construction, it is important that the asphalt continues to adhere to the aggregates even with the presence of water. If this bond between the asphalt & the aggregates is lost, the asphalt will strip from the aggregates, resulting in the deterioration of the pavement. The asphalt therefore must sustain its ability to adhere to the aggregates even in the presence of water. In hot-mix, hot-laid asphaltic concrete, where the aggregates are thoroughly dried before mixing, stripping does not normally occur & so no preventive action is usually taken. However, when water is added to a hot-mix, cold-laid asphaltic concrete, commercial antistrip additives are usually added to improve the asphalt's ability to adhere to the aggregates.
Comparison of Asphalt & tar binders

There is considerable debate between engineers as to whether bitumen is "better" than tar & vice versa. It is not intended to take sides in this controversy as in fact, it can really be said with validity that each has particular advantages in certain situations.

Some properties of tar & bitumen materials are:-

1. Both binders appear blackish in colour when viewed in large masses, but make a brownish stain if appear bitumen in colour when viewed in thin films.

2. Bitumens respond less readily than tars to small changes in temperature. Tar is liquid at lower temperatures & solidifies at comparatively higher ones.

3. Tars may be overheated & spattered more easily than bitumens, but is much easier to get tar out of a road tanker.

4. Tar tends to penetrate more freely into open road surfaces.

5. Tar is not susceptible to the dissolving action of petroleum solvents or distillates. In parking areas, where petrol & oil are likely to drip or spill from vehicles, a tar surfacing may have a longer life than a bitumen one.

6. Bitumens is less brittle & low temperatures; this is because tar contains a higher percentage of free carbon.

Bitumen has 1.5% of free carbon.
Binder Tests & their significance

It is most convenient to discuss tests on binders by dividing them into the following four categories:
1. Consistency tests.
2. Composition tests.
3. Specific gravity tests.
4. Flash & fire point tests.

Consistency Tests:
The consistency means the resistance of a material to flow & it varies as the temperature changes. There is no single method of test which can readily evaluate all bituminous binders for consistency over such a wide range. Instead there are a number of tests, each of which has a certain advantages under specific conditions. The ones of importance are the penetration, viscosity & softening point tests.

1. Penetration Test:
Significance of test:
1. The penetration test measures the consistency of semi-solid asphaltic bitumes so that they can be classified into standard grades.
2. The penetration test on its own has no relation to quality of bitumen since asphalt grades does not imply quality.
3. The higher penetrations are preferred for use in colder climates.
4. Although it is more difficult to get lower penetration bitumes to adhere to aggregates since adhesion has been established the cohesive bond is much stronger than if softer ones are used.
5. The penetration test, when carried out @ different temperatures, can also determine the temperature susceptibility of a bitumen.
6. Where resistance to flow is important, e.g., when bitumen is used to fill cracks in concrete road slabs, a small change in consistency with wide change in temperature is desirable.

7. **Viscosity Test:**
   In basic terms, it can be said that the viscosity of a liquid is the property that retards flow so that when a force is applied to a liquid, the slower the movement of the liquid, the higher the viscosity.
   **Significance of test:**
   1. The viscosity of a bituminous binder is its most important physical characteristic.
   2. Viscosity measurements are useful not only in ensuring that the material with the desired properties has been obtained, but also as a means of selecting binders for specific uses.
   3. If a binder with too low a viscosity is pre-mixed with an aggregate, it may flow off the stone. Conversely, if the viscosity is too high, the mixture may be unworkable by the time it reaches the site.
   4. If too low a viscosity is used for surface dressing purposes, the result may be "bleeding" or a loss of chippings under traffic.
   5. With low-viscosity binders, mixing & application temperatures can be kept lower, & aggregates are more easily crated.

5. **Softening point Test (R & B Test) (Ring & Ball Test):**
   **Significance of test:**
   1. The softening point is not a melting point; bituminous binders do not melt but instead gradually change from semi-solids to liquids on the application of heat.
   2. The softening point of the pitch residue is a means of characterizing its rate of setting.
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3. It is useful for determining the temperature susceptibilities of bitumens which are to be used in thick films, such as in crack fillers.

