Chapter One

Introduction

1.1General

Long-term performance of asphalt pavement is a major challenge and ultimate goal of highway Engineering agencies. Polymer modification of asphalt concrete mixtures has been considered by many researchers to achieve this goal. When polymers are added to asphalt, the properties of the modified asphaltic mixture depend on the compatibility of the polymer with the asphalt. Therefore, choosing the right polymer modifier is an essential task that can aid in providing better and long lasting roads. Polymer modifiers can be classified into two major groups: elastomeric modifiers, and the plastomeric modifiers. Elastomeric modifiers such as styrene/butadiene polymers, a natural rubber and crumb rubber tends to improve the mixture elasticity and low temperature properties. Plastomeric modifiers such as polyethylene, ethyl-vinyl-acetate and polyvinyl chloride tend to improve the stiffness and high temperature properties of asphaltic mixtures (Hozayen and Othman, 2008; Mohammad *et al*., 2007)

There are many waste materials resulting from manufacturing operations of waste materials continues to increases. The capacity to handle them decreases. Many landfills have closed, And new facilities are often difficult to site due to economic and environmental constraints (Gucbilmez and Alhaj, 2001).

There are three techniques for waste disposal; recycling, incineration with and without generation of energy, and burial. The management of these waste materials is becoming very challenging due to improper disposal facilities and processes as well as environmental considerations. The use of variety of waste products in highway construction has been looked into to find an alternative source of material supply to offset the rising cost of quality natural aggregates ,waste disposal ,and energy .for the past several years there have been limited studies to incorporate some of these waste material in hot mix asphalt (HMA),materials involved to date include ground rubber tires ,ground glass ,incinerator ash ,and various kinds of waste polymer ;there may also ether waste materials that could be included in similar studies in the future (Ahmed, 1992)

The use of scrap tyres in asphalt mixture applications is not a recent development with reclaimed tyre crumb being used in the asphalt industry for over 30 years. Documentation is extensive but disjointed, making a summary of its history difficult (Epps, 1994).

The use of crumb rubber in asphalt paving is gaining more attention in many parts of the world as this material gives better mechanical and functional performance of the mixture as well as being a proficient way of dealing with this waste product (Epps, 1994). Crumb rubber modified (CRM) asphalt is a general type of modified asphalt that contains scrap tyre rubber. Modified asphalt paving products can be made with crumb rubber by several techniques, including a wet process and a dry process. In the wet process CRM binders are produced when finely ground crumb rubber (0.075 mm to 1.2 mm) is mixed with bitumen at elevated temperatures prior to mixing with the aggregate. Binder modification of this type is due to physical and compositional changes in an interaction process where the rubber particles swell in the bitumen by absorbing a percentage of the lighter fraction of the bitumen, to form a viscous gel. In the dry process, granulated or ground rubber and/or crumb rubber (0.4 to 10 mm) is used as a substitute for a small portion of the fine aggregate (typically 1-3 percent by mass of the total aggregate in the mixture). The rubber particles are blended with the aggregate prior to the addition of the bitumen

1.2 Justification

Conventional bituminous materials have tended to perform satisfactorily in most highway pavement and airfield runway applications. However, in recent years, increased traffic levels, larger and heavier trucks, new axle designs and increased tyre pressures, have added to the already severe demands of load and environment on the highway system. This has resulted in the need to enhance the properties of existing asphalt material. Bitumen modification offers one solution to overcome the deficiencies of bitumen and thereby improve the performance of asphalt mixtures. The best known form of modification is by means of polymer modification, traditionally used to improve the temperature susceptibility of bitumen by increasing binder stiffness at high service temperatures and reducing stiffness at low service temperatures .In addition, PMBs generally possess improved resistance to permanent deformation, thermal and fatigue cracking. The polymers that are used for bitumen modification can be divided into two broad categories, namely plastomers and elastomers. Plastomers modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation, while elastomers have a characteristically high elastic response and, therefore, resist permanent deformation by stretching and recovering their initial shape (Airey, 2002; Hamid *et al*., 2008).

Waste throughout materials the world is casing costly disposal problems. Some are by-products of industrial production processing, while others are waste materials from day to day usage by consumers. Disposal of waste material is a difficult task because the government and public agencies are becoming more environmental conscious, it is found that using tire rubber instead of other waste materials in pavement construction is less expensive (Gucbilmez and Alhaj, 2001).

Waste material recycling into useful products has become a main solution to waste disposal problems. Many highway agencies are conducting wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction (Collins and Ciesielkia, 1993).

Different asphalt modifiers are proposed to improve the resistance of asphaltic mixtures to environmental changes in hot climate. Among these modifiers is crumb rubber that has been considered by many researchers to improve the performance of asphalt pavement mixtures (Epps, 1994). Another important objective of using crumb rubber as an asphalt modifier is to avoid environmental problems resulting from scrap tire disposal. Many studies have reported the improvement of properties of asphalt concrete mixtures when crumb rubber was used. Most of those studies were based on standard traditional tests like Marshall Stability, indirect tensile strength, and resilient modulus. (Othman, 2006)

Studying the effect of different types of additives on improving the properties of asphalt concrete mixtures is a field of interest for many researchers (Hozayen and Othman, 2008).

1.3 General Objectives

Evaluation of Crumb Tire Rubber Modified Bitumen for Hot Mix Asphalt Concrete at Khartoum State

1.4 Specific Objectives

- To assess the method for blend the rubber with bitumen
- To study the effects time &temperature on homogeneity of rubber with bitumen
- To examine the asphalt-rubber performance
- To determine optimum bitumen content for conventional HMA
- To determine optimum asphalt-rubber content (OARC) for (ARHM)
- To assess the optimum rubber percentage for Asphalt-Rubber Hot Mix

1.5 Thesis Structures

This introductory chapter gives a general idea of the research need, justification, general and specific objectives. The background and previous study and experiences were reviewed in the second chapter. Chapter three explain the material imported, experimental investigations on rubber-bitumen homogenous and the laboratory tests performed to evaluate the bitumen physical properties, laboratory tests performed on coarse and fine aggregates, Crumb rubber properties and finally deals with Examination of Hot mixes asphalt (HMA) & asphalt rubber hot mix (ARHM).the results of experimental works were detailed in chapter four which explain modified bitumen morphology, bitumen and modified bitumen physical properties results and hot mixtures design data and analysis. Chapter five explain the analysis and discussion of the results. Finally Conclusions and recommendations for future research are presented in Chapter Six. Figure 1.1 shows the flow chart of the thesis Structures

Chapter Two

Literature Review

2.1 General

This chapter gives general idea about the bituminous material which includes Refinery Operation of Petroleum Bitumen, Occurrence of natural bitumen, Bitumen Composition and Structure and physical properties, Also its deal with Molecular Structure, Processing of Rubber and Production, Composition and Recycling of Tires, Also it gives a general idea about Aggregate which includes Aggregate Properties and tests and finally deals with bituminous Mixers

2.2 Bituminous Materials

Bituminous binders used in pavement constructions works include both bitumen and tar. Bitumen is petroleum product obtained by distillation of petroleum crude whereas road tar is obtained by the destructive distillation of coal or wood. Both bitumen and tar have similar appearance black in color though they have different characteristics (Khanna and Justo, 1990).

2.2.1 Bitumen

Bitumen is manufactured from crude oil that originates from the remains of marine organisms and vegetable matter deposited on the ocean bed (Whiteoak, 1990). Over millions of years, the matter is accumulated and through the immense weight of the upper layers the matter in the lower layer is compressed. Combined with heat from the Earth's crust, the matter forms crude oil that is trapped by impermeable rock forming large underground reservoirs. The crude oil can sometimes rise through faults in the layers above, coming to the ground surface. Most crude oil is now extracted from underground by drilling (Whiteoak, 1991).

Bitumen may be further divided as petroleum asphalt or bitumen and native asphalt (Khanna and Justo, 1990)

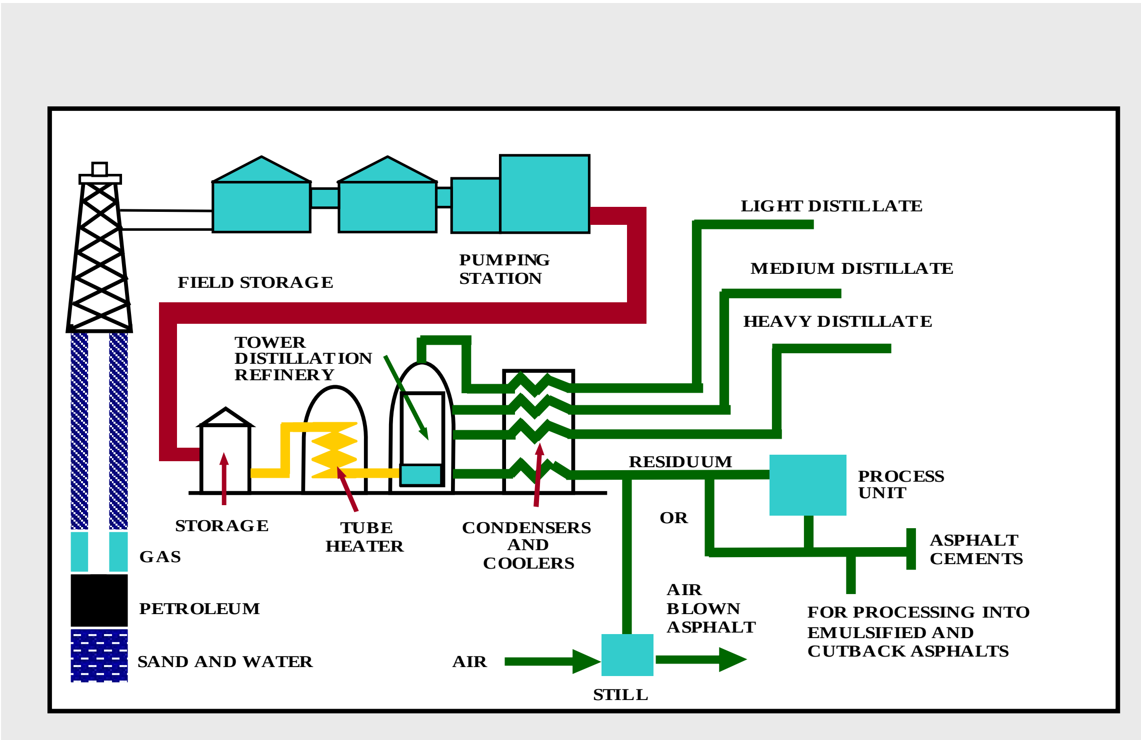


Figure 2.1: Refinery Operation of Petroleum Bitumen (http://www.asphaltwa.com)

Figure 2.2: Occurrence of Natural Bitumen (http://www.asphaltwa.com)

*** ASTM define Bitumen** as class of black or dark-colored (solid, semisolid, or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, pitches, and asphaltites are typical. (ASTM), when the bitumen contains some inert material or minerals, it is some times called asphalt (Khanna and Justo, 1990).

**** ASTM define Asphalt** as dark brown to black cementitious material in which the predominating constituents are bitumens which occur in nature or are obtained in petroleum processing.

2.2.1.1 Bitumen Composition and Structure

Bitumen is a complex mixture of organic molecules. Both the chemical (constituent) and the physical (structural) part of the bitumen comprise mainly hydrocarbons with minor amounts of functional groups such as oxygen, nitrogen and sulphur. As bitumen is extracted from crude oil, which has variable composition according to its origin, the precise breakdown of hydrocarbon groups in bitumen is difficult to determine. However, elementary analysis of bitumen manufactured from a variety of crude sources show that most bitumens contain:

- Carbon: 82-88%
- Hydrogen: 8-11%,
- Sulphur: 0-6%
- Oxygen: 0-1.5%
- Nitrogen: 0-1%

The precise composition of bitumen varies according to the crude source. Although the chemical composition is very complex, it is possible to separate bitumen into four main chemical compositions (Whiteoak, 1990; Airey, 1997).

These are:

- Asphaltenes
- Resins
- Aromatics
- Saturates

The four groups are not well defined and there is inevitably some overlap between the groups. A schematic representation of the bitumen structure is presented in Figure (2-3)

2.2.1.1.a Asphaltenes

Asphalt black or brown amorphous (without shape) solids. They are highly polar, complex materials of high molecular weight (between 1,000 and 100,000). Within a medium they have a tendency to associate together to form micelles with a molecular weight between 20,000 and 1,000,000. Asphaltenes typically constitute 5% to 25% of the bitumen. The molecular weight relates to the size of each molecule, so the higher the molecular weight, and the larger the molecules.

The asphaltenes content has a considerable effect on the rheological characteristics of bitumen. Increasing the asphaltenes content produces harder bitumen with a lower penetration, higher softening point and higher viscosity. The association of asphaltenes is not fixed; on heating the gel structure Figure (2-3) of the micelles is broken down and reformed on cooling. During long-term heating the asphaltenes micelles may break down, therefore, it is not unusual for the molecular weight of bitumen to decrease after heating. In short, asphaltenes define the stiffness and rigidity of the bitumen constituent.

2.2.1.1.b Resins

Resins are black or brown solid or semi-solid highly polar molecules. The high polarity makes the resins very adhesive. The molecular weight ranges from 500 to 50,000. The resins part of the bitumen acts as a peptising agent for the asphaltenes, therefore an increase in resins results in a solution (sol) structure whereas a reduction forms a gelatinous (gel) structure in the bitumen Figure (2-3). Resins work as stabilisers, which hold everything together in the bitumen (Kerbs and Walker, 1971).

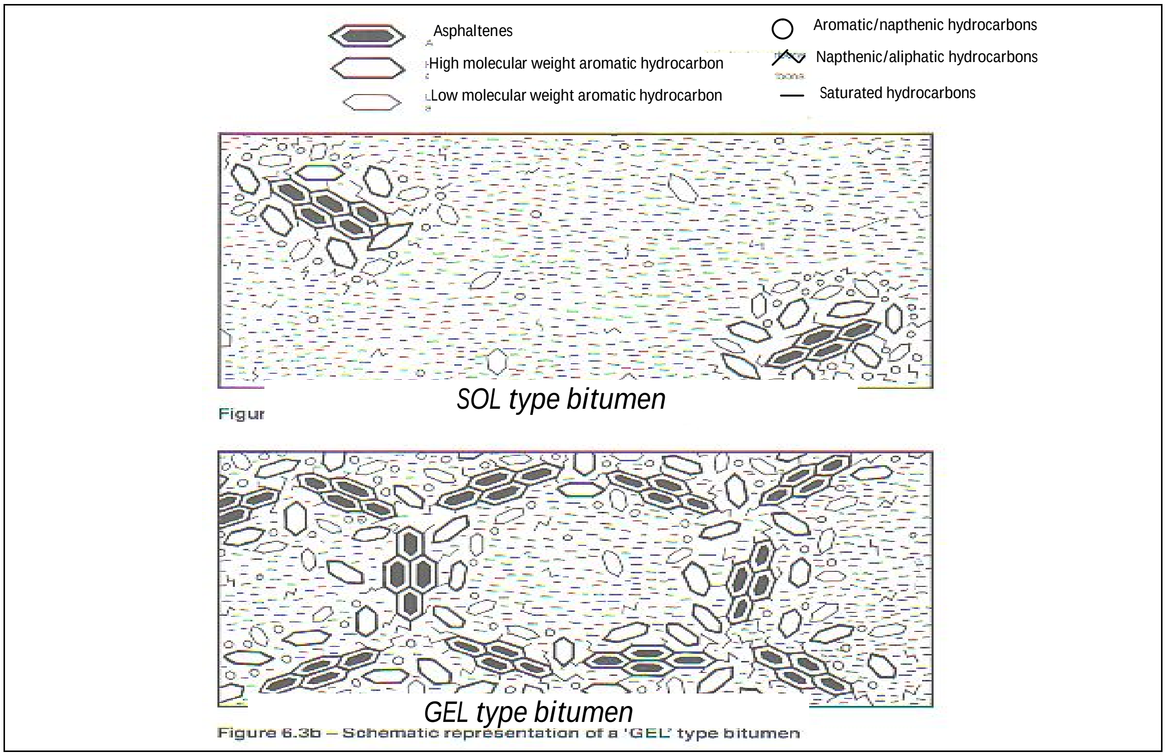


Figure 2.3: Schematic representation of typical bitumen structure (Whiteoak, 1990)

2.2.1.1.c Aromatics

Aromatics have the lowest molecular weight and form the major proportion of the bitumen (40-65%). They have a very low polarity and form a dark brown viscous liquid that acts as a dispersion medium for the asphaltenes in the bitumen and have a molecular weight in the range of 300 to 20,000. They give the adhesive properties of the bitumen.

2.2.1.1.d Saturates

Saturates are similar to oil and give the fluid properties of the bitumen. They have the lowest molecular weight (similar to aromatics) and are straw or white in colour and form between 5-20% of the bitumen.

2.2.1.2 Bitumen Conventional Physical Properties

There are several conventional physical property tests to evaluate the quality and consistency of manufactured bitumens. These tests are standardised in many specifications, e.g., British specifications, ASTM and European standards. However, all these methods are practically identical with negligible differences. Consistency tests are one of the main types of conventional tests that describe the degree of fluidity of bitumen at any particular temperature.

2.2.1.2.a Penetration Test According to ASTM-D5

The penetration test determines 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 five seconds. The sample is maintained at a temperature of 25^{o}C. The penetrometer consists of a needle assembly with a total weight of 100g and device for releasing and locking in any position. There is a graduated dial to read penetration values to 1/10th of a millimeter.

2.2.1.2.b Softening Point Test According to ASTM-D36

The softening point test is also an empirical method to determine the consistency of a penetration or oxidised bitumen. In this test two steel balls are placed on two discs of bitumen contained within metal rings and these are raised in temperature at a constant rate (5^{0}C/min) in a water bath (bitumen with softening point 80^{0}C or below) or in glycerol (bitumen with softening point greater than 80^{0}C). The softening point is the temperature (^{0}C) at which the bitumen softens enough to allow the balls enveloped in bitumen to fall a distance of 25 mm into the bottom plate. In short, this test method measures a temperature at which the bitumen phase changes from semi-solid to liquid.

2.2.1.2.c Specific Gravity Test According to ASTM-D70

The density of a bitumen binder is a fundamental property frequently used as aid to classify the binders for use in paving jobs in most applications, the bitumen content is converted on volume basis using density values the specific gravity value of bitumen is also useful in bituminous mix design The density of bitumen is greatly influenced by its chemical compounds or mineral impurities cause an increase in specific gravity, the specific gravity of bituminous materials is defined as the ratio of the mass of a given volume of the substance to the same of an equal volume of water, the temperature of both being 25° C The specific gravity is determined either by using a pycnometer or by preparing a cube shape specimen in semi solid or solid state and by weighing in air and water .Generally the specific gravity of pure bituminous is in the range of 0.97 to 1.02.

2.2.1.2.d Ductility Test According to ASTM-D113

In the flexible pavement constructions where bitumen binders are used, it is important that the binders form ductile thin films around the aggregates. This serves as a satisfactory binder in improving the physical interlocking of the aggregate bitumen mixes. Under traffic loads the bituminous pavement layer is subjected to repeated deformation and recoveries. The binder material which does not possess sufficient ductility would crack and thus provide pervious pavement surface. Ductility test is carried out on bitumen to test this property of the binder. The test is believed to measure the adhesive property of bitumen and its ability to stretch. The bitumen may satisfy the penetration value, but may fail to satisfy the ductility requirements. Bitumen paving engineer would however want that both test requirements are satisfied in the field jobs. Penetration and ductility tests cannot in any case replace each other.

2.2.1.2.e Flash and Fire Point Test According to ASTM-D92

Bitumen materials leave out volatiles at high temperatures depending upon their grade these volatiles catch fire causing a flash. This condition is very hazardous and it is therefore essential to qualify this temperature for each bitumen grade, so that paving engineers may restrict the mixing and application temperatures as mentioned above, this test gives an indication of the critical temperature at and above which suitable precaution should be taken to eliminate fire hazards during heating of bitumen.

- **Flash Point**

The flash point of a material is the lowest temperature at which the vapour of substance momentarily takes fir in the form of a flash under specified conditions of test

- **Fire Point**

The fire point is the lowest temperature at which the mineral gets ignited and burns under specified condition of test

2.2.1.2.f Viscosity

Viscosity is defined as inverse of fluidity. Viscosity thus defines the fluid property of bituminous material. Viscosity is the general term for consistency and it is measure of resistance to flow. Many researchers believe that grading of bitumen should be by absolute viscosity units instead of the conventional penetration units.

The Viscosity of bitumen is reduced some times by a volatile diluents; this material is call **cutback** , when bitumen is suspended in a finely divided condition in an aqueos medium and stabilized with an emulsifier ,the material is known as **emulsion** (Khanna and Justo, 1990).

2.2.2 Tar

Tar is the viscous liquid obtained when natural organic materials such as wood and coal are carbonized or restrictively distilled in the absence of air.

There are five grades of road tars, RT-1, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties; RT-1 has lowest viscosity and RT-5 has highest viscosity among the road tar (Khanna and Justo, 1990).

