LABORATORY INVESTIGATION OF BITUMINOUS CONCRETE (GRADE – 1) USING DIFFERENT TYPES OF ADDITIVES

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DECLARATION

I hereby declare that this thesis titled **"Laboratory Investigations of Bituminous Concrete (Grade – 1) Using Different Types of Additives"** is an authentic record of the work carried out as per the requirement for the award of degree of **Master of Engineering** in **Civil Infrastructure Engineering** in the Civil Engineering Department of **Thapar University, Patiala** under the guidance of **Mr. Tanuj Chopra, Assistant Professor**, Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2016. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

DATE: July 14, 2016

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CERTIFICATE

This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.

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ABSTRACT

India boasts of the third largest road network in the world. To keep up with the continuous infrastructure development, new roads are being constructed. The ever increasing population has further raised the vehicular density due to increased passenger traffic and freight transport over the last few decades. India and many other countries have more than 90 percent of roads which are constructed with flexible pavements or bituminous courses. So, to achieve the requirements, properties of asphalt binder and bituminous mixes are to be improved by using various additives. For a pavement section different types of additives are used such as Polymers, Crumb Rubber and other waste materials like waste plastic, discarded tyre tubes etc which increases the life of the pavement depending upon the degree of modification and type of additives used.

Due to increase in population, the vehicular traffic density is also increasing. Due to this, the wear and tear of tyres from these vehicles is undoubted due to which large number of scrap tyres are being generated. A large number of waste and worn out tyres are already in existence and with an annual generation rate of 15-20% each year. These tyres are discarded indiscriminately or stockpiled. The used tyres had a great threat to human health and environment, since it is non-biodegradable so it is having disposal problems also. Similarly, consumption of waste plastic is increasing day by day. More than 50% of the plastic is used as a packaging material. As plastic is a non-biodegradable waste so it does not under goes decomposition. In this, we projected to study the use of the waste tyre rubber and waste plastic as a blending material in bitumen, which is further used for road construction. If waste plastic and used tyre rubber can be added in bitumen for improving the properties of bituminous mixes.

The present research focuses at developing modified bituminous mixes for Bituminous Concrete Grade 1 by partially replacing the bitumen content with waste plastic and waste tyre tube. Also the study focuses on the different blends of Bituminous Concrete Grade 1 by using Polymer Modified Bitumen (PMB) and Crumb rubber Modified Bitumen (CRMB) and Stability-Flow analysis was done with modified binders and with the replacement of waste plastic and waste tyre tubes were done. It is found that out of two materials, replacement of optimum binder content (OBC) by 8% of waste plastic and 12% of waste tyre tube was observed. The optimum binder content for Polymer Modified Bitumen (PMB) for Bituminous Concrete Grade 1 is 5.2% and for Crumb Rubber Modified Bitumen (CRMB) is 5%.

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CHAPTER – 1

INTRODUCTION

1.1 Introduction

For a developing country like India an efficient road network is pre-requisite for national integration, country's development and for socio-economic development. Over a last few years, the use of vehicles has increased, which has further evaluated the vehicular density on roads. Due to increase in vehicular traffic, there is a huge demand for improved pavement sections which can resist the increasing vehicular loads. A highway pavement is a structure consisting of different layers of prepared materials above the natural soil subgrade. The primary function of these layers is to disperse the applied vehicle load to the subgrade. The pavement surface should provide the acceptable riding quality, competent skid resistance i.e. adequately smooth. The main aim is to ensure that stresses conveyed due to wheel loads are adequately reduced, so that they will not go beyond the bearing capacity of the soil subgrade. There are mostly two types of pavements which are primarily recognized as, Flexible pavements and Rigid pavements.

1.2 Flexible Pavements

Flexible Pavement is constructed with the bituminous treated top surface course and its pavement structure is composed of several layers. Flexible pavements are those which have low or almost negligible flexural strength. Flexible pavements conveys wheel load stresses to the lower layers of the pavement by grain-to-grain particles by the contact of the aggregate through the granular particles of the structure.