4. When two bitumens have the same penetration value, the one with the higher softening point is normally less susceptible to temperature changes.

4. **Ductility Test**
   
   A ductile material is one which elongates when in tension. The ductility of a bituminous binder is expressed as the distance in centimeters that a standard semi-solid briquette will elongate before breaking.

   **Significance of test:**
   1. Ductility is desirable in road bitumens in order to overcome surface movements induced by traffic & temperature stresses.
   2. The ductility test is actually a measure of the internal cohesion of a bitumen.
   3. Since bitumens possessing high ductility are normally cementitious & adhere well to aggregates, the test is better used as a measure of whether or not ductility is present in the material, rather than as a means of determining the exact degree of ductility available.
   4. Bitumens possessing high ductility are also usually highly susceptible to temperature changes, while low ones are not.
   5. The lack of ductility does not necessarily indicate poor quality; indeed, bitumens of low susceptibility & low ductility are highly desirable as crack fillers in roadways.
   6. The harder grades of bitumen are less ductile than the softer ones.
Composition Tests:

1. Loss-on-Heating Test:
   - **Significance of test:**
     1. Specifications for penetration-grade asphaltic bitumen may require that the maximum loss of weight on heating & the maximum drop in penetration should not exceed particular values.
     2. The loss on heating is essentially on accelerated volatilization test.
     3. Although it is perhaps somewhat representative of heating conditions in field storage tanks, it is certainly not all representative of conditions during plant mixing or distributor operation, because of differences in film thickness as well as temperature.
     4. The test is of use only as a general indication of volatile content under the specified conditions of test.

2. Distillation Test
3. Water content Test
4. Ash content Test
5. Solubility Test

Specific Gravity Test:

The specific gravity of a bituminous binder is the ratio of the weight of a given volume of material @ a given temperature to that of an equal volume of water @ the same temperature.
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Significance of test:

1. The principal use of specific gravity determinations is in establishing the relation between binder weight & volume for transporting & billing purposes.
2. Knowledge of the specific gravity is also very useful in differentiating between the different types of binders.
3. The specific gravity of refinery penetration-grade bitumens normally lie between 1.00 & 1.05.
4. It is also necessary to know the specific gravity of the binder in order to determine the percentage of voids in designed mixtures of bitumens & mineral aggregates.

Flash & Fire point Test:

Flash point is the lowest temperature at which the vapours given off from the binder first burn with a brief flash of blue flame under specified conditions of test.

Fire point is the lowest temperature at which a specimen will sustain burning for 5 seconds.

Significance of tests:

1. The flash & fire point tests are primarily safety tests.
2. They may also be considered as indirect reflections of binder volatility.
3. The flash point is the more important of the two, since it indicates the maximum temperature at which the binder can safely be heated.
4. The flash points of most refinery penetration-grade bitumens lie in the range of 245 – 335°C, while RC cutbacks may flash at temperatures as low as 27°C. MC cutbacks usually flash between 52 – 93°C, while SC ones have flash points above 110°C.
5. The fire point is of little significance & its use in specifications is negligible.
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**Bituminous Mixes**

**Types of Asphalt Mixes**

1. **Dense-Graded Mix**
   - It has particle sizes evenly distributed from coarse to fine.
   - When compacted it has a low air void content and presents a surface of close texture.
   - It depends largely on grading, binder content, and density for stability.
   - The workability depends largely on its temperature.
   - Such mixes are often called "Asphalt Concrete".
   - It requires careful proportioning of materials and mix of high efficiency for uniform coating of all aggregate particles with the binder.
   - It is most commonly used for surfacing of new constructed or reconstructed pavement. The surfacing may consist of a wearing course only, or a wearing course and an intermediate course (binder course).
   - It may be used as a replacement for the granular material used as a base course or subbase. When asphaltic concrete is used for this purpose, the term "full depth" or "deep strength" are used.
   - It may be used to strengthen pavement by removal and replacement of portions of the existing pavement material or by overlying.