2.2.2.1 Tar definition: ASTM define Tar, as brown or black bituminous material, liquid or semisolid in consistency, in which the predominating constituents are bitumens obtained as condensates in the destructive distillation of coal, petroleum, oil-shale, wood, or other organic materials, and which yields substantial quantities of pitch when distilled

2.3 Rubber

2.3.1 Molecular Structure of Rubber

There are two types of rubber; natural and synthetic. Natural rubber latex is obtained from the rubber tree called Hevea braziliensis. The primary composition of the raw rubber molecule is a long straight-chain isoprene hydrocarbon**.** The physical appearance of this hydrocarbon is of a spongy, flocculent nature. At temperatures below 100^0C this spongy rubber becomes stiff, hard whereas when warmed above 100^0C, it becomes flexible, soft and transparent (Blow, 1971).

Synthetic rubbers are made from petroleum products and other minerals and produced in two main stages: first the production of monomers (long molecules consisting of many small units), then polymerisation to form a rubber. There are various types of synthetic rubber available for different applications. Some of them are: Styrene-Butadiene Rubber (SBR, used in bitumen, tyres etc); Silicon rubbers (used in gaskets, seals etc); Fluorocarbon rubber (resistant to heat and chemical attack); and Epichlorohydrin rubber (jackets, hose, cable, packing etc) (Blow, 1971).

The functionality of the rubber depends on how the molecules are arranged.

There are three types of molecular arrangements; linear, side branched and cross-linked.

2.3.1.1 Linear and Side Branched Polymers

The mechanical properties of this type of polymer are dependent on the length and shape (side branch) of the molecule. Both the linear and side branched polymers can be reversibly heated to melt and then cooled to crystallise time and time again. On melting they flow as a liquid and are therefore called thermoplastic. The number of the side branches can be varied by changing the polymerisation conditions. Even small variations in the number of side branches can cause appreciable changes in elastic modulus, creep resistance and toughness. Microwaveable food containers, Dacron carpets and Kevlar ropes are examples of products made with linear polymers. Soft, flexible shampoo bottles and milk jugs are examples of products generally made using branched polymers.

2.3.1.2 Cross-Linked Polymers

In cross-linked polymers, the chains are joined chemically at the tie points with cross-linking agents and formed into one simple giant molecular network. Many cross-linked networks are produced by chemical reactions triggered by heating. After heating, the network gets permanent shape and this state is called "Thermoset". Cross-linked polymers do not flow when heated. Tyres and bowling balls are two examples of products composed of cross-linked polymers. The mechanical behaviour of an elastomer depends strongly on cross-link density, which is shown schematically in Figure 2.4 (Hamed, 1992). It shows that the modulus and hardness increase monotonically with cross-link density and the network becomes more elastic. Fracture properties such as tear and tensile strength pass through a maximum as cross-linking is increased.

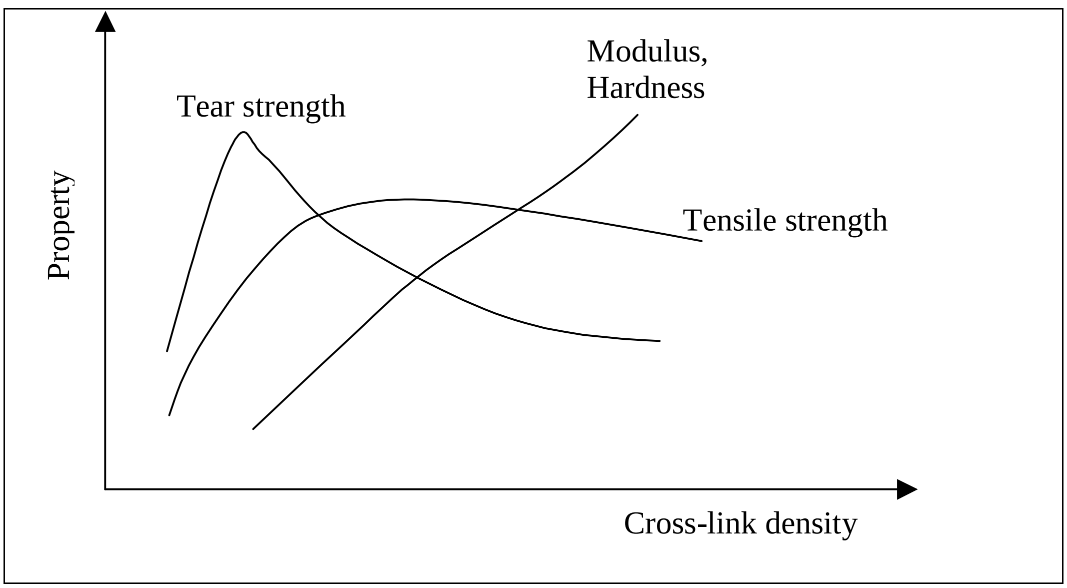


Figure 2.4: Effect of cross-link density on some mechanical properties of rubber (Hamed, 1992)

2.3.2 Processing of Rubber

2.3.2.1 Vulcanisation

Vulcanisation is the curing process of rubber, which transforms the raw rubber into a strong, elastic and rubbery hard state. There are two types of vulcanisation processes: hot (mould cured) and cold (pre-cure system). The hot process is used for the majority of rubber goods, including tyres. Cold vulcanisation is used to produce soft, thin rubber products such as surgical gloves or sheeting. Table 2.1 shows the effect of temperature on rubber

Table 2.1: Effect of Different Temperatures on Rubber

Base structure	Hard transparent and solid
-10^{o}C	Brittle and opaque
+20 ^{o}C	Soft, resilient and translucent
+50 ^{o}C	Plastic and sticky
120 ^{o}C-160 ^{o}C	Vulcanised when agents e.g., sulphur are added
~182 ^{o}C	Break down as in the masticator
200 ^{o}C	Decomposes

Natural rubber is insoluble with water, alkali and weak acids, but it is soluble in benzene, gasoline, chlorinated hydrocarbons and carbon bisulphate (Blow, 1971). While it is easily oxidised by chemical oxidising agents, atmospheric oxygen produces a very slow reaction. The most common vulcanisation is through sulphur. The proportion of sulphur agents to rubber varies from a ratio of 1:40 for soft rubber goods, to as much as 1:1 for hard rubber (Shulman, 2000). The sulphur is ground and mixed with the rubber at the same time as the other dry ingredients during the compounding process. When rubber is heated with sulphur to a temperature between 120^{o}C and 160^{o}C, it becomes vulcanised by combining the sulphur agents with the rubber molecules and produces a cross-linking network, which makes the rubber stronger and more durable and contributes to improve tyre wear and durability. The reactions of rubber to temperature extremes are an important factor in their applicability that produces improved strength and elasticity as well as greater resistance to changes in temperature, impermeability to gases, and resistance to abrasion, chemical action, heat, and electricity. Vulcanised rubber exhibits high frictional resistance on dry surfaces and low frictional resistance on water-wet surfaces, it has good abrasive resistance, flexibility, elasticity and electric resistance (Blow, 1971). Although vulcanisation converts soft rubber into a hard, usable stage, it is essential to add certain chemicals and additives to make it readily usable in commercial applications. This formulation process is called compounding.

2.3.2.2 Compounding

Compounding is the process by which a number of ingredients are added to modify and improve the physical properties of rubber. The first reason for compounding is to incorporate the ingredients and ancillary substances necessary for vulcanisation. The second is to adjust the hardness and modulus of the vulcanised product to meet the end requirement. Different techniques are available to do compounding using the same fundamental constituents (Stern, 1954), such as base polymer, cross-linking agent, accelerator for the cross linking reaction, reinforcing filler (carbon black, mineral), processing aids (softeners, plasticisers, lubricants), diluents (organic materials, extending oils), colouring materials (organic or inorganic), specific additives (blowing agent, fibrous materials). When designing a mixture formulation for a specific end use, it is necessary to take account not only of those vulcanisate properties essential to satisfy service requirements but also the costs of the raw materials involved and the production processes by which these will be transformed into final products.

The rubber compound used in rubber tyres is a complex mixture. In the compounding process, a number of ingredients are added to modify and improve the physical properties of the rubber and to make it more readily useable (modify the hardness, strength, toughness and to increase resistance to abrasion in oil, oxygen, chemical solvents and heat) for various applications. It is important to note that some of the ingredients still remain when the tyres are recycled at the end of their life. As an example, the stabilisers which provide resistance to cracking and degrading of the tyre, also prolong the life of roads, sports and safety surfaces etc; the pigments which produce uniform colour in the tyre also contribute to the consistent and long term colour of roads which utilise post consumer tyre materials.

2.4 Tyres

2.4.1 Production

A tyre is made up of three main materials; elastomeric (rubber) compound, fabric and steel. The fabric and steel form the structural skeleton of the tyre with the rubber forming the "flesh" of the tyre in the tread, side wall, apexes, liner and shoulder wedge. The tyre skeleton consists of beads made of steel or fabric depending on the tyre application, which form the 'backbone' in the toe of the tyre Figure (2-5). The beads are designed to have low extensibility and provide reinforcement for the rubber tyre. The tyre has a series of reinforcing cords or belts that extend from bead to bead transversely over the tyre.

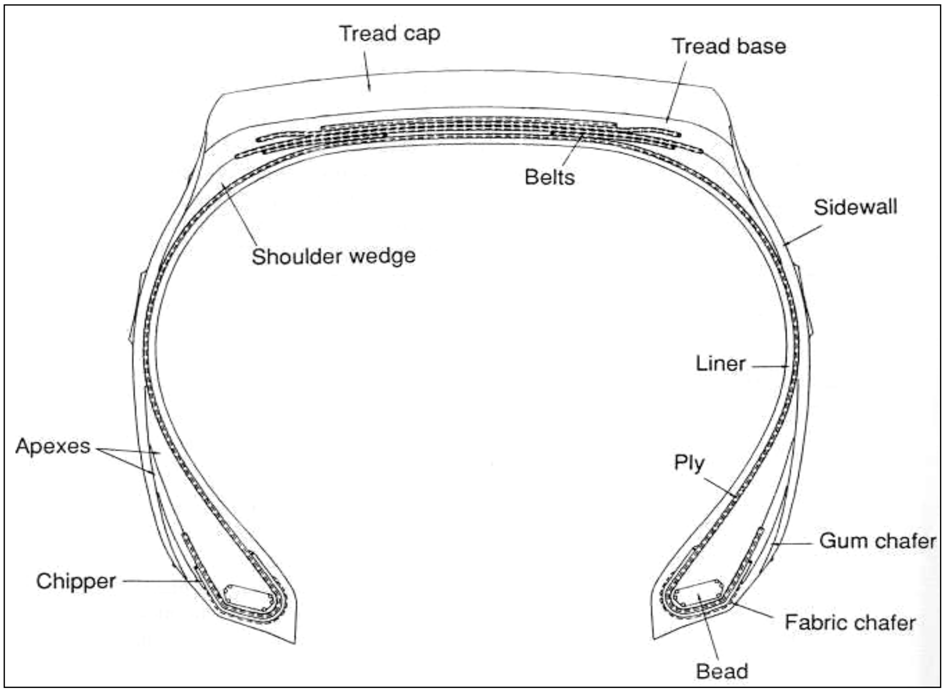


Figure 2.5: Schematic diagram of a typical truck tyre cross-section (*Mujibur, **2004***)

The belts are made of nylon fabric or steel but more commonly both types are used. The rubber treads then cover the belts providing the contact area for the tyre on the pavement. The objective of the skeleton is to reinforce the tyre to allow it to perform well without excessively deforming. Tyre construction is a complex process of compounding to combine the elastomer (rubber), process the steel and fabric with the rubber, extrude the treads, sidewalls and then cure the tyre under heat and pressure. The inherent characteristics of tyres are the same worldwide. They include the resistance to mould, mildew, heat and humidity, retardation of bacterial development, resistance to sunlight, ultra-violet rays, some oils, many solvents, acids and other chemicals. Other physical characteristics include their non-bio-degradability, non-toxicity, weight, shape and elasticity. However, many of the characteristics, which are beneficial during their on-road life as consumer products, are disadvantageous in their post-consumer life and can create problems for collection, storage and/or disposal. Modern tyres have extremely high load bearing capacity up to fifty times of its own weight. The compressed air within the tyre carries 90% of the load. The complex structure of the shell or casing of the tyre is designed to carry the remaining 10%.

2.4.2 Composition

The composition of tyres consists of four main ingredients: rubber, carbon black, metal and textiles. The remaining materials are additives, which facilitate compounding, and vulcanisation. Table 2-2 is a summarised version of general tyre composition in cars and truck tyres in the EU (Shulman, 2000).

In general, tyres are composed of natural and synthetic rubber. The proportion varies according to the size and use of the tyre. The generally accepted rule of thumb is that the larger the tyre and the more rugged its intended use, the greater will be the ratio of natural to synthetic rubber.

The second most important component of a tyre is carbon black. This is not a generic product, which means that wide ranges of specific grades of carbon black are used depending upon the compounding formula used by the individual manufacturer. Carbon black is mainly used to enhance rigidity in tyre treads to improve traction, control abrasion and reduce aquaplaning; in sidewalls to add flexibility and to reduce heat build up (HBU) (Shulman, 2000). The particle size of the carbon black, as defined by its specific surface area and structure, impacts upon its integration and utilisation in compounding.

The third largest component is steel, mainly high grade steel. This provides rigidity, and strength as well as flexibility to the casing. New, higher strength metals are being tested by tyre manufacturers, some which are said to resist rusting as well as deterioration, which could impact upon the way that the tyre is recycled.

The most common traditional textiles used in rubber are nylon, rayon and polyester. In recent years, a range of new textiles, primarily amarid, which is an ultra-light weight material, have been substituted for more traditional materials, primarily in the more expensive tyres.

Table 2.2: Comparison of Passenger Car and Truck Tyres in the EU (Shulman, 2000)

Material	**Car**	**Truck**
Rubber/Elastomers	48%	45%
Carbon Black	22%	22%
Metal	15%	25%
Textile	5%	--
Zinc oxide	1%	2%
Sulphur	1%	1%
Additives	8%	5%

2.4.3 Recycling

The life cycle of a consumer product is defined as the time span of the product serving the purpose for which it was created. The life span for a tyre is approximately 5-7 years during which time a tyre can be retreaded. It comprises three principal periods: new, continued use (continued chain of utility), and consignment to a waste treatment system (end of tyre life). A post consumer tyre, which may or may not have a structurally sound casing or residual tread depth suitable for further road use, will be discarded and/or consigned to another use, such as scrap tyres in road construction. The brief life cycle of a tyre is shown in Figure (2.6).

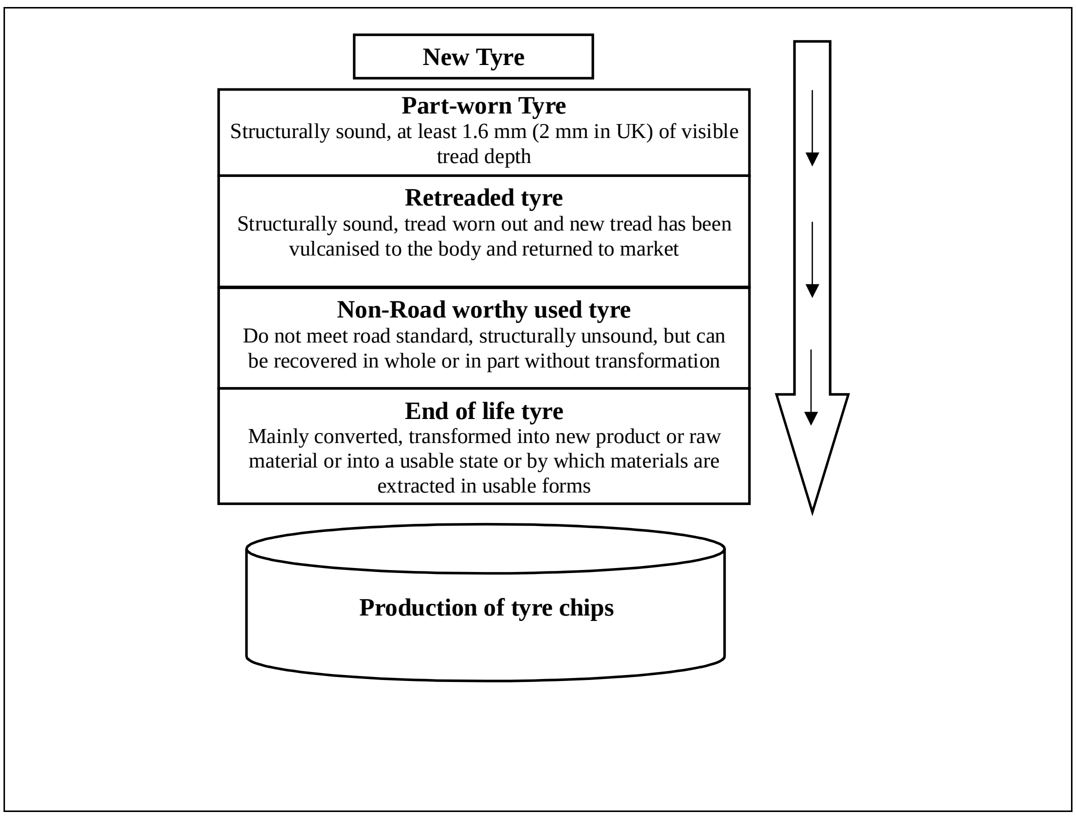


Figure 2.6: Flow Chart of Service Life of a Tyre (Shulman, 2000).

Once the tyre is permanently removed from a vehicle, it is defined as waste (scrap tyre). A scrap tyre can be useable in different forms, such as a whole tyre, a slit tyre, a shredded or chipped tyre, as ground rubber or as a crumb rubber product. In the following paragraphs a brief description of the use of scrap tyres will be outlined.

2.4.3.1 Whole Tyre

Typical weights of scrapped automobile (car and truck/bus) tyres are presented in the Table 2.3 including amount of recoverable rubber and percentage of natural and synthetic rubber. Although the majority of truck tyres are steel-belted radial, there are still a number of bias ply truck tyres, which contain either nylon or polyester belt material. Scrap tyres have a heating value ranging from 28000kJ/kg to35000 kJ/kg, which is the same as coal, and therefore, have been widely used as a cement-making fuel worldwide for the last ten years (Shulman, 2000).

2.4.3.2 Slit Tyres

Slit tyres are produced in tyre cutting machines. These cutting machines can slit the tyre into two halves or can separate the sidewalls from the tread of the tyre.

Table 2.3: Comparisons of Car and Truck Tyres

Type of tyre	**Weight (kg)**	**Recoverable rubber (kg)**	**% Rubber**
Passenger car	9.1	5.4-5.9	35% natural, 65% synthetic
Truck	18.2	10-12.5	65% natural, 35% synthetic

2.4.3.3 Shredded or Chipped Tyres

In most cases the production of tyre shreds or tyre chips involves primary and secondary shredding. When the tyres are disposed, they can be used whole and/or as chips for different applications.

2.4.3.4 Ground Rubber

Ground rubber particles are intermediate in size between tyre chips and crumb rubber. The particle sizing of ground rubber ranges from 9.5 mm to 0.85 mm.

2.4.3.5 Crumb Rubber

Crumb rubber used in hot mix asphalt normally has 100 percent of the particles finer than 4.75 mm. The majority of the particle sizes range within 1.2 mm to 0.42 mm. Some crumb rubber particles may be as fine as 0.075 mm. The specific gravity of the crumb rubber varies from 1.10 to 1.20 (depending on the type of production) and the product must be free from any fabric, wire and/or other contaminants (Heitzman, 1992., Schnormeier, 1992).

Figure 2.7: Crumb Rubber Particles

2.4.3.5.a Crumb Rubber Modified Bitumen

Scrap tyre rubber can be incorporated into asphalt paving mixtures using two different methods, which are referred to as the wet process and the dry process (Heitzman, 1991). In the wet process, crumb rubber acts as an asphalt binder modifier, while in the dry process, granulated ground rubber and/or crumb rubber is used as a portion of the coarse and/or fine aggregate. The dry process is normally used only with hot bituminous mixtures, whereas the wet process has been applied in crack sealants, surface treatments and hot bituminous mixtures. Historically rubber in asphalt mixtures has been used to improve the elasticity of the binders and mixtures. However, the application of rubber into asphalt mixtures requires careful consideration as rubber reacts with bitumen at high temperatures, consequently changing the performance of the mixtures (Singleton, 2000, Heitzman, 1991). Therefore, it is important to understand the interaction process of rubber in solvents.

*** Wet Process**

The wet process was first developed by Charles H. McDonald (McDonald, 1981) and refers to the modification of bitumen with 5-25% by mass of fine tyre crumb at an elevated temperature. The wet process includes the blending of crumb rubber with bitumen at high temperatures and produces a viscous fluid through rubber-bitumen interaction (Takallou, 1988). The interaction process depends on a number of variables, such as blending temperature, blending time, type and amount of mechanical mixing, crumb rubber type, size and specific surface area of the crumb rubber and the type of bitumen. During the interaction process, the aromatic fraction of the bitumen is absorbed into the polymer network of the natural and synthetic rubber (Heitzman, 1991).