Flexible Pavement consists of different layers which are as follows:

a) **Surface course:** Surface course is the topmost layer which comes directly in contact with the traffic loads and it is also known as Wearing course. These are usually constructed with the asphalt concrete. Various functions and requirements of Surface Course layer are as follows:

- It provides various characteristics such as friction, smoothness, drainage, etc. Also, it prevents the entrance of excessive surface water into the underlying base, sub-base and sub-grade layers.

- It must be enough tough to resist the distortion under traffic loads and should deliver a smooth and skid- resistant riding surface.
- It must be water proof so that it can protect the base and sub-grade from the weakening effect of water.

b) Base course: It is the layer of material below the surface course. It provides an additional load distribution layer and contributes the sub-surface drainage and consists of crushed stones or aggregates.

c) Sub-Base course: It is a layer of material beneath the base course and its primary function is to deliver the structural support to the top layers and improved drainage. It is the layer which is not always needed. For example, a pavement constructed is over a high quality, so stiff sub-grade may not need the additional features offered by sub-base course. In such situations, sub-base course may not be provided.

d) Subgrade: Subgrade is the material which is placed beneath the constructed pavement structure. Subgrades are usually compacted before the construction of a road and are sometimes stabilized by the addition of Portland cement, lime etc. The subgrade is the foundation of the structure on which the sub-base is laid. The overall strength and performance of a pavement is dependent not only on its design (including both mix design and structural design) but also depends on the load bearing capacity of the subgrade soil. The load bearing strength of subgrade is measured by California Bearing Ratio test (CBR Test). The CBR value of the subgrade material is mostly used to design the pavement crest thickness as per IRC: 37-2012 guidelines.

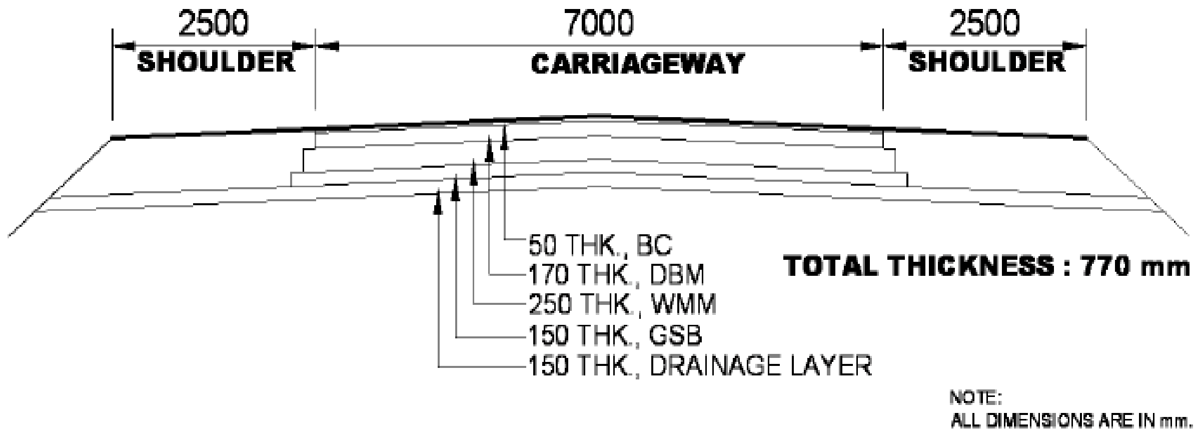

Plate 1.1 Section of Flexible Pavement designed as per IRC 37:2012

1.3 Failure of Flexible Pavement

Failures in flexible pavements can occur due to failure of one of the four different layers. There are several causes of failure in the flexible pavements. Some of them are listed as follows:

a) **Fatigue Cracking:** This a common type of failure in flexible pavement. It is also known as Map Cracking or Crocodile Cracking. Following are the primary causes of the fatigue cracking:

- Inadequate structural design.
- Due to the relative movement of the pavement layer material.
- Due to the repeated application of heavy wheel loads.
- Shrinkage or swelling of the subgrade layer due to moisture variation.