2. **Open-Graded Mix**
   - It may have a reasonably even grading but contains only a small amount of fine material.
   - It has relatively high air voids.
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3. It relies largely on mechanical interlock of the aggregate particles for stability.

4. The best results are achieved through the use of coarse grained & textured crushed aggregates having a good angular shape.

5. When used as a wearing coarse, an open graded mix provides several desirable properties.

6. The interconnected air voids allow free drainage of water through the mix so that water spray caused by traffic is minimized.

7. The open texture combined with the use of a polish resistance aggregate, provides a high level of skid resistance and reduces the reflection of light during wet & dark operating conditions.

8. Because the surface texture composed of many holes below, it gives an even riding surface which produces less tyre noise than a seal coat of similar texture depth.

9. It is sometimes used as a thick intermediate layer over a cracked surface, to minimize reflective cracking.

10. An open graded asphalt wearing course does not distribute any strength to the pavement, if it should only be placed on a water proof, free drainage base.

3. **Gap-Graded Mix**

   - It is similar to dense-graded mix but with intermediate fractions replaced by finer fractions. It may also contain more filler.
   - It can be more tolerant to minor variations in grading than a dense-graded mix.
   - Gap-graded relies to a large extent on the stiffness of the fine aggregate/filler/binder mixture for stability. For this reason, harder grade binder may be used.
4. It is used for surfacing residential streets & car parks, where a smooth fine textured surface is desired.
5. When gap-graded asphalt is used on heavily trafficked & high speed roads, it is necessary to roll pre-coated aggregate into the surface immediately after spreading, to provide a coarse surface texture for skid resistance.

Lead Carrying Mechanism

There are mainly two types of load carrying mechanism:

1. Interlock & friction mechanism

This type of loading mechanism is noticed in "open-graded" mixtures like coated stone. It is clear that the traffic stresses imposed on the surface are distributed by "stone to stone" contact & by friction and interlock between the stones. Therefore
Pavement Materials

It is necessary to use high crushing strength stone in a mix and undergoes this type of mechanism. The bitumen coating serves only to hold the stones together.

2. Mastic Mechanism

Mastic asphalt “Gap-graded” is an example of this type of mechanism. This type of mixes distribute the traffic stresses within the mortar. To resist the deformation under the stresses imposed, the mortar must have a high stiffness, which is obtained by the use of a hard bitumen and a high filler content. In most paving mixes, the stresses are distributed by one or both of these mechanisms.

Asphalt concrete “Dense-graded” mix is a type of mix in which both mechanisms operate. A considerable proportion of stresses are distributed by the “stone interlock mechanism”, but between the stones there is mortar in which some of the stresses are distributed by the “mortar mechanism”.

Aggregate Mastic Mechanism
Aggregate interlock mechanism
Stability:
Stability is the ability of the asphalt paving mixture to resist deformation from imposed loads. Unstable pavements are marked by channeling (ruts) & corrugations. Stability is dependent upon both internal friction & cohesion. Internal friction is dependent on surface texture, gradation of aggregate, particle shape, density of mix, & quantity of asphalt. It is a combination of the frictional & interlocking resistance of the aggregate in the mix. Cohesion is that binding force that is inherent in the asphalt paving mixture. The asphalt serves to maintain contact pressures developed between aggregate particles. Cohesion is dependent upon rate of loading, loaded area, viscosity of the asphalt, temperature, & asphalt content.

If aggregate interlock mechanism predominates, good stability is achieved by using coarse aggregate with high crushing strength, singular in shape, to achieve good packing & rough surface.