**** Dry Process**

The process was first developed in Sweden in the 1960s and widely known in Europe under the name “Rubit”. It was then patented in the USA under the name “PlusRide” in 1978 (Heitzman, 1991). In this process, the crumb rubber is added to aggregate in a hot mix central plant operation before adding bitumen. The basis of the dry process is to use the crumb rubber to replace a percentage of aggregate and modify the grading. During the production to laying stage some reaction is known to take place depending on the gradation of the crumb rubber (Buncher, 1994). However, evidence from work carried out by Green and Tolonen (1977) has shown that the degree of reaction is also affected by the time the mixture is held at the mixing temperature, the proportion of rubber to bitumen and the type of bitumen. As the reaction time is much shorter and the grading size of crumb rubber is larger with less specific surface area, it was deemed unimportant to the properties of the material compared to the wet process (Takallou, 1988). However, recent research at University of Nottingham (Singleton, 2000) demonstrated that the interaction of rubber-bitumen makes the bitumen stiffer and more elastic and, consequently, changes the properties of the asphalt mixture.

- **Asphalt Rubber:** is used as a binder in various types of flexible pavement construction including surface treatments and hot mixes. According to the ASTM definition (ASTM 2001) asphalt rubber is “a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles”. By definition, asphalt rubber is prepared using the “wet process”.

2.4.3.6 Characteristics of Rubber

2.4.3.6.a Shredded Tyres

The shreds are basically flat, irregularly shaped tyre chunks with jagged edges that may or may not contain protruding sharp pieces of metal, which are parts of the steel plates or beads. The size of the tyre shreds may range from as large as 460 mm to as small as 25 mm, with most particles within the 100 mm to 200 mm range. The average loose density of the tyre shreds varies according to the size of the shreds, but can be expected to be between 390 kg/m^3 to 535 kg/m^3. The average compacted density ranges from 650 kg/m^3 to840 kg/m^3 (Shulman, 2000). They are non-reactive under normal environmental conditions (Mujibur Rahman**,** 2004).

2.4.3.6.b Tyre Chips

Tyre chips are finer and more uniformly sized than tyre shreds, ranging from 76 mm down to approximately 13 mm in size. Although the size of tyre chips, like tyre shreds, varies with the make and condition of the processing equipment, nearly all tyre chip particles can be gravel sized. The loose density of tyre chips can be expected to range from 320kg/m^3 to 490 kg/m^3. The compacted density of the tyre chips ranges from 570 kg/m^3 to 730 kg/m^3 (Bosscher *et al*, 1992). The chips have absorption values that range from 2.0 to 3.8 percent and are non-reactive under normal environmental conditions (Mujibur Rahman**,** 2004).The shear strength of tyre chips varies according to the size and shape of the chips with friction angles in the range of 19^o to 26^o, while cohesion values range from 4.3 kPa to 11.5 kPa. Tyre chips have permeability co-efficients ranging from 1.5 to 15 cm/sec (Mujibur Rahman**,** 2004).

2.5 Aggregate

The amount of mineral aggregates in asphalt mixtures is generally 90 to 95 percent by weight and 75 to 85 percent by volume. Mineral aggregates are primarily responsible for the load supporting capacity of pavement accordingly, Asphalt pavements performance is heavily influenced by aggregate. Mineral aggregates have been defined as any hard, inert mineral material used for mixing in graduated particles or fragments. It includes sand, gravel, crushed stone, slag, rock dust or powder. (Asphalt Institute, 1989**)**

- **ASTM definition:** Aggregate granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, used with a cementing medium to form mortars or concrete, or alone as in base courses, railroad ballasts, etc.

- **Coarse Aggregate** predominantly retained on the 4.75-mm (No. 4) sieve or that portion of an aggregate retained on the 4.75-mm (No. 4) sieve.

- **Fine Aggregate** passing the 3⁄8-in. (9.5-mm) sieve and almost entirely passing the 4.75-mm (No. 4) sieve and predominantly retained on the 75-µm (No. 200) sieve that portion of an aggregate passing the 4.75-mm (No. 4) sieve and retained on the 75-µm (No. 200) sieve.

2.5.1 Aggregate Properties

2.5.1.1 Strength

The aggregate to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel loads. the aggregates which are to be used in top layers of the pavements, particularly in the wearing course have to be capable of withstanding high stresses in addition to wear and tear ; hence they should posses sufficient strength and resistant to crushing .

2.5.1.2 Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. They should be hard enough to resist the wear due to abrasive action of traffic. Abrasive action may be increased due to the presence of abrasive material like sand between the tyres of the moving vehicles and the aggregates exposed at the top surface. This action may be sereve in the case of steel tyred vehicles. Heavy wheel loads can also cause deformations on some types of pavement resulting in relative movement of aggregates and rubbing of aggregates with each other within the pavement layer. The mutual rubbing of stones is called attrition, which also may cause a little wear in the aggregates; however attrition will be negligible or absent in most of the pavement layers.

2.5.1.3 Toughness

Aggregates in the pavement are also subjected to impact due to moving wheel loads. Severe impact like hammering is quite common when heavily loaded steel tyred vehicles move on water bound macadam roads where stones protrude out especially after the monsoons. Jumping of the steel tyred wheels from one stone to another at different levels causes severe impact on the stones. The magnitude of impact would increase with the roughness of the load surface, the speed of the vehicle and other vehicular characteristic. The resistance to impact of toughness is hence another desirable property of aggregates.

2.5.1.4 Durability

The stone used in pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may be called soundness. The aggregates are subjected to the physical and chemical action of rain and ground water, the impurities there-in and that of atmosphere. Hence it is desirable that the road stones in the construction should be sound enough to withstand the weathering action.

2.5.1.5 Shape of Aggregates

The size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass, and not by the shape. Aggregates which happen to fall in a particular size range may have rounded cubical, angular flaky or elongated shape of particles. It is evident that the flaky and elongated particles will have less strength and durability when compare with cubical, angular are rounded particles of the same stone. Hence too flaky and too much elongated aggregates should be avoided as far as possible. Rounded aggregates may be preferred in cement concrete mix due to low specific surface area and better workability for the same proportion of cement paste and same water-cement ratio, whereas rounded particle are not preferred in granular base course, WBM construction and bituminous construction as he stability due to interlocking of rounded particles is less. In such constructions angular particles are preferred. The voids present in a compacted mix of coarse aggregates depends on the shape factors, highly angular, flaky and elongated aggregates have more voids in comparison with rounded aggregates.

2.5.2 Aggregate Tests

The essential features of these tests are discussed below. Separates tests are available for testing cylindrical stone specimens and coarse aggregates for crushing abrasion and impact tests. But due to the difficulties of preparing cylindrical stone specimen which need costly core drilling, cutting and polishing equipment, the use of such tests are now limited testing of aggregates is easy and stimulate the field condition better, as such these are general preferred.

2.5.2.1 Aggregate Crushing Test

The strength of coarse aggregate may be assessed by aggregate crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement aggregates possessing high resistance to crushing or low aggregate crushing value are preferred. The apparatus for the standard test consists of a steel cylinder 15.5 cm diameter with a base plate and a plunger, compression testing machine, cylindrical measure of diameter 11.5 cm and height 18 cm, tamping rod and sieves.

2.5.2.2 Los Angeles Abrasion Test According to ASTM C131-81

The principle of Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregate and steel balls used as abrasive charge. Pounding action of these balls also exists during the test and hence the resistance to wear and impact is evaluated by this test. The Los Angeles machine consist of a hallow cylinder closed at both ends, having inside diameter 70 cm and length 50 cm and mounted so as to rotate about its horizontal axis. The abrasive charge consists of cast iron spheres of approximate diameter 4.8 cm and each of weight 390 to 445 g. the number of spheres to be used as abrasive charge and their total weigh have been specified based on grading of the aggregate sample.

2.5.2.3 Impact Test

A test designed to evaluate the toughness of stones or the resistance of the aggregates to fracture under repeated impacts is call impact test. The aggregate impact test is commonly carried out to evaluate the resistance to impact of aggregates. The aggregate impact value indicates a relative measure of resistance of aggregate to impact, which has a different effect than the resistance to gradually increasing compressive stress. The aggregate impact testing machine consists of a metal base and a cylindrical steel cup of internal diameter 10.2 cm and depth 5 cm in which the aggregate specimen is placed. A metal hammer of weight of 13.5-14 kg having a free fall from a height 38 cm is arranged to drop through vertical guides.

2.5.2.4 Shape Test According to BS 812

The particles shape of aggregate mass is determined by the percentage of flaky and elongated particles contained in it and by its angularity. The evaluation of shape of the particles made in terms of flakiness index, elongation index and angularity number.

2.5.2.5 Specific Gravity and Water Absorption Test According to ASTM C127-88

The specific gravity of an aggregate is considered to a measure of the quality or strength of the material. Stones having low specific gravity value generally weaker than those having higher values. The specific gravity test also helps identifying the stone specimens.

Stones having higher water absorption value are porous and thus weak. They are generally unsuitable unless found acceptable based on crushing and hardness test.

The specific gravity of an aggregate is the ratio of the weight of a unit volume of material to the weight of the same volume of water 20to25˚C. there are three generally types of specific gravities for aggregate ,depending on the defined volume of the particle. They are:

1. Apparent Specific gravity
2. Bulk Specific gravity
3. Effective Specific gravity

2.6 Hot Mixes Asphalt (HMA) & Asphalt Rubber Hot Mix (ARHM)

2.6.1 Hot-Mix Asphalt (HMA) Definition

Hot mix asphalt materials consist of a combination of aggregate that are uniformly mixed and coated with asphalt cement. To dry the aggregates and obtain sufficient fluidity of the asphalt cement for proper mixing and workability , both must be heated prior to mixing – giving origin to term" hot-mix." (Asphalt Institute, 1995)

2.6.2 Requirements of Bituminous Mixes

The mix design should aim at an economical blend, with proper gradation of aggregates and adequate proportion of bitumen so as to fulfil the desired properties of the mix. bituminous concrete or asphaltic concrete is one of the highest and costliest types of flexible pavement layers used in the surfacing course .the desirable properties of a good bituminous mix are ,Stability, Durability, Flexibility, Skid resistance ,and Workability (Khanna and Justo, 1990).

2.6.2.1 Stability

Is the ability of asphalt paving mixture to resist deformation from imposed loads unstable pavements are marked by channeling (ruts), and corrugations (wash boarding). Stability is dependent upon both internal friction and cohesion. Internal friction is dependent on surface texture, gradation of aggregate, particle shape, density of mix and quantity and type of asphalt, cohesion is the internal binding force that is inherent in the asphalt paving mixture. The asphalt serves to maintain contact points developed between aggregate particles, cohesion increase with increasing asphalt content up to optimum point and then decreases (Asphalt Institute, 1989).

2.6.2.2 Durability

It is the property of asphalt paving mixture that describes its ability to resist the detrimental effects of air, water, temperature and traffic. Included under weathering are changes in characteristics of asphalt, such as oxidation and volatilization, and changes in the pavement and aggregate due to the action of water, including freezing and thawing. Durability is generally enhanced by high asphalt contents, dense aggregate gradations, and well compacted, impervious mixtures (Asphalt Institute, 1995).

2. 6. 2.3 Flexibility

Is the ability of asphalt paving mixture to be able to blend slightly, without cracking, and to conform to gradual settlements and movements of the base and subgrade. Generally, Flexibility of the asphalt paving mixture is enhanced by high asphalt contents and relatively open graded aggregates (Asphalt Institute, 1989).

2.6.2.4 Skid Resistance

It is 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. (Asphalt Institute, 1989)

2.6.2.5 Workability

It's the ease with which the mix can de laid and compacted. It is function of gradation of aggregates, their shape and texture, bitumen content and its type (Khanna and Justo, 1990).

2.6.3 Bituminous Mixes Design Methods

2.6.3.1 Hveem Method of Bituminous Mix Design

The concept of the Hveem method of designing paving mixtures have been advanced and developed under the direction of francis N. Hveem , formerly Materials and research engineer for the California Department of transportation .the test procedures and their application were developed through extensive research and correlation studies on asphalt highway pavements (Asphalt Institute, 1989).

2.6.3.2 Modified Habbard-Field of Bituminous Mix Design

This method was developed by P. Habbard and F.C. Field. The original method was

Intended to design sheet asphalt mix, Later the method was modified for the design of bituminous mixes having coarse aggregate up to 19mm size (Khanna and Justo, 1990).

2.6.3.3 Superpave Method of Bituminous Mix Design

Superpave it is the product of the Strategic Highway Research Program (SHRP) this research effort led to new system for design hot mix asphalt upon mechanistic concepts. The Superpave has been fully implemented by most of the state highway agencies. Superpave is an acronym for Superior Performing Asphalt Pavements. The Superpave system accounts for materials characteristics in light of climatic and traffic considerations (AI, 2001, 1996, 1997). Perhaps the most significant component of Superpave it is new asphalt binder grading system. This is designed to link with pavement Performance .the Superpave methodology is believed to be the best available at this time. However, it is an evolving methodology, and as such there are various asphalt characteristics routines that are under consideration as future additions To the Superpave (Witczak, *et al.* 2002)

2.6.3.4 Marshall Method of Bituminous Mix Design

The concepts of the Marshall Method of designing paving mixtures were formulated by Bruce Marshall, formerly bituminous engineer with Mississippi State highway department. The U.S Corps of engineers, through extensive research and correlation studies, improved and added certain features to Marshall's test procedure, and ultimately developed mix design criteria. The Marshall Test procedure has been standardized by the American Society for Testing and material (ASTM) (Asphalt Institute, 1989).

There are two major features of the Marshal method of designing mixes namely,

- Density –voids analysis
- Stability –flow test

The stability of the mix is defined as a maximum load carried by compacted specimen at a standard test temperature of 60˚C. the flow is measured as the deformation in units of 0.25 mm between no load and maximum load carried by the specimen during stability test. The flow value may also be measured by deformation units of 0.1mm (Khanna and Justo, 1990).

Table 2.4: Marshall Mix Design Criteria **(**Asphalt Institute, 1997)

Mix Criteria	**Heavy Traffic ESALs (> 10^6)**	
	Min.	**Max.**
Compaction (number of blows on each end of the sample)	75	
Stability (minimum),kg	8006	-
Flow (0.25 mm)	8	14
Percent Air Voids	3	5
VMA%	Varies with aggregate size	

2.6.4 Bituminous Mixes Design Steps

The following steps may be followed for the a rational design of Bituminous Mixes

- Selection of aggregate grading
- Proportioning of aggregate

- Preparation of specimen
- Determination of specific gravity of compacted specimen
- Stability test on compacted specimen
- Selection of optimum bitumen content

2.6.4.1 Selection of Aggregate Grading

The properties of a bituminous mix including the density and stability are very much dependent on the aggregate and their grain size distribution. Most agencies and engineering organization have specified the use of densely mixes and they do not prefer the open grading. As higher maximum size of aggregate gives higher stability, usually the biggest size that can be adopted keeping in view of the compacted thickness of the layer is selected. The gradation of final mix after blending of the aggregates and filler should be within the specified range (Khanna and Justo, 1990).

2.6.4.2 Proportioning of Aggregate

Aggregates are proportioned either by analytical method, or graphical method, or by the trial and error basis from laboratory test (Khanna and Justo, 1990).

2.6.4.3 Preparation of Specimen

The Preparation of specimen depends on the stability test method employed. The Stability test methods which are in common use for the design mix are, Marshall, Hubbard-field and Hveem.

2.6.4.4 Determination of Specific Gravity of Compacted Specimen

The specific gravity of compacted specimen, as moulded was determined with known values of specific gravity of aggregate and bitumen (Khanna and Justo, 1990).

2.6.4.5 Stability Test on Compacted Specimen

One of Stability tests were carried out based on the design method selected (Khanna and Justo, 1990).

2.6.4.6 Selection of Optimum Bitumen Content

The optimum bitumen content was Selected based on the method adopted and design requirements considered (Khanna and Justo, 1990).

Chapter Three

Materials and Methods

3.1 General

This chapter explain the material supply, experimental investigations on rubber-bitumen homogenous and the laboratory tests performed to evaluate the bitumen properties, laboratory tests performed on coarse and fine aggregates, Crumb rubber properties and finally deals with Examination of Hot mixes asphalt (HMA) & asphalt rubber hot mix (ARHM)

3.2 Bitumen Material

Asphalt binder 60/70 was used in this research obtained from petrodalta Company for road and bridge. The laboratory tests performed to evaluate the bitumen properties were Specific Gravity, Ductility, Flash and fire Point and Penetration, Softening point

3.3 Aggregate Material

The coarse and fine aggregates used were crushed aggregate imported from Khartoum Company for road and bridge at Toria Mountain at Omdurman district .The filler used was obtained to supplement the fine materials size in hot mix asphalt (HMA) mixture design. The laboratory tests performed on coarse aggregates were: Los Angeles Abrasion (ASTM C131–81), Aggregate Impact Value, Aggregate Crushing Value, Sieve Analyses (ASTM C136-84), Specific Gravity and Water Absorption (ASTM C127–88), Fractured Faces of Aggregate and Angularity (BS 812) Flakiness and Elongation (BS 812). The tests for fine aggregates were: sieve Analyses (ASTM C117–87), Specific Gravity

(ASTM C128–88) and Water Absorption, while for filler the test was Specific Gravity and Atterberge limits.

3.4 Crumb Tire Rubber Material

The Crumb Tire Rubber used was imported from Sarco Company for road and bridge at Khartoum district. The laboratory tests performed to evaluate the Crumb rubber properties were Sieve Analyses (ASTM C136-84), Specific Gravity (ASTM C127–88)

3.5 Examination of Crumb Tire Rubber

The laboratory tests performed to evaluate the Crumb rubber properties were Sieve Analyses (ASTM C136-84) Water Absorption, Specific Gravity (ASTM C127–88)

3.5.1 Crumb Rubber Specific Gravity Test (ASTM C128 -88)

100g of Crumb Tire Rubber was placed in a bottle, then bottle was filled with water using a specified procedure and weighted, then the Crumb Tire Rubber was removed from the bottle and bottle was dried and weighted, finally the specific gravities were calculated

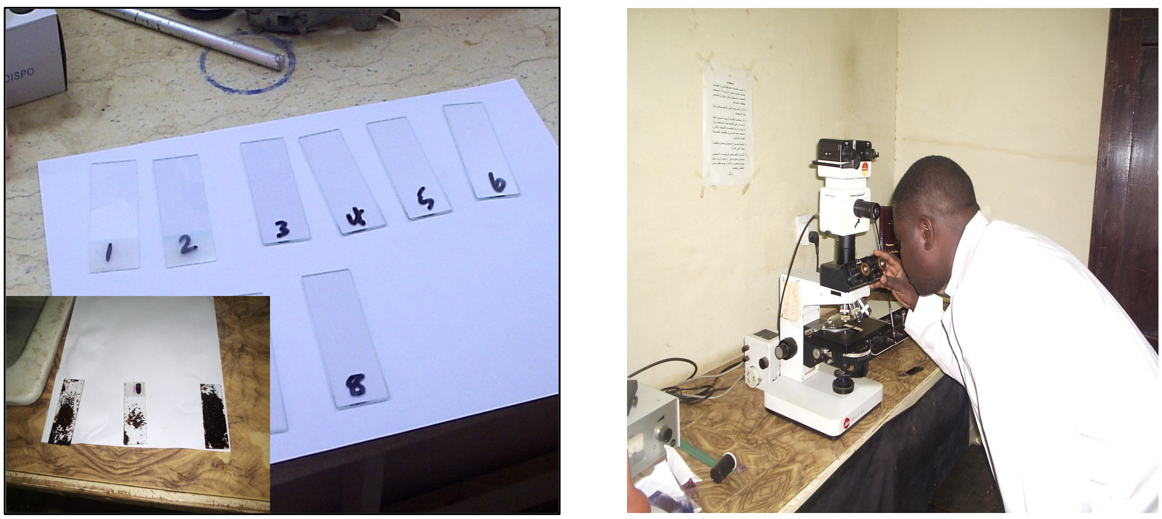
3.5.2 Sieve Analysis of Crumb Tire Rubber (ASTM C117 -87)

Samples for sieve analysis were prepared by a sample splitter, samples weight were determined after dried to constant weight, then was placed in a container and was immersed in water containing a wetting agent, contents of the container were agitated vigorously and wash water was poured over the nested sieves, operation was repeated wash water is clear .Material retained on the sieves was returned to the washed aggregate dried to a constant weight, material was weight with the loss in weight representing the amount of material finer than (No. 200) sieve ,weight before washing was the true weight for using as 100 percent

3.6 Examination of Bitumen and Asphalt Rubber

3.6.1 Microscopic Examination

To examine the homogeneity of rubber with bitumen were blended together at a temperature of 160˚C in thermostatic oven, and homogenized manually for 2hrs and 4hrs for 15% and 25% respectively, and then four smears were prepared, one after every 30 minutes from 15% and other one during each hour from25%, slides were examined microscopically using magnification lens of X10 and 40.