Plate 1.2 Fatigue Cracking

b) **Rutting:** Rutting is also a type of failure in flexible pavements. Usually, a rut is a depression or groove formed due the movement of wheels. Rutting is caused due to the following reasons:

- Due to the repeated application of load along the same wheel path results in longitudinal rutting.
- Wearing of the surface course along the wheel paths results in shallow rutting.

Plate 1.3 Rutting Failure

c) **Lack of binding to the lower course (Potholes):** When there is lack of binding between the surface course and underlying layer, due to this, some portion of surface course looses up the materials creating patches and potholes. The reason of formation of pothole is due to the lack of prime coat or tack coat in between the two different layers. Generally, potholes are the end results of the fatigue cracking. As fatigue cracking becomes severe, the interconnected cracks are converted into smaller pieces of pavements, which further get converted into potholes due to application of loads.

Plate 1.4 Formation of Pothole

1.4 Bituminous Mix Design

The bituminous mix design is used to determine the appropriate proportion of coarse aggregate, fine aggregate, bitumen and filler is required to build a mix which should be strong, workable, durable and economical.

Main objective of bituminous mix design are to calculate:

1. Optimum bitumen content (OBC) to ensure a strong and durable pavement.
2. The design mix should have adequate strength so that it can resist shear deformation under large traffic loads even at higher temperature.
3. There should be sufficient amount of air voids in the compacted bitumen to allow additional compaction done by traffic.
4. The mix must possess sufficient workability to avoid cracking in the pavement structure.
5. Should have sufficient flexibility so that it can avoid cracking due to heavy repeated traffic load.

1.4.1 Requirement for Bituminous Mixes

Bituminous mixes are composed of various composite materials consisting of coarse aggregates, fine aggregates, fillers together with bitumen. The mixes of flexible pavement consist of bituminous binder which binds the different aggregates with filler together to form a strong composite material.

In India, MORTH guidelines provide design specifications for different mixes like base course, binder course and for wearing course. The most important test in bituminous paving mixture is Marshall Mix Design which tests the major properties of the mixes like Stability value, Flow value, Durability, Flexibility & Skid Resistance (in case of wearing surfaces). In this mix design method, the Optimum Binder Content is determined that would perform satisfactorily and provide the desirable stability values and flow values. Selection of such components and their relative proportions has a major impact on the pavement section. Design of bitumen mixes for different layers widely consists of various steps which are as follows:

- Selection of gradation and type of mineral aggregates.
- Selection of grade and the type of binder to be used.

- Selection of the quantity of the binder which we are using so that it can satisfy the specific requirements of the mix properties.

The properties of asphalt mixes can be improved by making it more durable, cost effective and by the addition of various sustainable polymers like LDPE, HDPE etc. Various forms of modifications can be induced in physical properties of asphalt mixes and stability of asphalt mixes can be calculated by using different materials like waste crumb rubber, waste plastic (Polyethylene), mineral fillers and various different types of polymers.

1.5 Bituminous Concrete Mix

The bituminous concrete is the top layer in the road construction. Bituminous concrete mix layer is also called Surface course layer. Surface course is the layer which comes directly in contact with traffic loads so it is mainly composed of superior quality of materials. These are normally constructed with the dense graded asphalt concrete. Bituminous concrete layer should be tough enough so that it can resist the traffic loading and should provide a smooth and skid – resistant riding quality to the surface. Marshall Mix Design method is usually adopted for the mix design of Bituminous Concrete Mix.

1.5.1 Material Specification for Bituminous Concrete Mix

Bitumen

The bitumen used for Bituminous Concrete layer is a paving bitumen of different viscosity grade (VG10, VG20, VG30, VG40) following the IS specifications for “Paving Bitumen” IS 73:2013 and the penetration is specified by MORTH Specifications for Road & Bridge works (Fourth Revision, Reprint March 2007) for Bituminous Concrete.

Different Viscosity grades of bitumen are as follows:

- VG-10 Bitumen: VG-10 is widely used in spraying applications such as surface-dressing and paving in very cold climate. It is also used to manufacture Bitumen Emulsion.
- VG-20 BITUMEN: VG-20 is used for paving in cold climate & high altitude regions.
- VG-30 BITUMEN: VG-30 is primarily used to construct extra heavy duty bitumen pavements that need to endure substantial traffic loads. It is also called 60/70 Penetration grade.