If mortar mechanism predominates, good stability is achieved by using:
- high viscosity binder
- high filler content
- rough textured sand.
Durability

Durability is the ability of an asphalt paving mixture to resist disintegration by weathering & traffic. Included under weathering are changes in the characteristics of asphalt, such as oxidation & volatilization, and changes in the pavement & aggregate due to the action of water, including freezing & thawing.

Durability is generally enhanced by high asphalt contents, dense aggregate gradations, & well-compacted, impervious mixtures. A mixture having a high asphalt content, with voids completely filled with asphalt, may provide the ultimate in durability. However, this would be undesirable from the standpoint of stability. When placed in the roadway, the pavement would channel & creep under traffic. Bleeding or flushing of asphalt to the surface would also take place. It is therefore necessary to compromise, keeping the asphalt content as high as possible while maintaining adequate stability.

Flexibility

Flexibility is the ability of an asphalt paving mixture to conform to gradual settlements & movements of the base & subgrade. Differential settlements in the fill embankment occasionally occur. Thus, it is almost impossible to develop uniform density in the subgrade during construction because sections or portions of the pavement tend to compress & settle under traffic. Therefore, the asphalt pavement must have the ability to conform to localized & differential settlements without cracking. Generally, flexibility of the asphalt mixture is enhanced by high asphalt contents & relatively open-graded aggregates.
Fatigue Resistance

The ability of asphalt pavement to withstand repeated flexing caused by the passage of wheel loads. As a rule, the higher the asphalt content, the greater the fatigue resistance. Tests indicate that dense-graded asphalt mixes have more fatigue resistance than open-graded mixes. Well-graded aggregates that permit higher asphalt content without causing flushing or bleeding in compacted pavement should be incorporated in the mix.

Skid Resistance

The ability of asphalt paving surface, particularly when wet, to offer resistance to slipping or skidding. The factors for obtaining high skid resistance are generally the same as those for obtaining high stability. Proper asphalt contents & aggregates with a rough surface texture are the greatest contributors. However, not only must the aggregate have a rough surface texture, it must also resist polishing. Mixes so rich in asphalt as to fill the voids in the compacted pavement will probably cause asphalt to flush to the surface. This is usually called bleeding. Free asphalt on the pavement surface can also cause slippery conditions when the pavement is wet.

Impermeability

The resistance an asphalt pavement has to the passage of air & water into or through the pavement. While the void content may be an indication of the susceptibility of a compacted paving mixture to the passage of air &/or water, of more significance is the interconnection of the voids & their access to the surface.
Pavement Materials

Imperviousness to air & water is extremely important from the standpoint of durability in asphalt mixes.

7. Workability:
The ease with which paving mixtures may be placed & compacted with careful attention to proper design & with the use of machine spreading, workability is not a problem. At times, the properties of aggregates that promote high stability make asphalt mixtures containing these aggregates difficult to spread or compact. Since workability problems are discovered most frequently during the paving operation, mix design adjustments should be made quickly to allow the job to proceed as efficiently as possible.

Design of Bituminous Mixes

Asphalt mixture showing net or effective asphalt, absorbed asphalt, & air voids.
Mix = course agg. + fine agg. + filler + binder

\[ M_B = M_{Ba} + M_B \]

Density = \( \frac{M}{V} \)

Asphalt content = \( \frac{M_B}{M} \)

Asphalt absorption = \( \frac{M_{Ba}}{M - M_{Ba}} \)

Air voids (AV) = \( \frac{V_a}{V} \)

Voeds in mineral agg. (VMA) = \( \frac{V_a + V_{net}}{V} \)

where:
- \( V \) = total volume
- \( V_a \) = volume of air
- \( V_{net} \) = volume of net binder
- \( V_{ag} \) = volume of aggregate
- \( M \) = total mass
- \( M_B \) = mass of binder
- \( M_{Ba} \) = mass of absorbed binder
- \( M_{net} \) = mass of net binder
- \( M_{agg} \) = mass of aggregate.

Marshall Test & Design Procedure

Marshall test is a type of unconfined compressive strength test using cylindrical test specimens that are 101.6 mm diameter by about 63.5 mm high.