(a) Sample Preparation

(b) Sample under Microscope

Figure 3.1: Microscopic Examination

3.6.2 Penetration Test (ASTM -D5)

the bitumen was softened to pouring consistency stirred thoroughly and poured in iron containers to a depth at least 15 mm is excess of the expected penetration ,the sample containers were then placed in a temperature controlled water bath at temperature of 25˚C for one hour ,the sample with container was taken out and the needle is arranged to make contact with the surface of the sample ,the dial was set to zero or the initial reading is taken and the needle is released for 5 seconds the final reading is taken on dial gauge

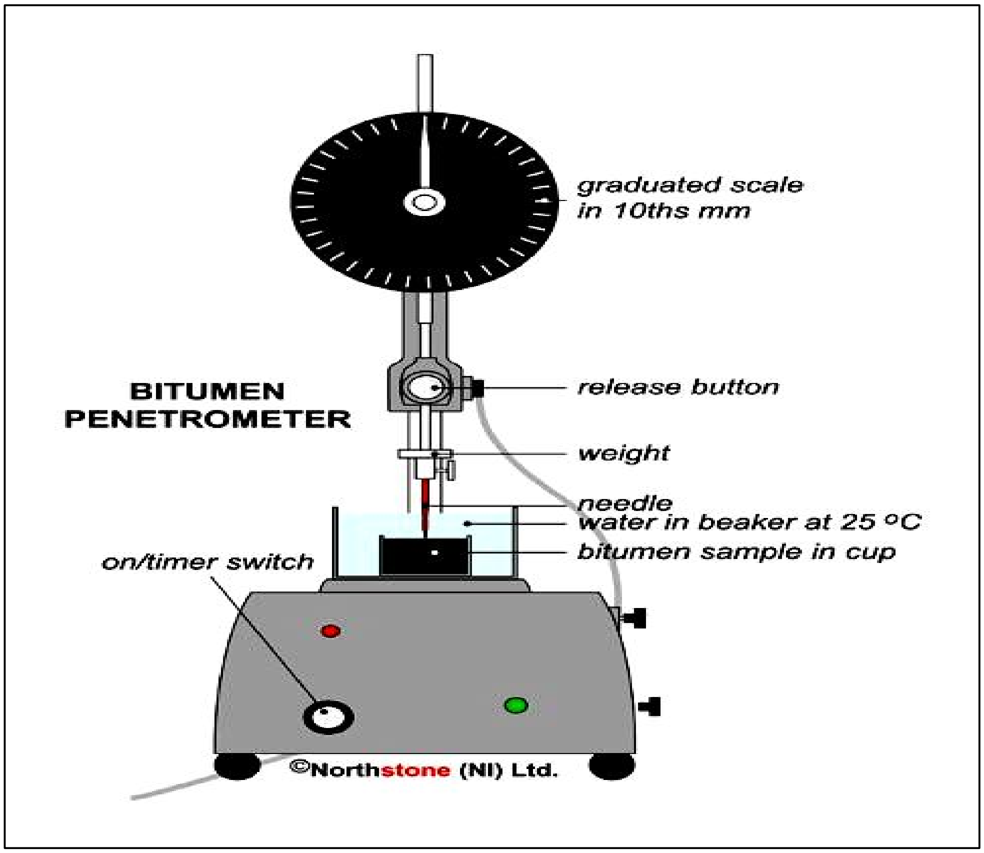


Figure 3.2: Penetrometer

3.6.3 Softening Point Test (Ring and Ball Method) (ASTM- D36)

A brass ring containing test sample of bitumen was suspended in water at 5˚C, steel ball was placed upon the bitumen sample and the water, then heated at a rate of 5˚C per minute the temperature at which the softened bitumen touches the metal placed at a specific distance below the ring is recorded as the softening point of bitumen

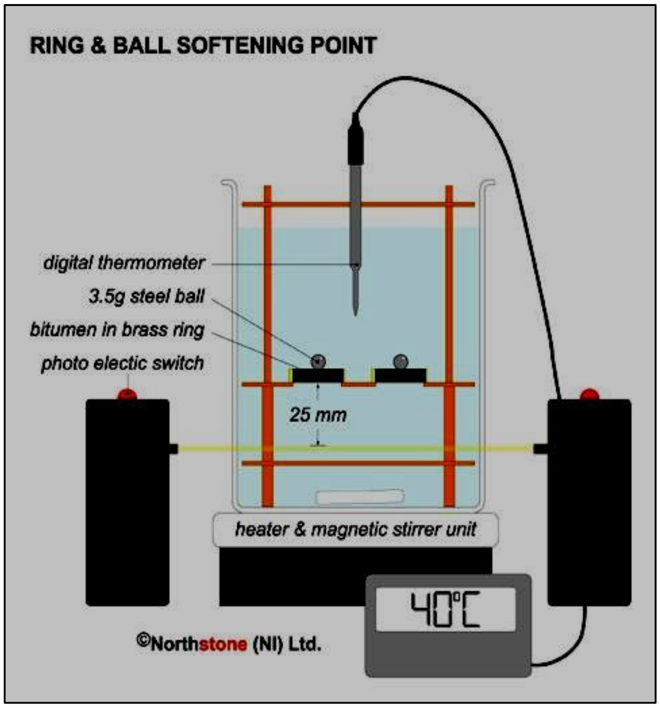
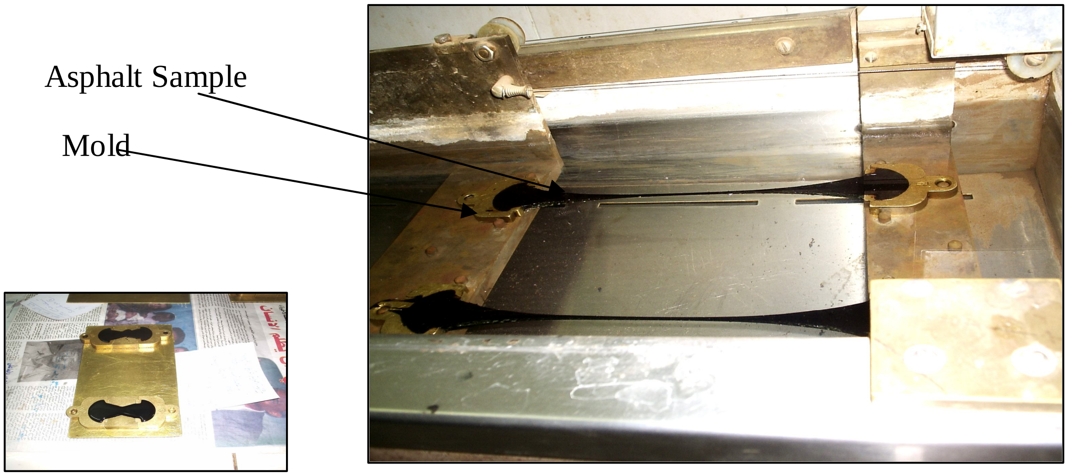


Figure 3.3: Ring and ball Softening Point Test

3.6.4 Ductility Test (ASTM- D113)

the bitumen sample was heated and poured in the mould assembly placed on a plate the samples along with moulds were cooled in air and then in water bath maintained at 25˚C the excess bitumen’s material was cut and the surface was leveled using a hot knife the mould assembly containing sample was replaced in water bath of the ductility testing machine for 85 to95 minutes the sides of the mould was removed the clips hooked on the machine and the

Pointer is adjusted to zero the distance up to the point of breaking of thread was reported in cm as ductility value



(a) Sample Preparation (b) Sample under Test

Figure 3.4: Ductility Test

3.6.5 Flash and Fire Point Test (ASTM- D92)

Open cup were used to conduct the test. The bitumen sample was filled in the cup up to a filling mark. The lid was placed to close the cup in closed system. All accessories including thermometer of the specified range are suitable fixed. The bitumen sample was then heated at arte of 5˚C to 6˚C per minute stirring the specimen. The test flame is applied at intervals depending upon the expected flash and fire points. The flash point was taken as the temperature read on the thermometer at the time of the flame application that causes a bright flash in the interior of the cup in a closed system. For open cup it is the instance when flash appear first at any point on the surface of the material, heating was continued until the material gets ignited and continues to-burn for 5 seconds; this temperature was recorded as the fire point

Figure 3.5: Cleveland Open Cup Flash Point

3.6.6 Specific Gravity Test (ASTM -D70)

The bitumen sample was heated and avoids incorporating air bubbles into the sample. Pour enough sample into the clean, dry, pycnometer to fill it about three fourths of its capacity. Allow the pycnometer and its contents was cooled to the ambient temperature for a period of not less than 40 min , weighted with the stopper to the nearest, mass of the pycnometer plus sample were designed to C ,then Removed the beaker from the water bath. Then filled the pycnometer containing the asphalt in water bath and placed the stopper loosely in the pycnometer**.** Allow the pycnometer to remain in the water bath for a period of not less than 30 minutes then removed the pycnometer from the bath and designated this mass of pycnometer plus sample plus water as D. then specific gravity value was calculated as following

$$\frac{C-A}{(B-A)-(D-C)} \text{ --- } (3.1)$$

Where:-

C : Wt. of Pycnometer + asphalt

A : Wt. of Pycnometer

D : Wt. of Pycnometer + water + asphalt

B : Wt. of Pycnometer fille with water

3.7 Aggregate Tests

3.7.1 Los Angeles Abrasion Test (ASTM C131 -81)

Specific weight of Aggregate specimen (5 to10 kg. depending on gradation) was placed in machine along with abrasive change. The machine was rotated at a speed of 30 to 33 rpm for the specific number of revaluations (500 to 1000 depending on gradation of the specimen). Then the abraded aggregate was sieved on 1.7mm sieve, and the weight of powdered aggregate passing this sieve was found.

The result of abrasion test was expressed as the percentage wear or the percentage passing 1.7 mm sieve expressed in terms of the original weight of the sample

Figure 3.6: Los Angeles Machine

3.7.2 Aggregate Crushing Test

Dry aggregate was passed 12.5mm sieve and retained on 10mm sieve, then was filled in cylindrical measure in three equal layers; each layer was tamped 25 times by the tamper. The test sample was weighed and given the name **(W_1 g),** placed in the test cylinder in three equal layers, tamping each layer 25 times. The plunger was placed on the specimen and a load of 40 tons was applied at a rate of 4 ton per minute by the compression machine. The crushed aggregate were removed and sieved on 2.36mm sieve; the crushed material which passes this were weighted and named **(W_2 g).** The aggregate crushing value was calculated as following

$$\frac{W_2}{W_1} * 100\% \quad \text{---} \quad (3.2)$$

Figure 3.7: ACV apparatus & Aggregate Crushing Test Machine

3.7.3 Aggregate Impact Test

Aggregate specimen was passing 12.5mm sieve and retained on 10mm sieve was filled in the cylindrical measure in 3 layers by tamping, each layer by 25 blows .the sample was transferred from the measure to the cup of the aggregate impact testing machine and compacted by tamping 25 times The hammer was raised to a height of 38cm above the upper surface of the aggregate in the cup and was allowed to fall freely on the specimen, after subjecting the test specimen to 15 blows ,the crushed aggregate was sieved on 2.36mm sieve .the aggregate impact value was expressed as a percentage of the fine formed in terms of the total weight of the specimen

Figure 3.8: Aggregate Impact Test Machine

3.7.4 Specific Gravity and Water Absorption Tests

3.7.4.1 Specific Gravity and Water Absorption for Coarse Aggregate (ASTM C127 - 88)

About 5 kg of thoroughly washed aggregate was retained on a 4.75 mm (No.4) sieve and oven –dried in an oven for 24 hours at 100-110˚C to constant weight, dried sample was immersed in water for 24 hours, then sample was removed from the water and surface dried, the weight of sample in surface- dry condition was obtained then The saturated surface- dry sample was placed in wire basket and its submerged weight in water was determined then the oven-dried sample was weighted and recorded finally the specific gravities were calculated as following

$$G_{sa} = \frac{A}{A-C} \quad \text{-----} \quad (3.3)$$

$$G_{sb} = \frac{A}{B-C} \quad \text{-----} \quad (3.4)$$

$$Absorption = \frac{(B-A)*100\%}{A} \quad \text{-----} \quad (3.5)$$

Where:-

G_{sa} : Apparent Specific gravity

G_{sb}: Bulk Specific gravity

A: Oven-dried weight of aggregate, g

B : Saturated surface-dry of aggregate, g

C: Submerged weight of aggregate in water, g

3.7.4.2 Specific Gravity and Water Absorption for Fine Aggregate (ASTM C128 -88)

About 1000 g of fine aggregate was passed the 4.75 mm (No.4) sieve and oven –dried in an oven for 24 hours at 100-110˚ C to constant weight, then the material was immersed in water for 24 hours. The saturated surface-dry condition was reached when the material slumps when an inverted cone is removed of material was lightly compacted, the 500g sample of the material in the saturated surface-dry condition was placed in a flask, then flask was filled with water using a specified procedure and weighted, then the fine aggregate was removed from the flask and was oven –dried to constant weight, and then weighted, finally the specific gravities were calculated as following

$$Gsa = \frac{A}{A + B - C} \text{ -------------------- } (3.6)$$

$$Gsb = \frac{A}{B + 500 - C} \text{ -------------------- } (3.7)$$

$$Absorption = \frac{(500 - A) * 100\%}{A} \text{ -------------------- } (3.8)$$

Where Gsa = apparent Specific gravity

Gsb = bulk Specific gravity

A= weight of oven-dry sample, g

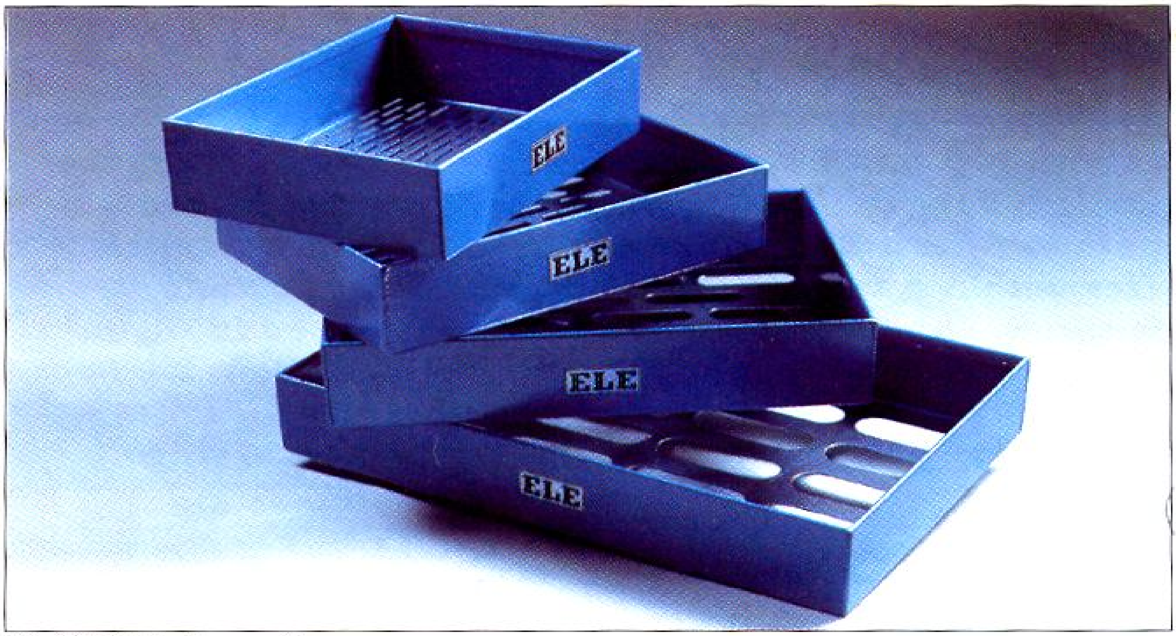
B= weight of flask filled with water, g

C= weight of flask with specimen and water to calibration mark,

3.7.5 Flakiness Index (BS 812)

The sample of aggregate was sieved through asset of sieves and separated into (20-14, 14 -10 and 10- 6.3mm) sieves size ranges, and the flaky material passing the appropriates slot from each size range of test aggregate were added up and let this weight as **w** and let the total weight of sample taken from different size ranges as **W**, the flakiness index was calculated as

$$\frac{w}{W} * 100\ \% \text{ -------------------- } (3.9)$$



BS 812 Flakiness Sieves

Figure 3.9: Flakiness Sieves

3.7.6 Elongation Index (BS 812)

The sample of aggregate was sieved through asset of sieve and separated into (20-14, 14 - 10 and 10- 6.3mm) sieves ranges, the aggregate from each of the size range was then individually passed through the appropriate gauge of the length gauge with the longest side in order to separate the elongated particles ,the portion of the elongated aggregate having length greater than the specified gauge from each size range was weighed and the total weight of the elongated stones was expressed as a percentage of the total weight of the sample ,to get the elongation index

Figure 3.10: Length Gauge

3.7.7 Sieve Analysis (ASTM C117 -87)

Sample for sieve analysis were prepared by a sample splitter, sample weights were determined after dried to constant weight, then was placed in a container and was immersed in water containing a wetting agent, contents of the container were agitated vigorously and wash water was poured over the nested sieves, operation was repeated wash water is clear .material retained on the sieves was returned to the washed aggregate dried to a constant weight, material was weight with the loss in weight representing the amount of material finer than (No. 200) sieve ,weight before washing was the true weight for using as 100 percent

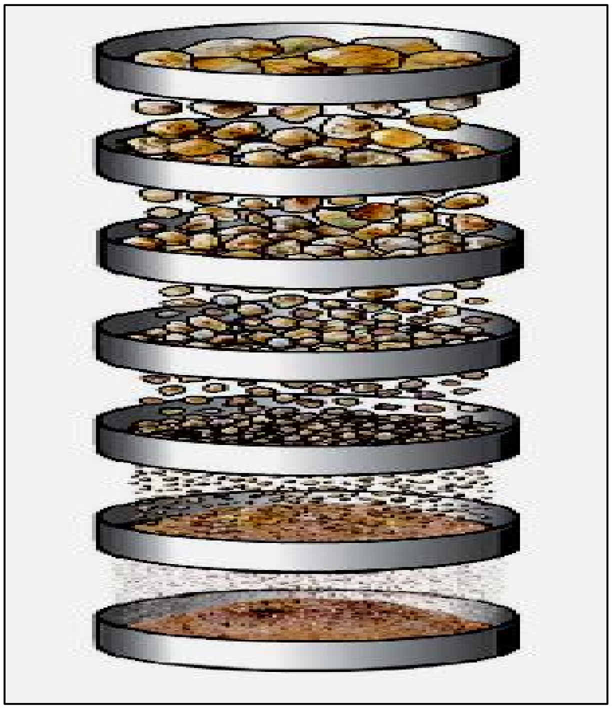


Figure 3.11: Sieve Analysis Test

3.8 Examination of Hot Mixes Asphalt (HMA) & Asphalt Rubber Hot Mix (ARHM)

3.8.1 Proportioning of Aggregates and Selection of Aggregate Grading

Ministry of Urban Planning & Public Utilities of Khartoum new modified technical specifications (2003) were used to define the mix gradation limits. Several trials were made to combine the coarse, medium and fine hot bin samples to obtain an all-in combined grading satisfying the specification, gradation limits as well as providing the appropriate mix properties,The performance of an asphalt mixture is based on the determination of the correct proportion of aggregate and asphalt and air, which are measured by volume.