Compressed radially at a constant rate of strain of 50.8 mm/min at 60°C.

The readings are:

- Marshall stability value - the maximum load resistance in newtons that the specimen develops.
Marshall flow value is the total movement or strain occurring in the specimen between no load & maximum load during the stability test (deformation & failure) in mm.

**Procedure of Test:**

To find the optimum binder content which meets specified requirements for stability, deformation, & voids content, the following steps are done:

**Step (1):**
Prepare a series of test specimens for ranges of different binder content.

Difference in binder content is 0.5% or 1%.

**Step (2):**
Determine the bulk density of each specimen.

\[ d = \frac{M_a}{V} = \frac{M_a - M_w}{M_a - M_w} \]

- \( d \): bulk density of the compacted mix (g/cm³)
- \( M_a \): mass of the specimen in air (gm)
- \( M_w \): mass of the specimen in water (gm)
- \( V \): volume of the specimen (cm³).

**Step (3):**
Calculate the percentage of air voids in each compacted specimen.

\[ W_a = \frac{W_b}{G_{bf}} + \frac{W_c}{G_{cf}} + \frac{W_{fr}}{G_{fr}} \]

Where:
- \( W_a \): maximum theoretical density (gm/cm³)
- \( W_a \): weight of specimen in g
- \( W_{bf}, W_{cf}, W_{fr} \): weight of binder, course agg., fine agg., & filler respectively.
- \( G_{bf}, G_{cf}, G_{fr} \): specific gravity of binder, course agg., fine agg., & filler respectively.
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\[ \% V.T.M. = \frac{\gamma - d}{\gamma} \times 100 \]

Where \( \% V.T.M. \) = percent of voids in total mix
\( \gamma \) = maximum theoretical density (g/cm^3)
\( d \) = bulk density (g/cm^3).

Step (4):

For each specimen, calculate the percentage of voids in the compacted mineral aggregate & the percentage of voids filled with binder.

\[ V.M.A. = V - (V_c - V_f - V_{nf}) \times 100 \]
\[ V.M.A. = \frac{W}{d} - \left( \frac{W_c}{G_c} - \frac{W_f}{G_f} - \frac{W_{nf}}{G_{nf}} \right) = 100 \times \frac{W_c + W_f + W_{nf}}{W} \]
\[ \% V.M.A. = \frac{V.M.A.}{V} \times 100 \]
\[ \% V.F.B. = \frac{V_{nf}}{V.M.A.} \times 100 \]
\[ \% V.F.B. = \frac{\% V.M.A. - \% V.T.M.}{\% V.M.A.} \times 100 \]

Where \( V.M.A. \) = volume of voids in compacted mineral aggregate (cm^3)
\( V \) = volume of specimen (cm^3)
\( V_c, V_f, V_{nf} \) = volume of coarse agg. + fine agg. + filler respectively (cm^3).
\( W \) = weight of specimen
\( d \) = bulk density of specimen
\( W_c, W_f, W_{nf} \) = weight of coarse agg. + fine agg. + filler respectively
\( G_c, G_f, G_{nf} \) = specific gravity of coarse agg., fine agg. + filler respectively
\( \% V.M.A. \) = percent of voids in mineral agg.
\( \% V.F.B. \) = % of voids filled with binder.
Stability = maximum load required to produce failure (N)
Flow = deformation at failure (mm).

Step (6): Correct the measured stability values to those which would have been obtained if the specimens had been exactly 63.5 mm high.

<table>
<thead>
<tr>
<th>Volume of specimen (cm$^3$)</th>
<th>Approximate thickness of specimen (mm)</th>
<th>Correlation ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 - 213</td>
<td>25.4</td>
<td>5.56</td>
</tr>
<tr>
<td>406 - 420</td>
<td>50.8</td>
<td>1.17</td>
</tr>
<tr>
<td>509 - 522</td>
<td>63.5</td>
<td>1.00</td>
</tr>
<tr>
<td>611 - 625</td>
<td>76.2</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Corrected stability = measured stability * correlation ratio.

Step (7): Prepare separate graphical plots for binder content versus each of (a) corrected Marshall stability (b) Marshall flow (c) %V.T.M. (d) %V.F.B. (e) %V.M.A. & (f) unit weight (density).
Step (8):
Determine the optimum binder content as an average of the binder content of maximum stability, maximum density, and for the V.F.B.

Step (9):
Check the optimum binder content with the design specifications.

Step (10):
If the optimum binder content does not meet the allowable limits of specification, it is necessary to reject the mix and to adjust the grading of the original aggregate blend and carry out steps 1-9 again.

**The Iraqi Roads Design Specification**

<table>
<thead>
<tr>
<th>Property</th>
<th>Wearing Course</th>
<th>Binder Course</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability (kN)</td>
<td>8 (min.)</td>
<td>7 (min.)</td>
<td>5 (min.)</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>2 - 4</td>
<td>2 - 4</td>
<td>2 - 5</td>
</tr>
<tr>
<td>V.T.M. (%)</td>
<td>3 - 5</td>
<td>3 - 7</td>
<td>3 - 7</td>
</tr>
<tr>
<td>V.F.B. (%)</td>
<td>70 - 85</td>
<td>60 - 80</td>
<td>-</td>
</tr>
</tbody>
</table>

**Adjustment of Mix Design**

The final design composition is usually a compromise between the requirements of stability & air void content and the requirements of good durability, flexibility & economy. Information to assist in the modification of mixes to meet specification requirements is given below:

1. Stability satisfactory, but voids too low:
   - Reduce the binder content of the binder contents of stability and density.
Pavement Materials

2. **Stability satisfactory but voids too high:**
   - Increase the amount of filler &/or binder. Porous aggregate absorbs binder & requires a higher binder content.
   - Change the proportions of the coarse aggregate to the fine aggregate to produce lower voids in the mineral aggregate.

3. **Stability too low & voids too low:**
   - Increase the filler & reduce the binder.
   - Increase the proportion of coarse aggregate.

4. **Stability too low & voids too high:**
   - Increase the percentage of filler.
   - Change the proportions of coarse to fine aggregate to produce lower voids in the mineral aggregate.

5. **Stability too low but voids within the specified limits:**
   If the percentage of binder is near the upper limit, try increasing the proportion of coarse aggregate & reducing the binder. If the percentage of binder is near the lower limit, it is probable that the aggregate is inherently unstable. It may therefore be necessary to change the source of aggregate. It is usual to change the fine aggregate if the coarse aggregate is a crushed stone, or the coarse aggregate if it is a round gravel.

6. **Stability too high:**
   - High stability may be due to one of the following factors:
     a. Critical location of one or more large aggregate fragments in the compacted specimen. This may result in a false value which does not indicate the true stability of the mix.
     b. Inherent stability of the mineral aggregate owning to interlocking of angular fragments. This type of high stability is very desirable & requires no upper limit. It can usually be identified by redesigning the mix to use a minimum of fine aggregate with a binder content slightly above the optimum for the particular mix. The
Pavement Materials

stability is still high, the apparently excessive stability of the original design is desirable rather than otherwise.

c- Excessively high density & low voids of the compacted mineral aggregate. This type of stability is undesirable as it leads to brittleness in cold weather & relatively low resistance to cracking & ravelling. Mixes of this type frequently carry an excess of mineral filler & a deficiency of binder. Proper correction is achieved by increasing the voids of the compacted mineral aggregate so that a greater amount of binder may be used without filling the voids. This can be achieved by the use of less fine aggregate & filler.

Example(1): Marshall test results for six specimens gave the results below:

1. Determine the optimum binder content for 4.7% V.T.M.
2. State for which layer would this mix be suitable to use according to Iraqi Roads & Bridges Specifications.