Table 3.1: Aggregate Gradations for all Test Series (Proposed mix gradation)

Sieve (mm)	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Sieve in (inch)	1"	3/4	1/2	3/8	No4	No8	No16	No30	No50	No100	No200
Minimum Limits	100	95	75	65	48	38	28	20	13	8	4
Used gradation	100	99.6	79.4	74.9	58.9	46.9	35.9	26.2	17.2	10.6	7.5
Maximum Limits	100	100	90	85	70	54	44	34	25	18	10

Table 3.2: Proportion of Aggregate

Sieve	**19**	**9.5**	**4.75**	**Sand**	**Filler**	**design**	**Specify**	**Max**	**Min**
%by mass	**26**	**24**	**30**	**15**	**5**		**100**		
sieve									
25	26.0	24.0	30.0	15.0	5.0	100.0	100	100	100
19	25.6	24.0	30.0	15.0	5.0	99.6	97.5	100	95
12.5	5.4	24.0	30.0	15.0	5.0	79.4	82.5	90	75
9.5	0.9	24.0	30.0	15.0	5.0	74.9	75	85	65
4.75	0.2	8.7	30.0	15.0	5.0	58.9	59	70	48
2.36	0.2	4.8	22.7	14.1	5.0	46.9	46	54	38
1.18	0.2	2.8	15.4	12.5	5.0	35.9	36	44	28
0.6	0.2	1.6	9.7	9.7	5.0	26.2	27	34	20
0.3	0.2	0.8	6.0	5.2	5.0	17.2	19	25	13
0.15	0.2	0.3	3.6	1.4	4.9	10.6	13	18	8
0.075	0.2	0.2	2.2	0.6	4.2	7.5	7	10	4

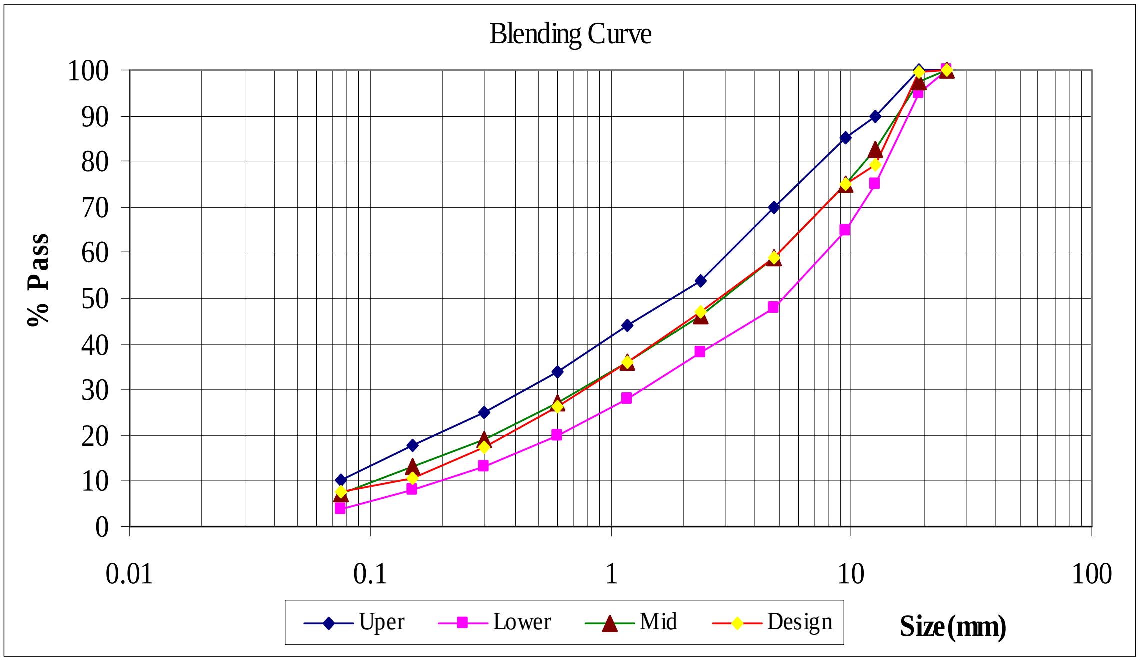


Figure 3.12: Aggregate Gradations for all Test Series (Upper, lower, mid and design Limits)

3.8.2 Sample Preparation, Compaction and Testing

Approximately 1200g of mixed aggregate and filler were taken and heated to a temperature of 150- 150ºC. Then the bitumen and asphalt rubber was heated to a temperature of 121 to 145. Percentage of 4.0%, 4.5%, 5.0%, 5.5% and 6.0% by weight of mineral aggregate was added to the heated aggregate and thoroughly mixed at the desired temperature of 150-155 ºC; the mix was placed in a preheated mould and compacted by a hammer with 75 blows (heavy traffic) in both sides at temperature of 150-155 ºC. Three specimens were prepared using each trial bitumen content. The compacted specimens was cooled to room temperature in the mould for 24hrs and then removed from the mould using specimen extractor, then weighted in air and suspended in water to subject to a density-voids analysis. The specimen was kept immersed in water in thermostatically controlled water bath at 60± 1 for 30-40 mints. The specimens were delivered to marshal test machine one by one to determine their stability and flow value. The corrected

Marshall Stability value of each specimen was determined by applying the appropriate correction factor. Crumb rubber content of 15, 20, and 25 % by weight of bitumen were used for all tested asphalt rubber hot mix specimens, Then the bulk density, percent air voids, voids in mineral aggregates and voids filled with bitumen are calculated, the average values of each of these properties are found for each mix with the different bitumen contents. All properties of Hot Mix Asphalt and Asphalt Rubber Hot Mix were Plotted graphically verses bitumen content on Y-axis and X-axis respectively

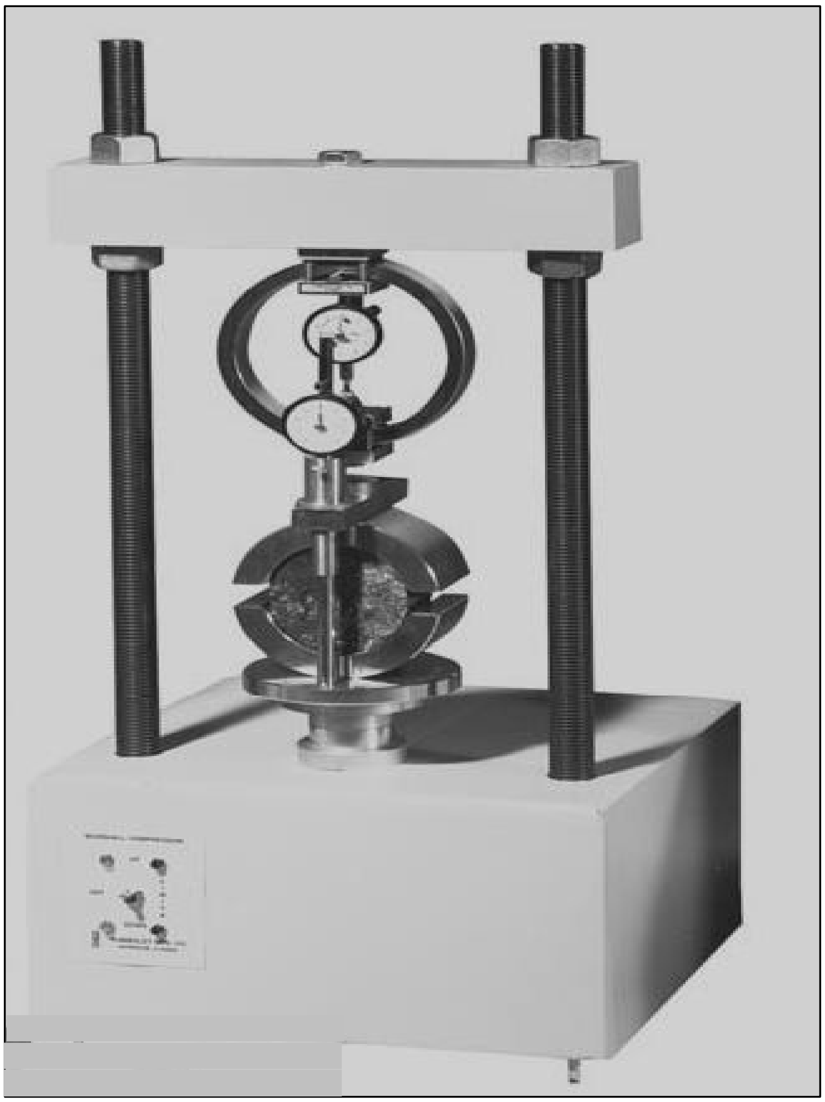


Figure 3.13: Marshall Machine

3.8.3 Determination of Optimum Bitumen Content

Optimum bitumen content for all mixtures was found by taking the average value of Bitumen content corresponding to maximum stability, maximum unit weight and (4%) median limits of percent air voids in total mix then the Marshall properties at optimum bitumen content for all mixture were checked with the Marshall Mix design criteria (see table 2.3)

Chapter Four

Results of the Experimental Works

4.1 General

This chapter explains the details of results of experimental works which deals with modified bitumen morphology, bitumen and modified bitumen physical properties results and hot mixtures design data and analysis.

4.2 Crumb Rubber Test Results

The laboratory tests performed to evaluate the Crumb rubber properties were Sieve Analyses (ASTM C136-84), Specific Gravity (ASTM C127–88)

Table 4.1: Crumb Rubber Gradation Test Result

Sieve in (inches)	Sieve in (mm)	Percentage passing
No 8	2.36	100
No 30	0.6	100
No 50	0.3	67.2
No 100	0.15	33.2
No 200	0.075	2.1
Pan		0.4

Table 4.2: Crumb Rubber Specific Gravity Test Result (gm/cm^3)

Bottle No.	1	2	3
Specific gravity	1.12	1.12	1.08
Average of Specific gravity	1.11		

4.3 Bitumen and Modified Bitumen Test Results

The laboratory tests performed to evaluate the bitumen properties were Microscopic Examination (Morphology), Specific Gravity, Ductility, Flash and fire Point and Penetration, Softening point

4.3.1 Microscopic Examination Results

The used rubber was blended with the asphalt binder at a temperature of 160˚C in thermostatic oven, and homogenized manually for 2hrs and 4hrs for 15% and 25% respectively, and then four smears were prepared, one after every 30 minutes from 15% and other one during each hour from25%, slides were examined microscopically using magnification lens of X10 and 40.

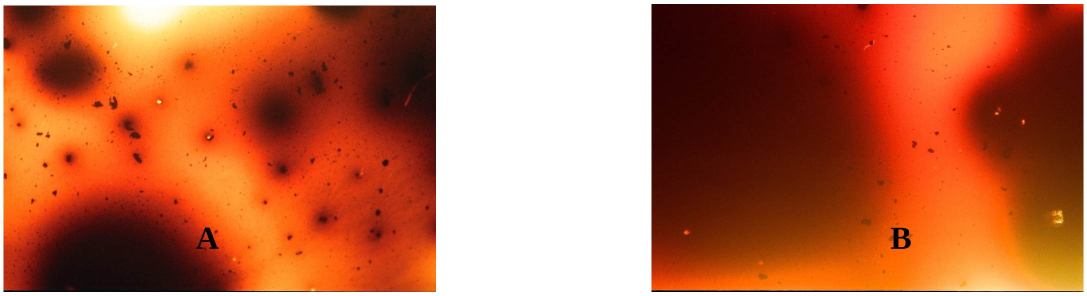


Figure 4.1: Microscopic Appearance of 15% Rubber Blended with Asphalt 60/70

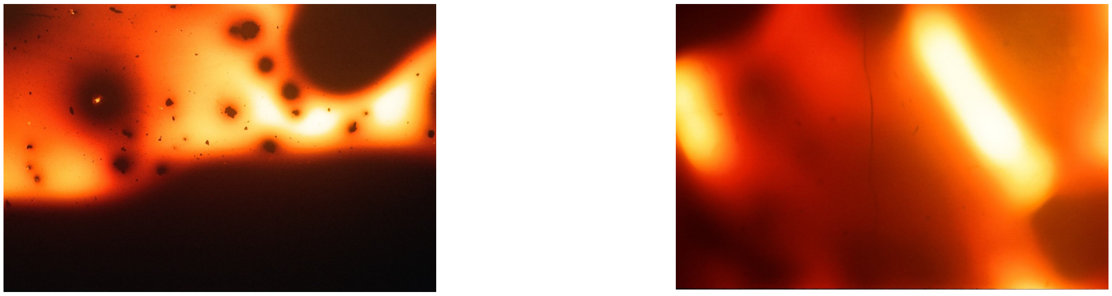


Figure 4.2: Microscopic Appearance of 25% Rubber Blended with Asphalt 60/70

4.3.2 Bitumen and Modified Bitumen Physical Properties Tests Results

Bitumen and Modified Bitumen Physical Properties Tests Results in term of Specific Gravity, Ductility, Flash and fire Point and Penetration, Softening point presented in table 4.3

Table 4.3: Bitumen and Modified Bitumen Tests Results

Rubber %	**Specific gravity**	**Penetration (0.1mm)**	**Ductility (cm)**	**Softening Point (˚C)**	**Flash point (˚F)**	**Fire point (˚F)**
0	1.03	67	105	47.2	610	620
15	1.03	68	15	53.5	554	572
20	1.04	55	10	59	554	581
25	1.04	62	12	56.7	572	590

4.4 Aggregate Test Results

The laboratory tests performed on coarse aggregates were: Los Angeles Abrasion (ASTM C131–81), Aggregate Crushing Value, Aggregate Impact Value, Sieve Analyses (ASTM C136-84) Water Absorption, Specific Gravity (ASTM C127–88), Fractured Faces of Aggregate and Angularity (BS 812) Flakiness and Elongation (BS 812). The tests for fine aggregates were: sieve Analyses (ASTM C117–87), Specific Gravity (ASTM C128–88) and Water Absorption, while for filler the test was Specific Gravity and Atterberge limits. The results of number of tests are shown blow

Table 4.4: Results of Aggregate Tests

Aggregate	**3/4**	**3/8**	**3/16**	**Sand**	**Filler**
Test					
abrasion Value	11.1	12.6	-	-	-
Aggregate Crushing Value	10.2	-	-	-	-
Aggregate Impact Value	2.1	-	-	-	-
Specific gravity gm/cc (Bulk)	2.844	2.828	2.513	2.636	2.535
Specific gravity gm/cc (Apparent)	2.882	2.881	2.605	2.685	2.545
water absorption %	0.46	0.66	1.42	0.652	0.15
Flakiness index%	4.8	31	-	-	-
Elongation index%		21.3	-	-	-
Liquid Limit	-	-	-	-	N.L
Plastic Limit	-	-	-	-	N.P

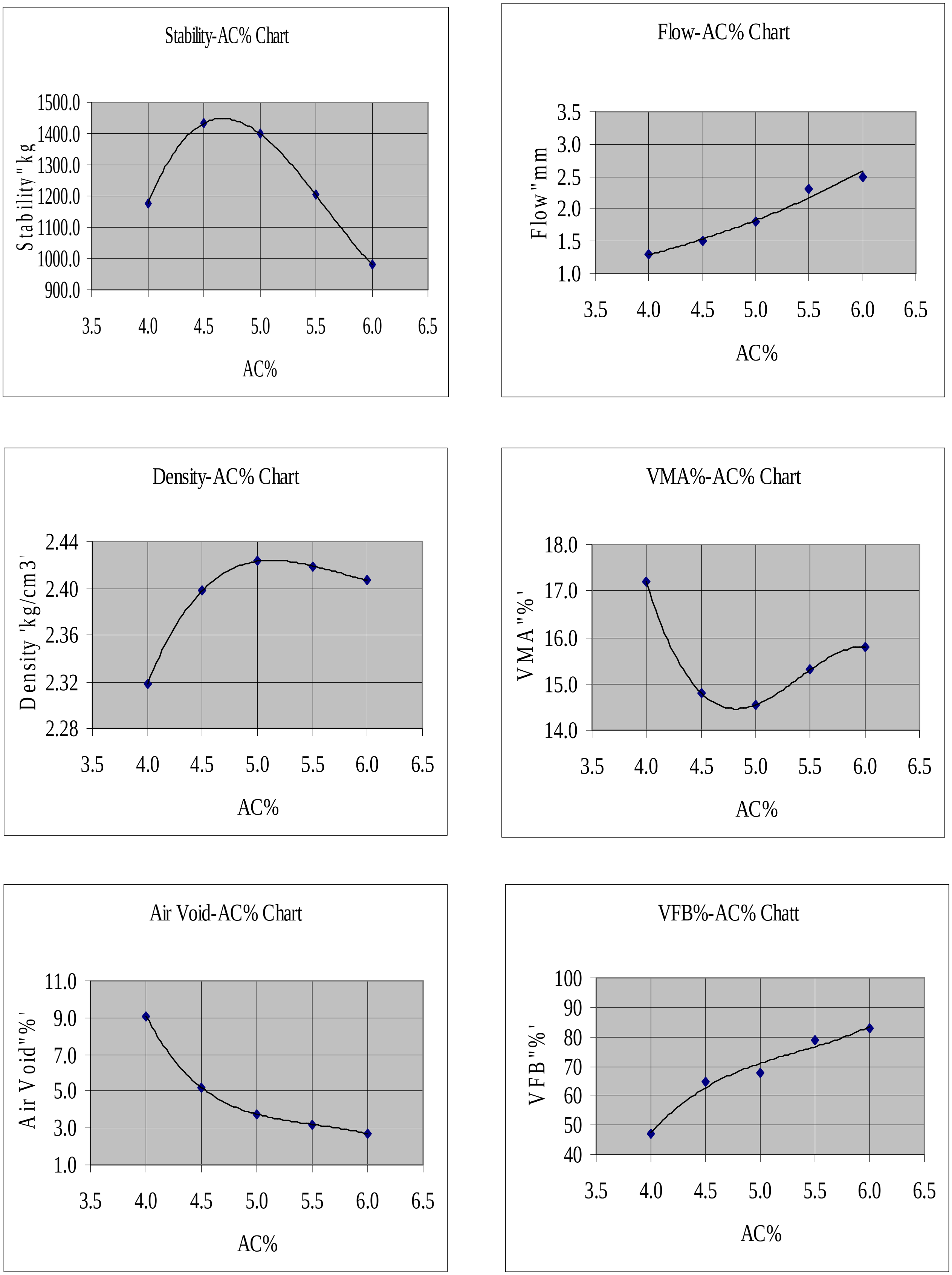


Figure 4.3: Property Curves of Hot Mix Asphalt Design

4.5.2 Asphalt Rubber Hot Mix Design Data and Test Results

Table 4.6: Asphalt Rubber Hot Mix Design Data and Test Results (15% Rubber)

%AC by Wt of Mix	Maximum Specific Gravity	Air voids (%)	Voids in Mineral Aggregate (%)	Voids Filled with Bitumen (%)	Stability (kg)	Flow (mm)
4.0	2.549	7.964	16.183	50.7879	1028.99	1.9
4.5	2.53	5.81	15.305	62.0385	1139.54	2.4
5.0	2.511	4.819	15.5011	68.9119	1155.09	2.6
5.5	2.492	3.13	15.101	79.2729	1363.47	2.8
6.0	2.474	2.021	15.201	86.7048	1085.63	3

Table 4.7: Asphalt Rubber Hot Mix Design Data and Test Results (20% Rubber)

%AC by Wt of Mix	Maximum Specific Gravity	Air voids (%)	Voids in Mineral Aggregate (%)	Voids Filled with Bitumen (%)	Stability (kg)	Flow (mm)
4.0	2.552	6.975	15.183	54.0605	1067.388	2.7
4.5	2.533	5.567	14.985	62.8495	1230.53	2.7
5.0	2.514	4.296	14.935	71.2354	1303.757	2.8
5.5	2.495	2.966	14.855	80.0337	1326.891	3
6.0	2.477	2.422	15.45	84.3236	1224.967	3.1

Table 4.8: Asphalt Rubber Hot Mix Design Data and Test Results (25% Rubber)

%AC by Wt of Mix	Max Specific Gravity	Air voids (%)	Voids in Mineral Aggregate (%)	Voids Filled with Bitumen (%)	Stability (kg)	Flow (mm)
4.0	2.552	8.307	16.397	49.3387	1020.7	2.8
4.5	2.533	6.751	16.051	57.941	1203.84	2.9
5.0	2.514	5.887	16.349	63.992	1223.74	2.9
5.5	2.495	3.657	15.383	72.124	1308.73	3
6.0	2.477	2.886	15.83	81.77	1254.16	3.1

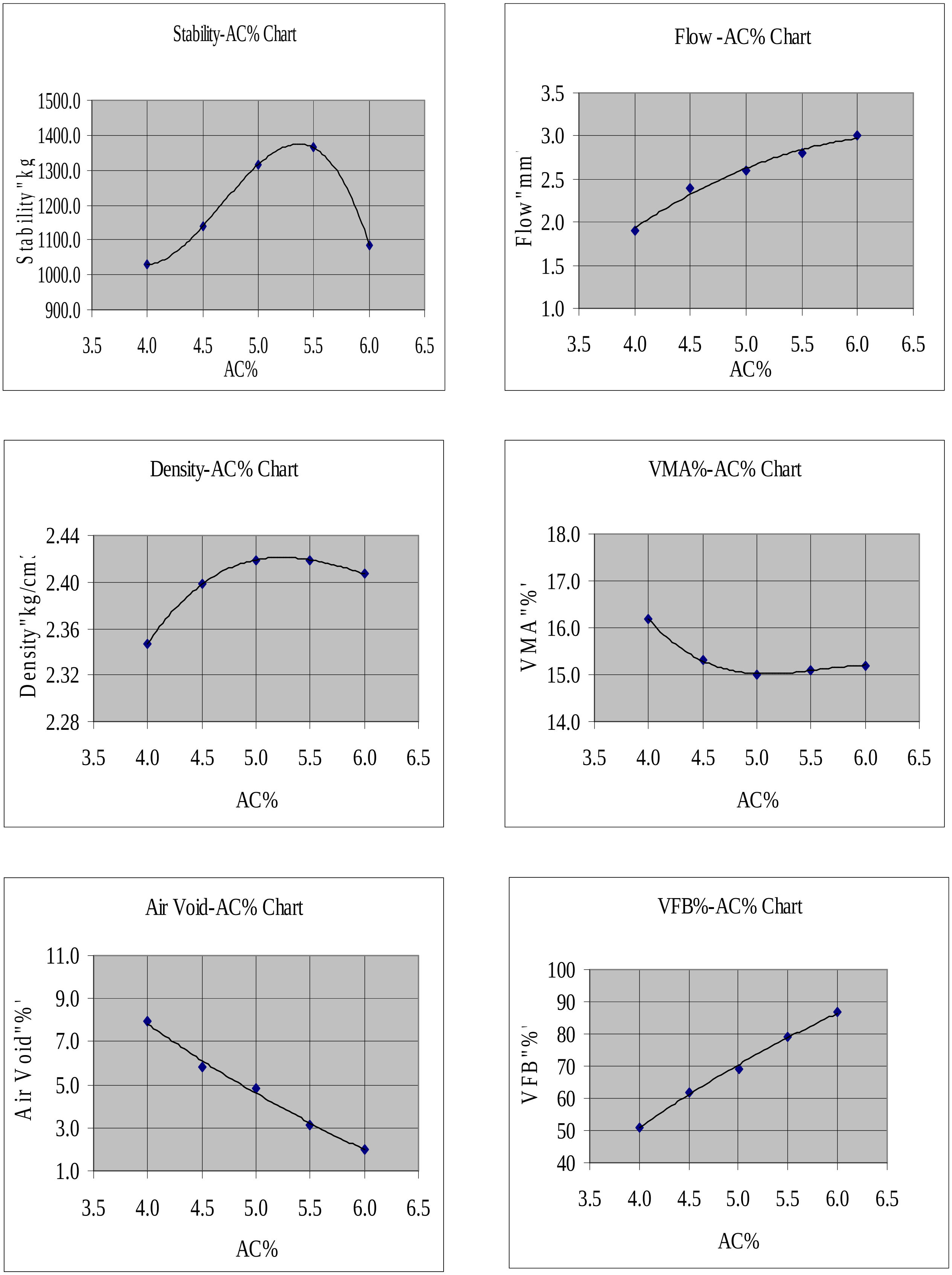


Figure 4.4: Property Curves of Asphalt Rubber Hot Mix Design (15% Rubber)