<table>
<thead>
<tr>
<th>Binder Content (%)</th>
<th>Stability (KN)</th>
<th>Flow (mm)</th>
<th>Unit at. (kg/m³) Density</th>
<th>V.T.M. (%)</th>
<th>V.F.B. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>14.6</td>
<td>0.18</td>
<td>2306</td>
<td>9.5</td>
<td>41</td>
</tr>
<tr>
<td>3.5</td>
<td>15.6</td>
<td>0.30</td>
<td>2332</td>
<td>7.8</td>
<td>50</td>
</tr>
<tr>
<td>4.0</td>
<td>15.2</td>
<td>0.40</td>
<td>2335</td>
<td>7.0</td>
<td>56</td>
</tr>
<tr>
<td>4.5</td>
<td>14.2</td>
<td>0.95</td>
<td>2381</td>
<td>4.5</td>
<td>69</td>
</tr>
<tr>
<td>5.0</td>
<td>12.0</td>
<td>3.30</td>
<td>2389</td>
<td>3.5</td>
<td>76</td>
</tr>
<tr>
<td>5.5</td>
<td>11.9</td>
<td>4.13</td>
<td>2381</td>
<td>3.0</td>
<td>80</td>
</tr>
</tbody>
</table>
1. B.C. O max. stability = 3.6 %  
B.C. O max. density = 5 %  
B.C. O 4.7 % V.T.M. = 4.4 %  
Optimum binder content = \( \frac{3.6 + 5 + 4.4}{3} = 4.3 % \)

2. Mix characteristics of the O.B.C.  
Stability = 14.7 kN  
Flow = 2.75 mm  
% V.T.M. = 5.2 %  
V.F.B. = 65 %

The mix is suitable to use as binder course layer or base layer & not suitable to use as wearing course from the standpoint of % V.T.M. (3-5) & % V.F.B. (40-85).
Pavement Materials

How: Typical Marshall test gave the following data:

<table>
<thead>
<tr>
<th>Binder Content (%)</th>
<th>Stability (%)</th>
<th>Flow (mm)</th>
<th>V.T.M. (%)</th>
<th>V.F.B. (%)</th>
<th>Unit wt. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4.89</td>
<td>2.2</td>
<td>12.5</td>
<td>34</td>
<td>2169</td>
</tr>
<tr>
<td>4</td>
<td>7.06</td>
<td>2.3</td>
<td>7.2</td>
<td>65</td>
<td>2207</td>
</tr>
<tr>
<td>5</td>
<td>8.06</td>
<td>2.9</td>
<td>3.9</td>
<td>84</td>
<td>2255</td>
</tr>
<tr>
<td>6</td>
<td>7.52</td>
<td>3.6</td>
<td>2.4</td>
<td>91</td>
<td>2227</td>
</tr>
<tr>
<td>7</td>
<td>6.49</td>
<td>4.8</td>
<td>1.9</td>
<td>93</td>
<td>2190</td>
</tr>
</tbody>
</table>


2. From these graphs determine the optimum binder content for assumed values of 4% V.T.M. & 32% V.F.B.

3. Check if that optimum binder content will meet the Iraqi Design Specification.

4. State whether the mix requires re-designing or it can be used in the pavement.

Solution:

1. Stability

2. Flow

3. V.T.M. (\%)
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2. B.C. D max. stability = 5.3 %
B.C. D max. density = 5.2 %
B.C. D 4% V.T.M. = 4.8 %
B.C. D 80% V.F.B. = 4.7 %
Optimum binder content = \(\frac{5.3 + 5.2 + 4.8 + 4.7}{4} = 5\%\).

3. Mix characteristics of the O.B.C.:
- Stability = 8 KN
- Flow = 2.9 mm
- V.T.M. = 3.75 %
- V.F.B. = 85 %

The optimum binder content meets the Iraqi Design Specifications for wearing course & base layer, and does not meet it for binder course layer from the standpoint of 4% V.F.B. (60-80).