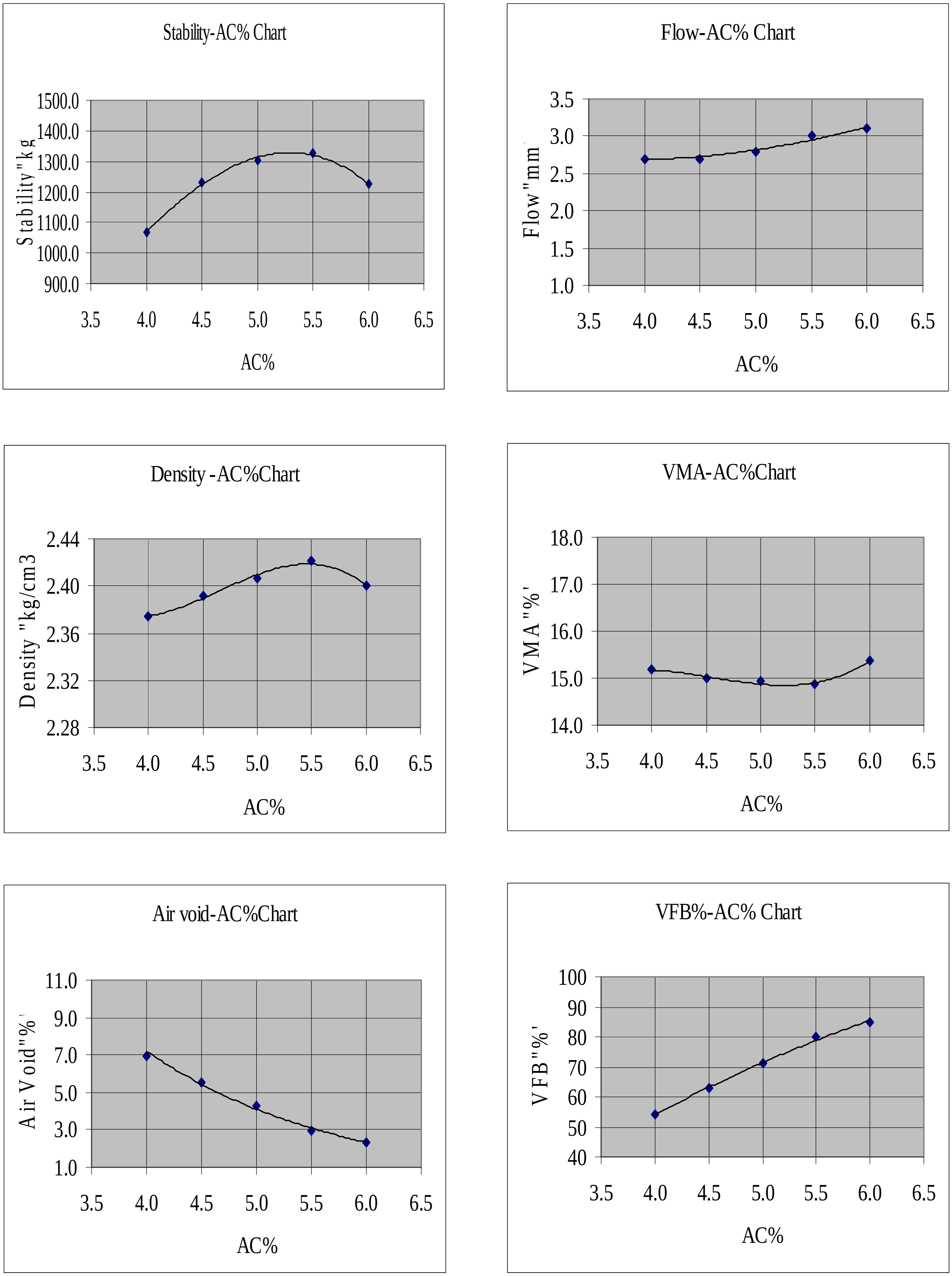


Figure 4.5: Property Curves of Asphalt Rubber Hot Mix Design (20% Rubber)

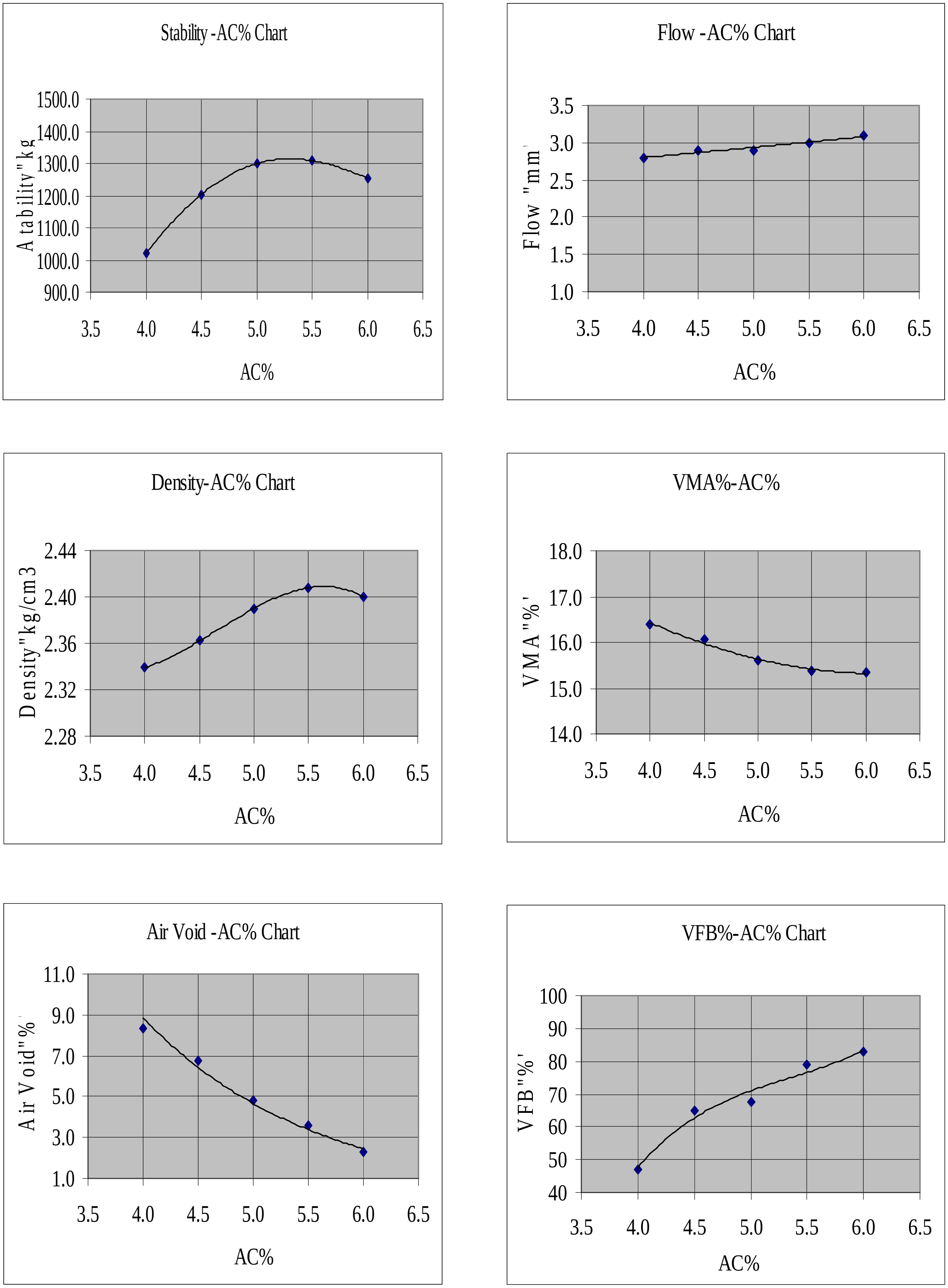


Figure 4.6: Property Curves of Asphalt Rubber Hot Mix Design (25% Rubber)

4.5.3 Optimum Bitumen Content Results

Optimum bitumen content for all mixtures was found by taking the average value of Bitumen content corresponding to maximum stability; maximum unit weight and (4%) median limits of percent air voids in total mix then the Marshall properties at optimum bitumen content for all mixture were checked with the Marshall Mix design criteria

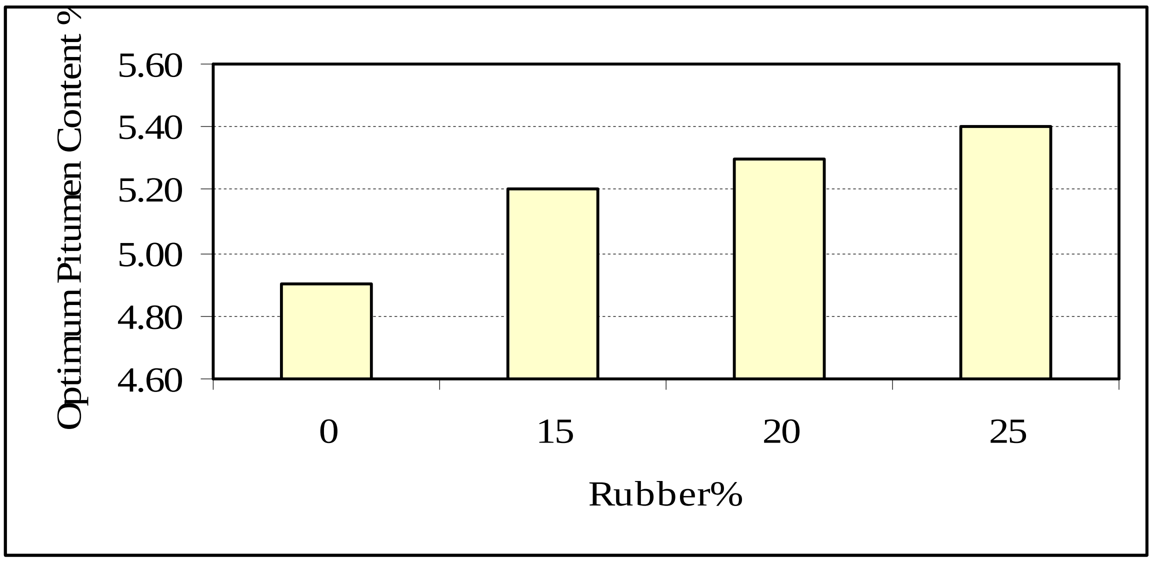


Figure 4.7: Optimum Bitumen Content for HMA &ARHM

Table 4.9: HMA & ARHM Properties at OBC%

Rubber %	Stability (kg)	Air voids (%)	Flow (mm)	Voids in Mineral Aggregate (%)	Voids Filled with Bitumen (%)
0	1420	4	1.8	14.5	70
15	1355	4	2.7	15	72
20	1320	3.5	2.9	14.8	73
25	1310	3.5	3	15.5	73

Chapter Five

Analysis &Discussions of Results

5.1General

This chapter explains the analysis and discussion of the results of experimental works which include Result of Tests on Modified Bitumen Morphological, Bitumen Physical Properties in term of Penetration, Softening Point, Specific Gravity, Ductility, Flash and Fair Points, Results of Marshall test and Volumetric Analysis of Hot Mix Asphalt Properties Which include Bulk Density, Air voids, Void in Mineral Aggregate and Void Filled with Bitumen

5.2 Evaluation of Bitumen and Asphalt Rubber as Different Percentage of Crumb Rubber

One type of asphalt 60/70 penetration grade and three crumb rubber percentage modified asphalt 60/70 penetration grade were evaluated by six tests: microscopic examination (morphological analysis), specific gravity, penetration, softening point, ductility, flash and fire points. The effect of crumb rubber percentages on the morphology, specific gravity, penetration, softening point, ductility, flash and fire points are shown in paragraphs and figures below

5.2.1 Modified Bitumen Morphological Analysis

In wet process CRM binders made due to physical and compositional changes in an interaction process where the rubber particles swell in the bitumen by absorbing a percentage of the lighter fraction of the bitumen, to form a viscous gel,15% rubber by weight of bitumen was homogenized with asphalt 60/70 penetration grade under 160˚ C at last time of compatibility test (2 hour), these result according to microscopic appearances, 25% rubber by weight of bitumen was homogenized with asphalt 60/70 penetration grade under 160° C at last time of compatibility test (4 hour); these result according to microscopic appearances

5.2.2 Effect of Crumb Rubber Percentages on the Bitumen Specific Gravity

Figure (5.1) show the variation of specific gravity by using different rubber percentages modified asphalt 60/70 penetration grade, general trend shows that the specific gravity increases as the rubber percentage increases. Generally, the specific gravity of the asphalt rubber and regardless of the rubber percentage is higher than the specific gravity of asphalt 60/70 penetration grade. Figure (5.1) show the maximum specific gravity (1.04 g/cm3) was reported for asphalt modified with rubber at a proportion of 20 &25% by weight of bitumen content and it higher than those modified with 15 %.(1.03 g/cm3), Although the difference in specific gravity due to rubber percentage is marginal . The increasing in specific gravity may be attributed to the increasing in the Bulk Specific gravity of crumb rubber.

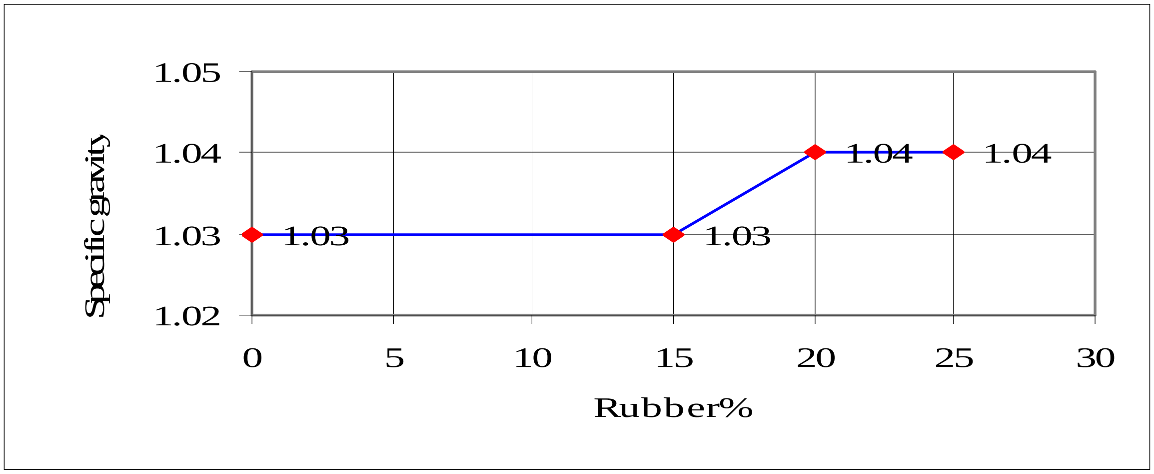


Figure 5.1: Effect of Crumb Rubber Percentages on the Bitumen Specific Gravity

5.2.3 Effect of Crumb Rubber Percentages on the Bitumen Penetration Value

Figure (5.2) show the variation of penetration value by using different rubber contents modified 60/70 asphalt grade. Figure show that as the percentages of crumb rubber increases the penetration values of asphalt Increase, the reason of increasing penetration values may be due to some oil extracting from rubber .these results indicate that the modified mixtures will be less stiff than the conventional ones and therefore the rutting resistance of the modified mixtures is expected to be less

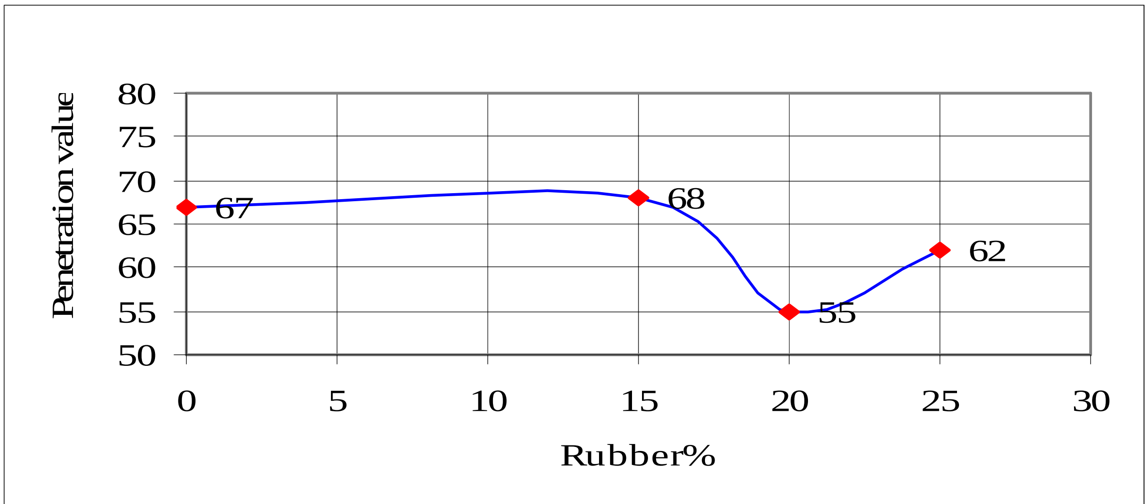


Figure 5.2: Effect of Crumb Rubber Percentages on the Bitumen Penetration Value

5.2.4 Effect of Crumb Rubber Percentages on the Bitumen Softening Point

Figure (5.3) show, the variation of softening point by using different rubber percentages modified asphalt 60/70 penetration grade. The Figure show that softening point for asphalt rubber, Increase by approximately 6 to 10˚ C by the addition 15 and 20% tire rubber percentages by weight of asphalt 60/70 penetration grade respectively and then start decreasing when more percentage is added for the asphalt 60/70 penetration grade. Generally, the softening point of the modified asphalt and regardless of the rubber percentages is higher than the conventional asphalt no modifier .The highest softening point was reported for asphalt rubber that is treated with a proportion of 20% by weight of asphalt 60/70 penetration grade (59˚ C), which is higher than asphalt rubber treated with the 15 &25% rubber modifier, These results indicate the asphalt-rubber concrete pavements should be less susceptible to traffic deformation (distress) at high pavement temperatures compared to conventional asphalt pavements.