The mix cannot be used in the pavement for the binder course layer & it requires re-designing.

Example (2): Determine the % of air voids & % of aggregate voids filled with binder given that:
- % coarse aggregate = 54 % \(\Rightarrow G_c = 2.64\)
- % fine aggregate = 40 % \(\Rightarrow G_f = 2.66\)
- % mineral filler = 6 % \(\Rightarrow G_m = 2.85\)

Using the value of 5.3 % binder content by weight of the total mix \((G_b = 1.02)\) to obtain a unit weight value for the mix = 2.34 kg/lm³.

Solution:
1. \% V.T.M. = \(\frac{V_T}{V} + 100\)
2. \(V = \frac{W}{1 + \frac{W_f}{G_f} + \frac{W_m}{G_m} + \frac{W_c}{G_c}}\)
% Coarse agg. = 0.54(100 - 5.3) = 51.1
% fine agg. = 0.46(100 - 5.3) = 37.9
% filler = 0.06(100 - 5.3) = 5.7
% binder = 5.3

\[
\psi = \frac{51.1}{2.64} \frac{37.9}{2.66} \frac{5.7}{2.85} + \frac{5.3}{1.02} \]

\%
V.T.M. = \frac{2.451 - 3.349}{2.451} \times 100 = 4.16 \%

2. \%
V.F.B. = \frac{V_b}{V.M.A.} \times 100

V_b = \frac{5.3}{1.02} = 5.196 \text{ cm}^3

V.M.A. = V - V_c - V_f - V_{ma}

\[
= \frac{w_c}{G_c} - \frac{w_f}{G_f} - \frac{w_{ma}}{G_{ma}} \\
= \frac{100}{2.349} - \frac{51.1}{2.64} - \frac{37.9}{2.66} - \frac{5.7}{2.85}
\]

= 6.97 \text{ cm}^3

\%
V.F.B. = \frac{V_b}{V.M.A.} \times 100

= \frac{5.196}{6.97} \times 100

= 74.5 \%

OR:

\%
V.M.A. = \frac{\% V.M.A. - \% V.T.M.}{\% V.M.A.} \times 100

\%
V.M.A. = \frac{V.M.A.}{V} \times 100

= \frac{6.97}{100} \times 100

= 16.37 \%

\%
V.F.B. = \frac{16.37 - 4.16}{16.37} \times 100

= 74.5 \%
Example (3): An asphalt concrete mix contains 2,250 kg of aggregate & 150 kg of asphalt per m³. The bulk specific gravity of aggregate is 2.67 & the specific gravity of asphalt is 1.05. If the asphalt absorption is 12%, find the mass-volume relationship.

Solution:

\[ M_G = 2,250 \text{ kg} \quad M_B = 150 \text{ kg} \]

\[ M = 2,400 \text{ kg} \]

\[ V = 1 \text{ m}^3 \]

Asphalt absorption = \[ \frac{M_{BA}}{M_G} \]

\[ M_{BA} = \frac{1.2}{100} \times 2,250 = 27 \text{ kg} \]

\[ M_B = M_{BV} + M_{BA} \]

\[ M_{BV} = 150 - 27 = 123 \text{ kg} \]

\[ V_C = \frac{2,250}{2.67 + 1000} = 0.843 \text{ m}^3 \]

\[ V_{BV} = \frac{123}{105 + 1000} = 0.117 \text{ m}^3 \]

\[ V = V_A + V_{BV} + V_G \]

\[ V_A = 1 - (0.843 + 0.117) = 0.04 \text{ m}^3 \]

\[ \% V \text{ M.A.} = \frac{V_A + V_{BV}}{V} \times 100 \]

\[ = \frac{0.04 + 0.117}{1} \]

\[ = 15.7\% \]

\[ \% V \text{ T.M. (or V A.V.)} = \frac{V_A}{V} \times 100 \]

\[ = \frac{0.04}{1} \times 100 \]

\[ = 4\% \]