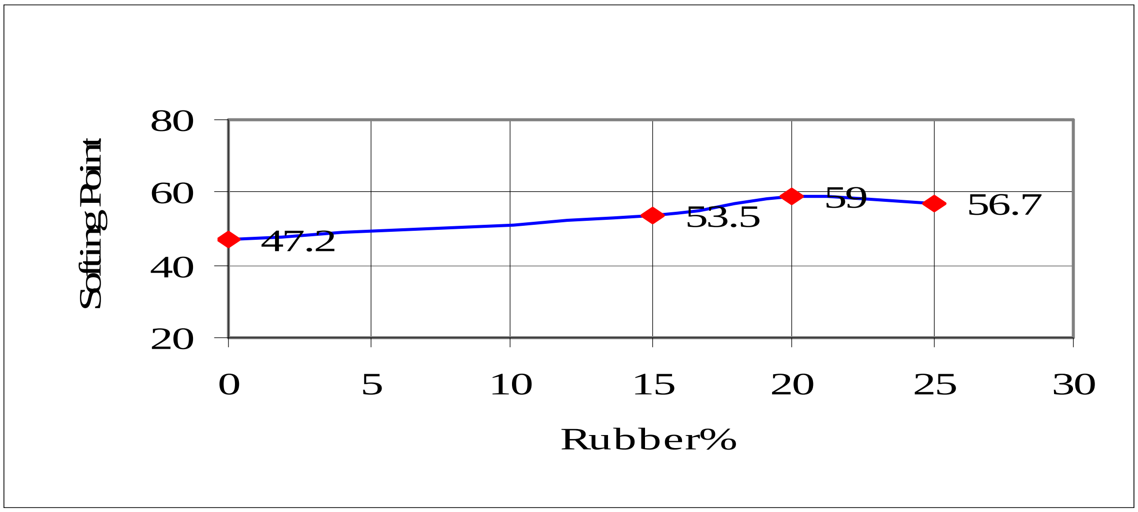


Figure 5.3: Effect of Crumb Rubber Percentages on the Bitumen Softening Point

5.2.5 Effect of Crumb Rubber Percentages on the Bitumen Flash Point

Figure (5.4) show, the variation of flash point by using different rubber percentage modified asphalt 60/70 penetration grade. These results show that the flash point for asphalt rubber decrease by approximately 56 to 38˚ F by the addition 15, 20 and 25% tire rubber percentage by weight to asphalt respectively . Generally, the flash point of the modified asphalt and regardless of the rubber percentage is lower than the conventional asphalt no modifier; The lower flash point was reported for asphalt rubber that is treated with 15 and 20 rubber percentage (554˚F), which is higher than asphalt rubber treated with 25 rubber percentage, the general trend shows that the flash point of Asphalt-rubber for all percentages have lower flash point than the conventional asphalt. The decreases in flash point of modified asphalt may be attributed to the some fabric content in tyre rubber

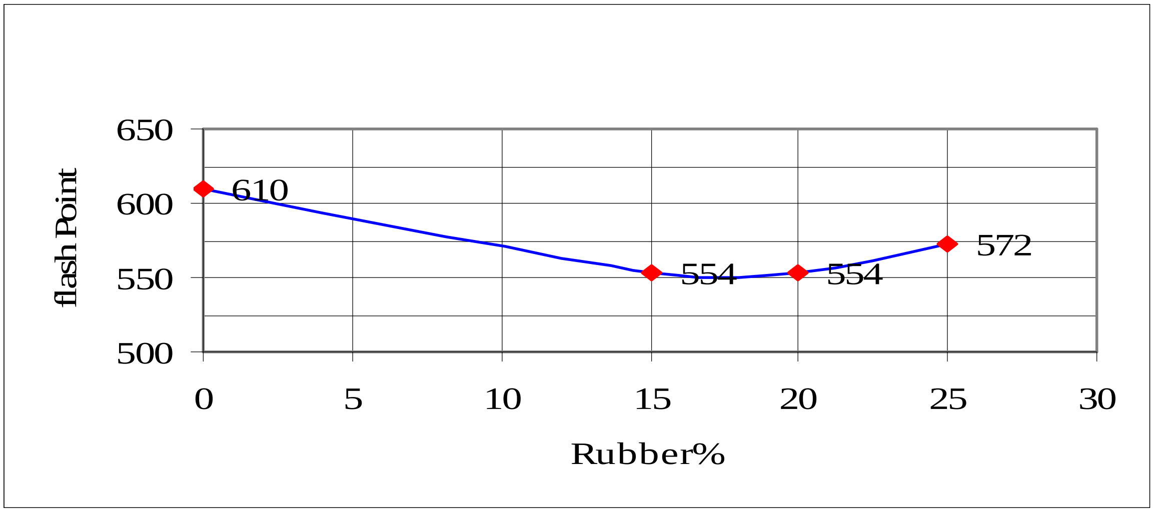


Figure 5.4: Effect of Crumb Rubber Percentages on the Bitumen Flash Point

5.2.6 Effect of Crumb Rubber Percentages on the Bitumen Fire Point

Figure (5.5) show, the variation of fire point by using different rubber percentages modified asphalt 60/70 penetration grade. These results show that the fire point for asphalt rubber decrease by approximately 48 ,39 to 30˚ F by the addition 15, 20 and 25% tire rubber percentage by weight to asphalt 60/70 penetration grade respectively . Generally, the fire point of the modified asphalt and regardless of the rubber percentage is lower than the conventional asphalt no modifier; The lower fire point was reported for asphalt rubber that is treated with 15 rubber percentage (572˚F), which is lower than asphalt rubber treated with 20 and 25 rubber percentage,. The decreases in fire point of modified asphalt may be attributed to the some fabric content in tire rubber modifier

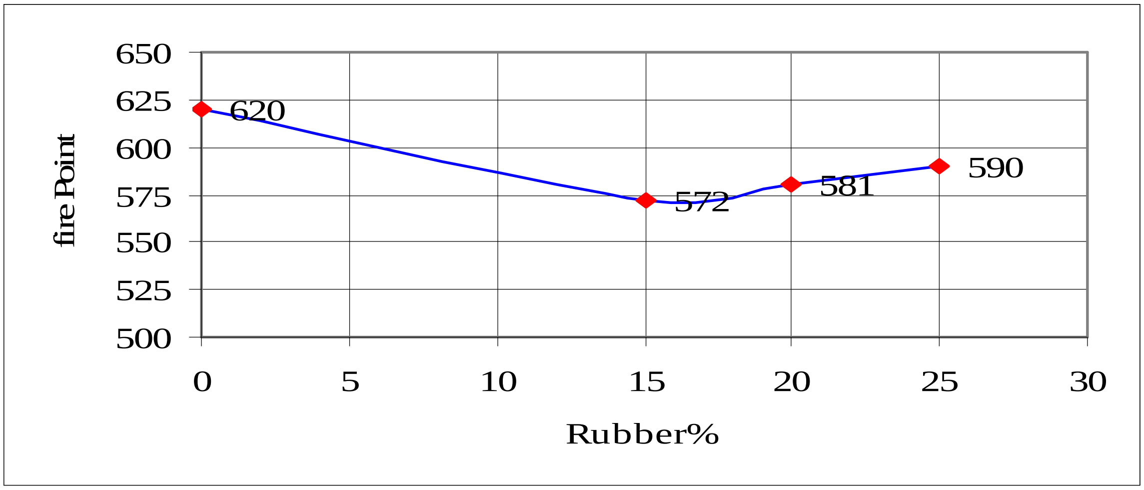


Figure 5.5: Effect of Crumb Rubber Percentages on the Bitumen Fire Point

5.2.7 Effect of Crumb Rubber Percentages on the Bitumen Ductility

Figure (5.6) show, the variation of ductility by using different rubber percentages modified asphalt 60/70 penetration grade. Generally, the ductility value of the modified asphalt and regardless of the rubber percentage is lower than the conventional asphalt no modifier .the decreases in ductility of modified asphalt may be attributed to the some fabric content in tire rubber modifier and some crumb rubber particles no homogenized with asphalt these cases decreases in the adhesion

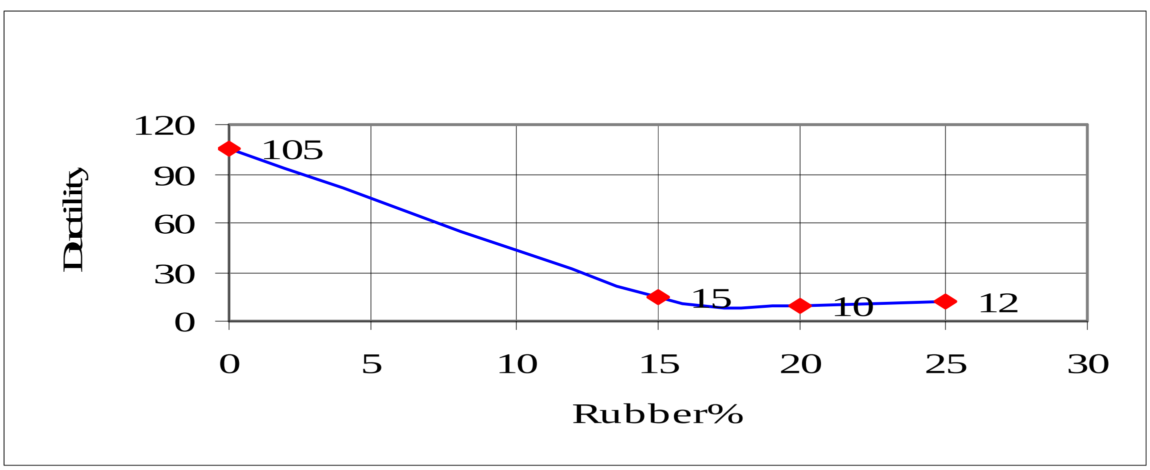


Figure 5.6: Effect of Crumb Rubber Percentages on the Bitumen Ductility

5.3 Evaluation of Asphalt Mixtures

A comparison between asphalt mixture performances due to Percentages of the added Rubber is presented below. The comparison also includes the conventional asphalt mixture (No rubber), which acts as the control group.

5.3.1 Mixtures Stability- Rubber Percentages Relationship

Stability of an HMA pavement, the most important property of the bitumen mixture in the wearing course design, it is ability to resist shoving and rutting under traffic. Therefore, stability should be high enough to handle traffic adequately, but not higher than the traffic conditions required. The lack of stability in an asphalt mixture causes unraveling and flow of the road surface.

Figure (5.7) show the variation of Mixtures stability by using different rubber percentages for asphalt 60/70 penetration grade, Generally, the stability of the modified asphalt concrete mixtures and regardless of the rubber percentages is less (lower) than the conventional asphalt concrete mixture - no modifier. Figure (5.8) show the highest stability was reported for asphalt mixture that is treated with asphalt 60/70 penetration grade (1420 kg), which is higher than mixture treated with the rubber modifier, stability of asphalt rubber concrete mixtures modified by using rubber is steadily decrease by the increased of the rubber percentages. The maximum stability of modified mixtures is (1355 kg) was reported for asphalt mixture modified with rubber at a proportion of 15% by weight of bitumen than those modified with 20 &25% rubber. The decreases in stability while increasing rubber percentage may be attributed to the decreases in the adhesion

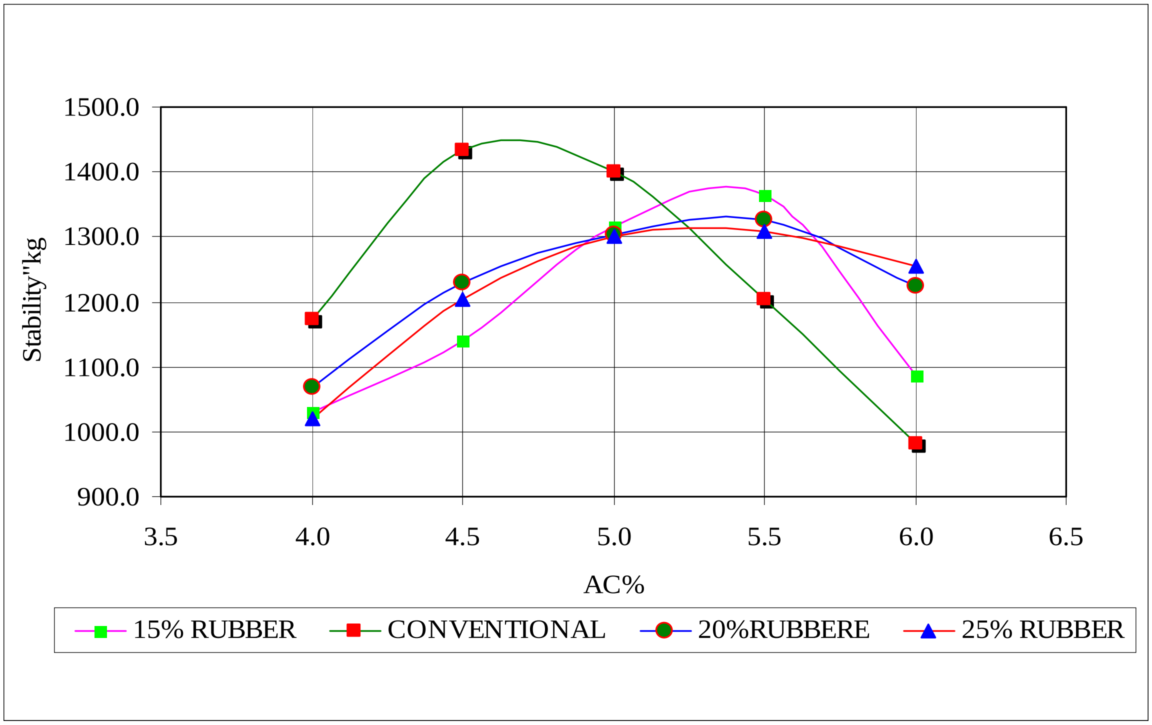


Figure 5.7: Variation of Mixtures Stability by using different Rubber Percentages and modified asphalt 60/70 Penetration grade

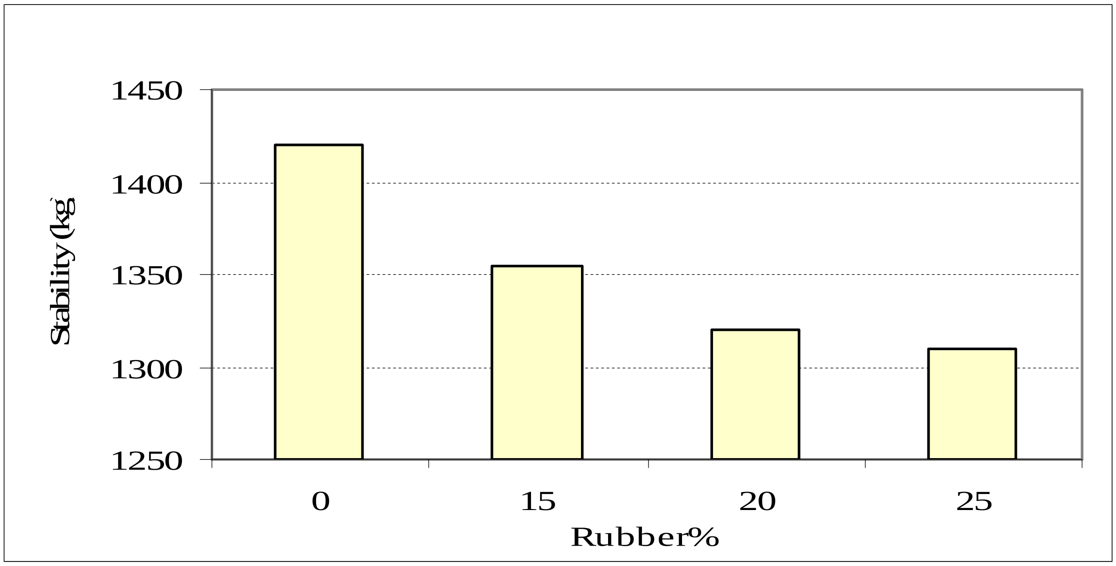


Figure 5.8: Maximum Stability of Mixtures

5.3.2 Mixtures Flow- Rubber Percentages Relationship

Flow is the ability of an HMA pavement to adjust to gradual settlements and movements in the subgrade without cracking. The flow may be regarded as an opposite property to the stability, determining the reversible behavior of the wearing course under traffic loads and affecting plastic and elastic properties of the asphalt concrete, flow is an important factor in designing hot mix asphalt mixtures it is not desirable to have high flow values because the mix becomes more plastic and this tends to create stability problems, however low flow values may indicate mix with higher than normal voids and insufficient asphalt for durability which cause brittle mixes and therefore cracks can occur on the pavement surface under loads.

Figure (5.9) show the variation of Mixtures flow by using different rubber percentage for asphalt 60/70 penetration grade, Generally, the flow of the modified asphalt concrete mixtures and regardless of the modified percentage is higher than the conventional asphalt concrete mixture - no modifier (1.8 mm), Figure (5.10) suggests that the flow increases continuously as the proportion of rubber modifier increases ,The maximum flow (3.0 mm) was reported for asphalt mixture modified with rubber percentage at a proportion of 25% by weight of bitumen content, this indicates that modified mixtures are less stiff, flow values of modified and unmodified mixtures fall within specification limits.

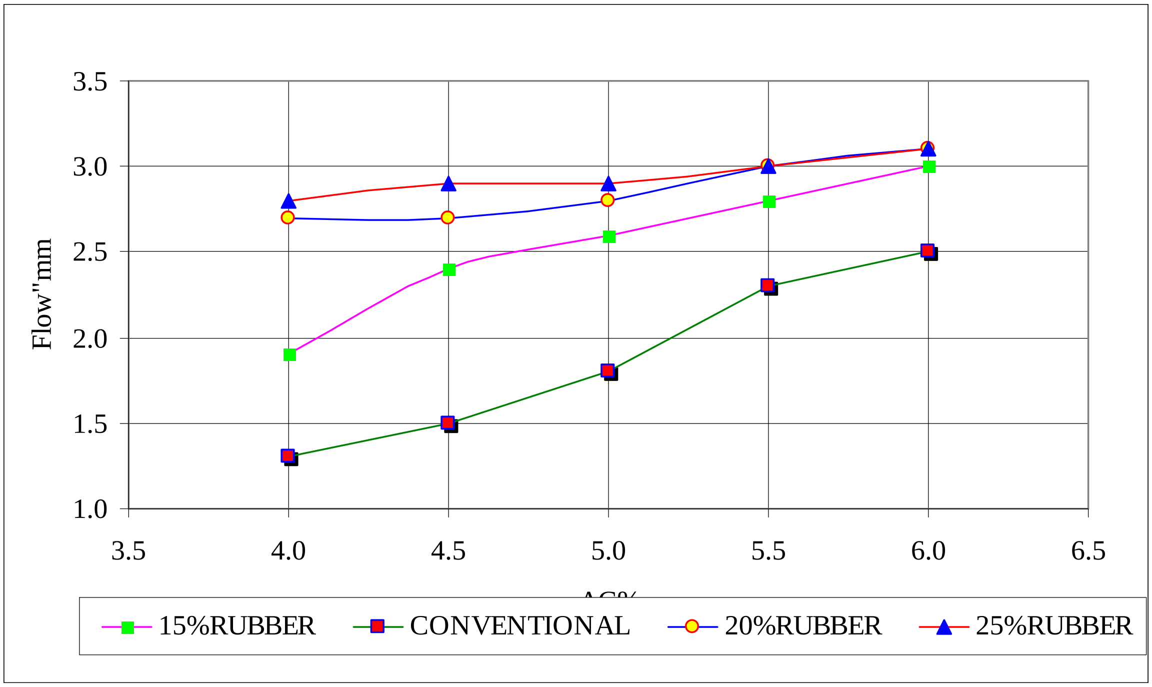


Figure 5.9: Variation of Flow by using different Rubber Percentages for asphalt 60/70 penetration grade

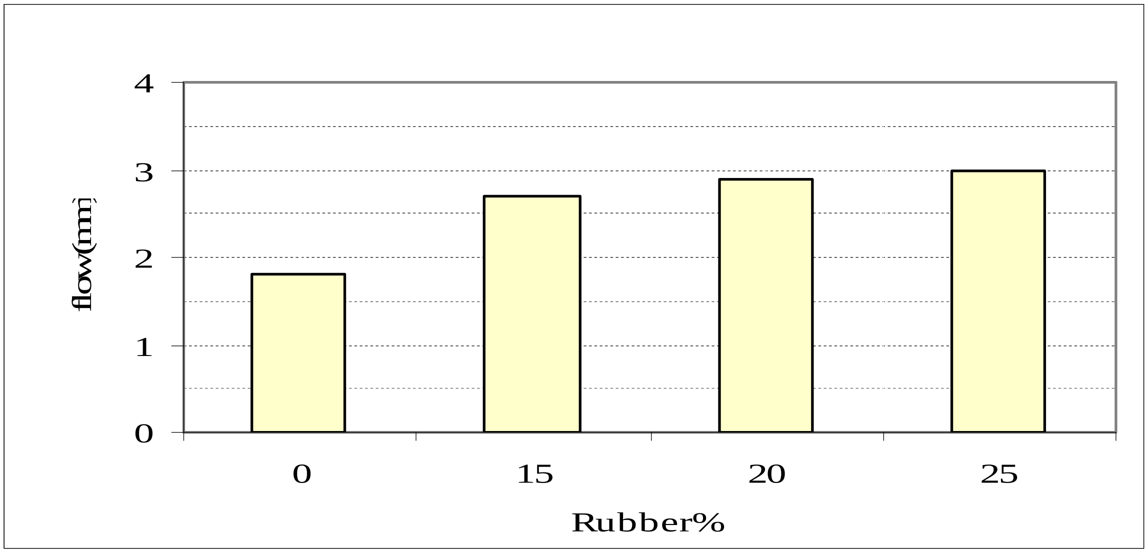


Figure 5.10: Minimum Asphalt Mixture Flow by Rubber Modifier Percentages

5.3.3 Mixtures Bulk Density- Rubber Percentages Relationship

Figure (5.11) show the variation of unit weight with different rubber Percentages for the asphalt 60/70 penetration grade, The bulk density of the asphalt rubber concrete mixtures and regardless of the rubber percentage is lower than the conventional asphalt concrete mixture (2.423gm/cm3), For all percentages of rubber, the maximum bulk density of the asphalt rubber is found when the rubber percentage is around 15% (2.42 gm/cm3). Although the difference in bulk density due to rubber percentage is marginal, the general trends show that the bulk density increases as the AC% increases until it reaches the peak that is associated with the highest bulk density and it started to decline significantly afterwards. Asphalt-rubber mixtures for all rubber percentages are less dense than the conventional asphalt mixtures as the asphalt becomes softer and the asphalt content increases thicker films are produced around the aggregates thereby pushing the aggregate particles further apart and resulting in lower density

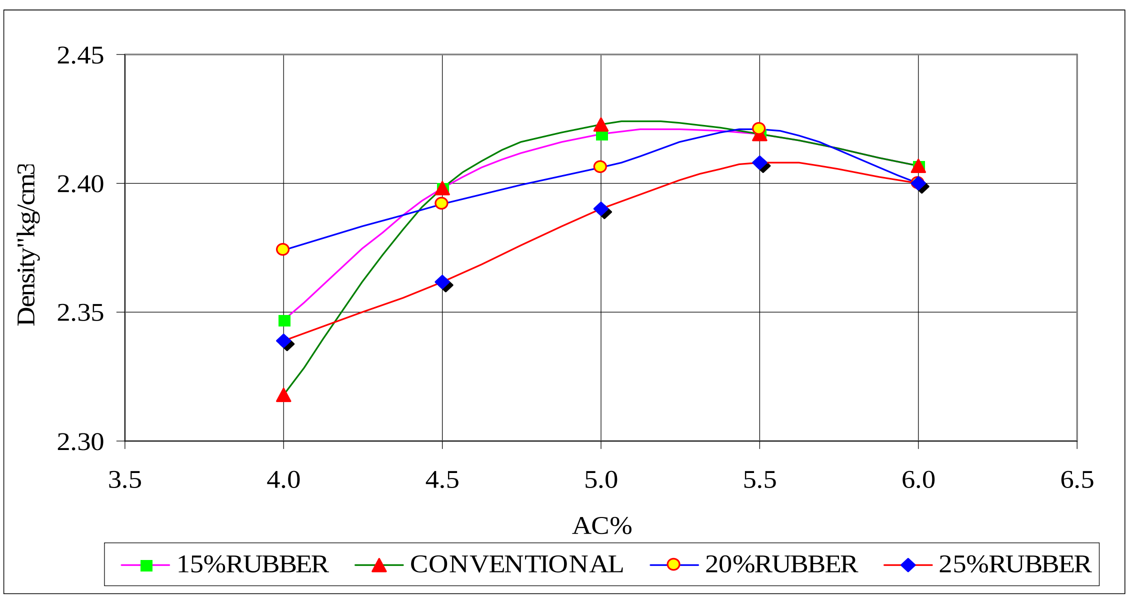


Figure 5.11: Variation of Unit weight with different Rubber Percentages for Asphalt 60/70 Penetration grade

5.3.4 Mixtures Air voids percentage - Rubber Percentages Relationship

Figure (5.12) show the variation of mixtures air voids with different rubber percentages for asphalt 60/70 penetration grade, Figure (5.13) show asphalt-rubber mixtures has lower air voids than conventional asphalt mixtures. The minimum percentage air void of modified asphalt mixture (3.5%) was reported for rubber modifier at a proportion of 20 and 25% by weight of bitumen content, and The air void content of asphalt mixtures modified with 15% approximates the air voids of conventional mixture (no additives) (4%) . The decreases in AV% while increasing rubber content may be attributed to the small crumb rubber particle size fill the voids. All mixtures modified with rubber content of 15, 20 and 25% by weight of bitumen, have air voids within the specification.

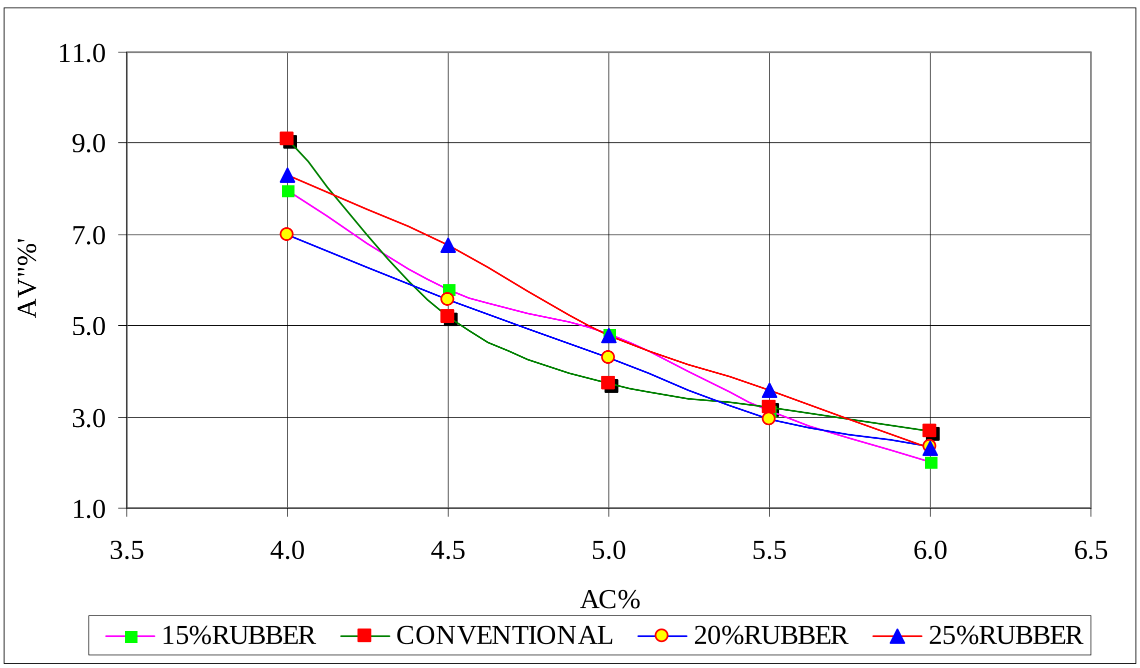


Figure 5.12: Variation of Air voids with different Rubber Percentages for asphalt 60/70 Penetration grade

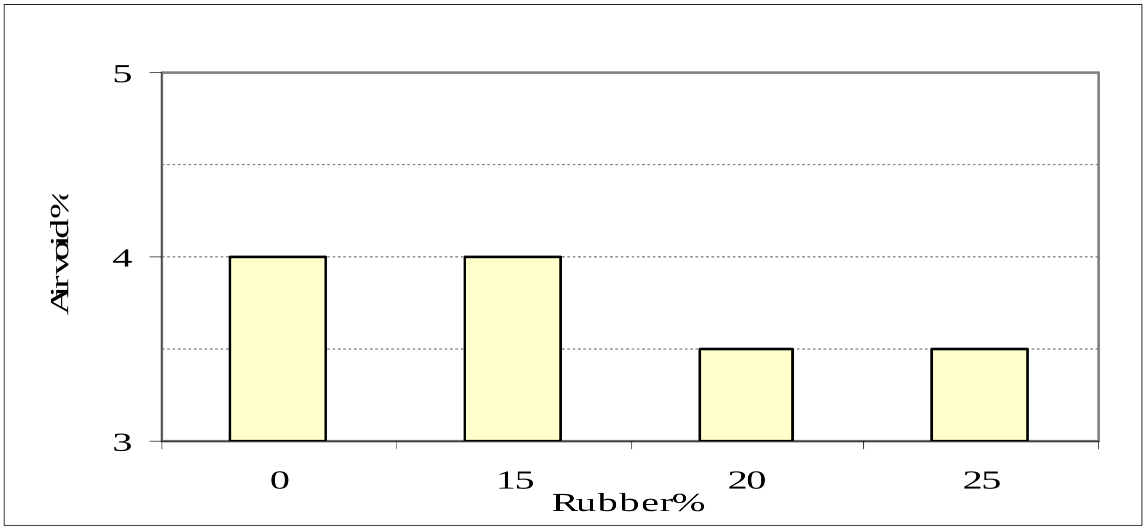


Figure 5.13: Minimum Asphalt Mixture Air void Percentage by Rubber Modifier Percentage

5.3.5Void in Mineral Aggregate Percentage-Rubber Percentages Relationship

Figure (5.14) show the variation of void in Mineral Aggregate with different rubber percentage for asphalt 60/70 penetration grade, In general the VMA percentages of the modified asphalt concrete mixtures and regardless of the modified percentages is higher than the conventional asphalt concrete mixture no modifier (14.5%). Only mixture modified with rubber content of 20% by weight of bitumen have a minimum VMA percentages that approximate the no-additive mixture case. The VMA percentage of asphalt mixture modified with 20% rubber are the lowest among other modified asphalt concrete mixtures. On the other hand, the VMA content of asphalt mixtures modified with 25% rubber are the highest among other modified asphalt concrete mixtures (15.5%); but the difference is minor.

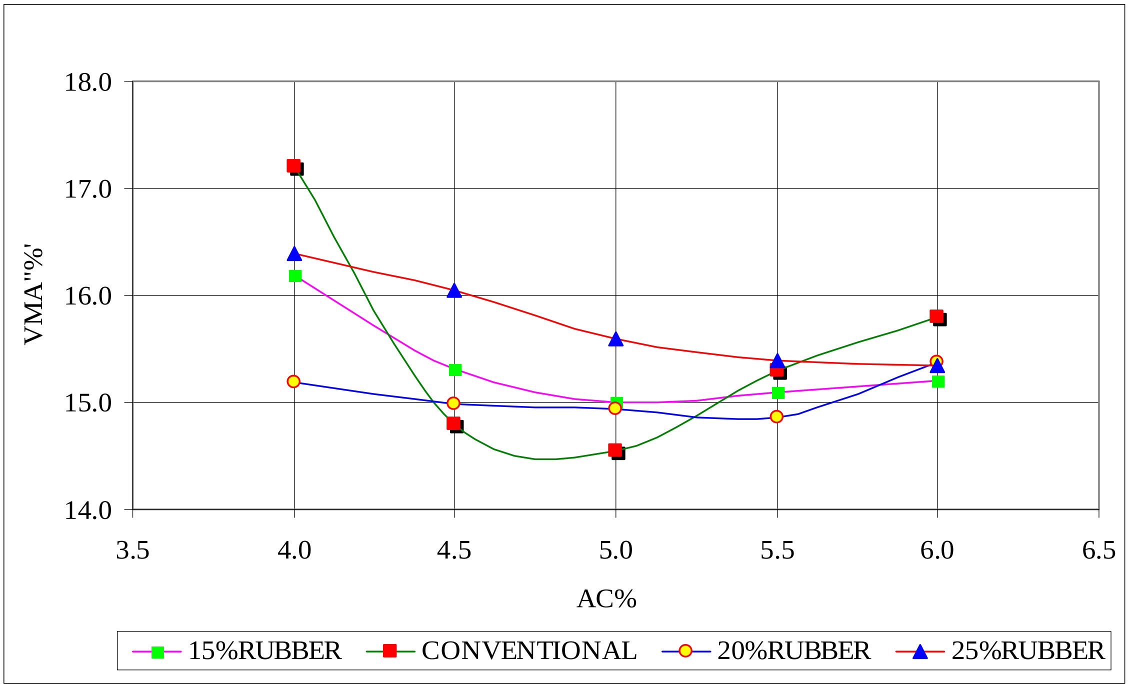


Figure 5.14: Variation of Void of Mineral Aggregate with different Rubber percentages Modified asphalt 60/70 Penetration grade

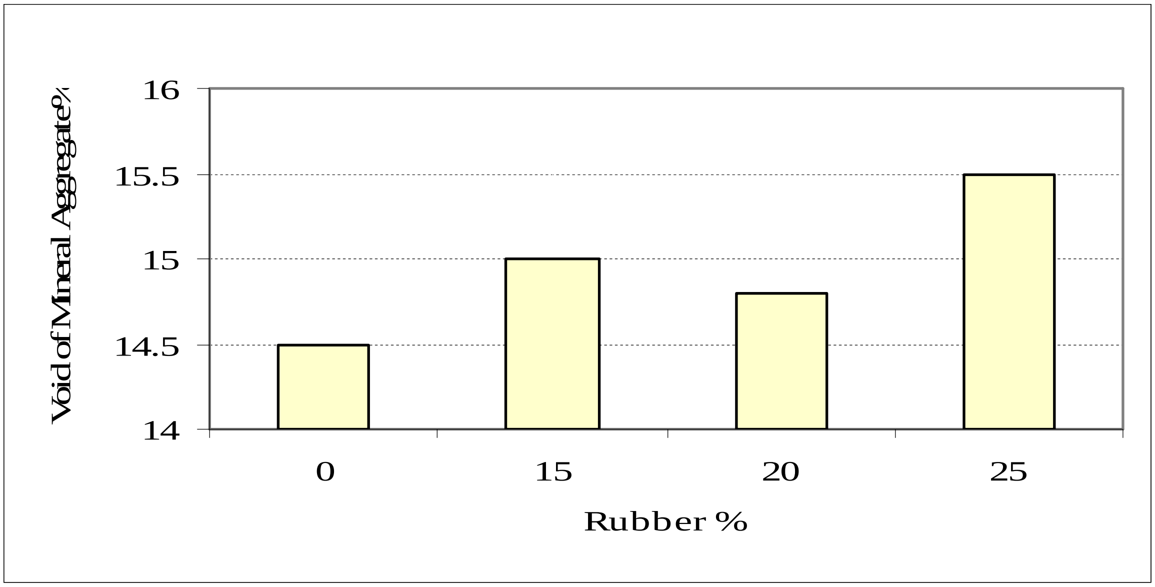
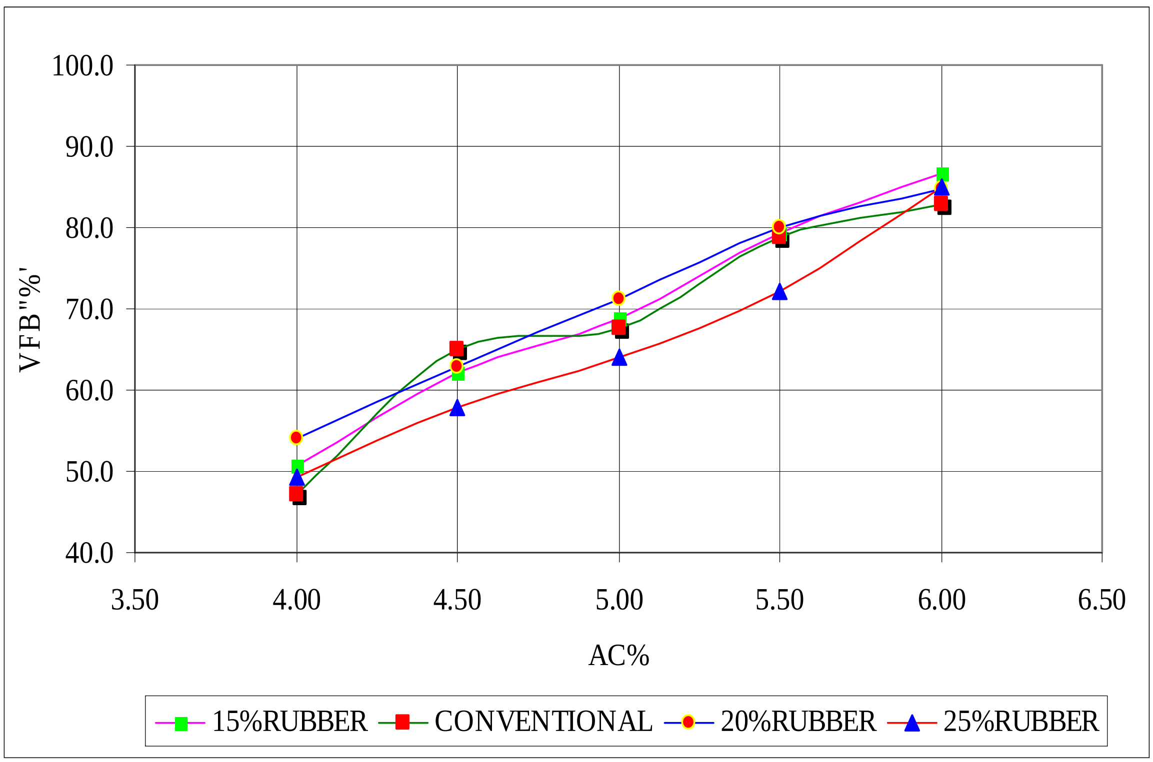


Figure 5.15: Minimum Void of Mineral Aggregate Percentage of Asphalt mixtures by Rubber Modifier Percentages

5.3.6 Void Filled with Bitumen VFB% - Rubber Percentage Relationships

Figures (5.16) show the variation of voids filled with Bitumen VFB% with different rubber percentages for the asphalt 60/70 penetration grade. Figures (5.17) show that the asphalt-rubber mixtures have highest VFB% values than conventional asphalt mixture because the VFB% is depend on the values of VMA % and VA %, all values fall within specification in the case of modified and unmodified asphalt and very close to each other, all values fall within specification.



Figures 5.16: Variation of Voids Filled with Bitumen VFB% with Different Rubber Contents Modified asphalt 60/70 Penetration grade

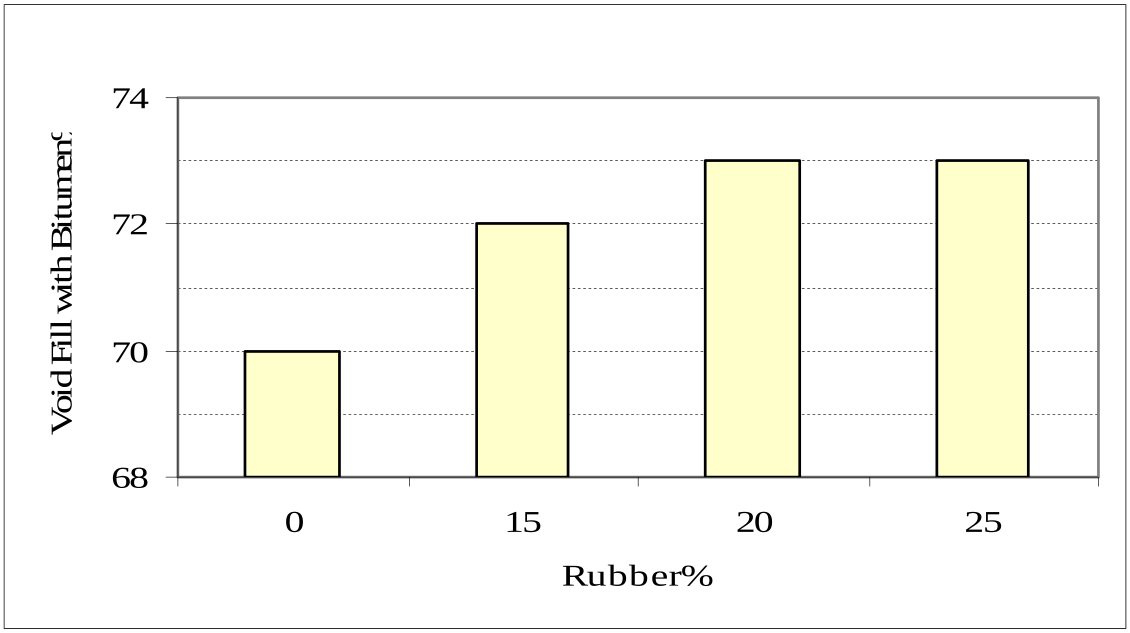


Figure 5.17: Minimum Voids Filled with Bitumen VFB% by Rubber Modifier Percentage

Chapter Six

Conclusions and Recommendations

6.1 General

The primary aim of this study was Evaluation of Crumb Tire Rubber Modified Bitumen for Hot Mix Asphalt Concrete at Khartoum State. In this chapter, the conclusions and recommendations that resulted from the study are presented. Paragraph 6.2 present the most important conclusions.

6.2 Conclusions

It can be concluded out of this study that rubber modification has enhanced the physical properties of asphalt cements and the asphalt concrete mixtures properties. Comparison between the three studied rubber binders produced with mixing different percentages of crumb tire rubber has shown that, 15% rubber modified asphalt experienced higher penetration and ductility lower specific gravity, softening point, flash and fire point. 20% rubber modified asphalt experienced lower penetration, ductility higher specific gravity and softening point.25% experienced higher flash and fire point but very close to15% and 20% in the other properties. 15% rubber modified mixture exhibited higher values of Marshall Stability, density, Air void in the other hand exhibited lower values of Marshall flow, Void in Mineral Aggregate and Voids Filled with Bitumen. 25% rubber modified mixture exhibited lower values of Marshall Stability, density, Air void in the other hand exhibited higher values of Marshall flow, Void in Mineral Aggregate and Voids Filled with Bitumen, The properties of modified mixtures prepared by 20% rubber are very close to 15% and 25% properties .The main conclusions that can be drawn from the study undertaken in this study are

1- The compatibility of the Crumb Tire Rubber with the asphalt depends on the mixing temperature and mixing time.
2- The binder prepared with the 160˚C mixing temperature and 2hrs and 4hrs for 15% and 25% rubber by weight of asphalt 60/70 penetration grade respectively were compatible in the end of mixing period.
3- Asphalt –rubber binder present higher softens point, specific gravity Lower ductility, flash and fire point and un-regular penetration results.
4- Asphalt –rubber are higher softening points, these results indicate the asphalt-rubber concrete pavements should be less susceptible to traffic at high pavement temperatures compared to conventional Asphalt 60/70 penetration grade pavements.
5- Lower flash and fire point indicated that the industry of asphalt –rubber mixtures is very hazardous than the control mix.
6- Lower ductility indicated that the construction of asphalt –rubber mixtures is very is make long constructed time than the control mix.
7- Asphalt –rubber mixtures present lower stability, density, higher flow, Voids Filled with Bitumen than the conventional asphalt mixture.
8- A stability decrease indicates that the asphalt –rubber mixtures are much soft than the control mix. This mixture is lower resistant to permanent deformation (rutting) than the control mix.

9- Flow value increase indicates that the asphalt –rubber mixtures are soft and low stiffness mixtures than the control mix. Thus, the pavements being more resistant to fatigue deformation.

10- Overall, using rubber in asphalt mixture reduces permanent deformation (rutting) resistance and increase fatigue resistance.

11- The air void contents and Void in Mineral Aggregate of the modified mixture are not far from that of the non-modified mixture.

12- The Optimum binder contents for the conventional and modified mixtures are very close to each other.

13- Crumb Tire Rubber Modified Bitumen for Hot Mix Asphalt is relatively solved a solid waste disposal problem.

6.3 Recommendations

Despite several conclusions being drawn from this study, a lot is still not known about the material and mixtures. Recommendations are summarized in the following

- The study recommended that farther studies should be carried out in mixing temperatures and mixing time.
- The study recommended that farther studies on bitumen physical properties in terms of penetration, viscosity and loss on heating.
- The study recommended that to use Tire-derived pyroltic oil to enhance the asphalt rubber ductility.
- The study Recommended that conducted field test on rubberized constructed section such as Coca-Cola industry district constructed section at Khartoum State.

- The result of this study was limited and related to the result of laboratory; therefore further studies should be carried out.

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