- VG-40 BITUMEN: VG-40 is used in highly stressed areas such as intersections, near toll booths and truck parking lots. Due to its higher viscosity, stiffer bitumen mixes can be produced to improve resistance to shoving and other problems associated with higher temperature and heavy traffic loads.

Coarse Aggregates

The coarse aggregates for Bituminous Concrete (BC) mix consist of crushed rock, gravel and other stiff or hard material which is retained on 2.36 mm sieve. The coarse aggregates should be clean, hard, durable, free from dust or undesirable material and any organic matter, of cubical shape having proper flakiness. The fragments of crushed stone should be durable or crushed gravel having uniform quality throughout where the contractor’s selected the source of aggregates has a poor affinity or bonding with bitumen, as a pre-requisite that bitumen shall be treated with a good quality anti-stripping agent without additional payment. The aggregates should be classified according the standard limits which are indicated in the Table 1.1.

Table 1.1 Physical Requirements of Coarse Aggregate for Bituminous Concrete [MORTH, Clause 507.2.2]

Property	Test	Specification
Cleanliness	Grain Size Analysis	Max 5% Passing 0.075mm Sieve
Particle Shape	Flakiness And Elongation Index	Max35%
Strength	Los Angeles Abrasion Value Aggregate Impact Value	Max 30% Max 24%
Durability	Soundness Sodium Sulphate Magnesium Sulphate	Max 12% Max 18%
Water Absorption	Water Absorption	Max 2%
Stripping	Coating And Stripping Bitumen Aggregate Mixtures	Minimum Retained Coating 95%
Water Sensitivity	Retained Tensile Strength	Min 80%

Fine Aggregates

Fine aggregates for BC layer consists of naturally occurring material or crushed aggregates passing through 2.36mm sieve and retaining on 75 micron sieve and should be free from dust and should be stiff and durable.

1.6 Aggregate Gradation and Binder Content

The word "grading" refers to diversity in the size of the aggregates. In accordance with IS: 2386 Part 1, the combined gradation of both fine aggregates and coarse aggregates for particular mixture should fall within the specified limits as shown in Table 1.2, for both Bituminous Concrete grading 1 and 2. In this table, the particular type and quantity of bitumen and thickness is specified for each type of mixture.

Table 1.2: Gradation of Bituminous Concrete [MORTH, Clause 507.2.5]

MORTH Specified Gradation For Bituminous Concrete		
Grading	1	2
Nominal Aggregate Size	19 mm	13.2mm
Layer Thickness	50 mm	30-40 mm
IS Sieve, mm	Cumulative % by weight of total aggregate passing	
45	-	-
37.5	-	-
26.5	100	-
19	90-100	100
13.2	59-79	90-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10
Bitumen content % by mass of total mix	Min 5.2*	Min 5.4**

The minimum binder content for Bituminous Concrete mix for Grading–1 is 5.2% by mass of total mix and for Grading-2 is 5.4% by mass of total mix. If the specific gravity of aggregates is more than 2.7, then minimum binder content can be reduced proportionately.

1.7 Mix Design of Bituminous Concrete

Apart from satisfying the grading & quality requirement for individual ingredient used as explained above, the mixture should satisfy the following requirements listed in the Table 1.3 as per MORTH (Fifth Revision)

Table 1.3 Requirements of BC Mix [MORTH, Clause 505.3.1]

Properties	**Viscosity Grade Paving Bitumen**	**Modified Bitumen**		**Test Method**
		Hot Climate	**Cold Climate**	
Compaction Level	75 blows on each face of the specimen			
Minimum Stability (KN at 60˚C)	9.0	12.0	10.0	AASTHO T245
Marshall Flow (mm)	2-4	2.5-4	3.5-5	AASTHO T245
Marshall Quotient (Stability/Flow)	-	2.5-5		MS-2 & ASTM D2041
% Air Voids	3-5			-
% Voids Filled With Bitumen (VFB)	65-75			-
Coating of aggregate particle	95% minimum			IS:6241
Tensile strength ratio	80% minimum			AASTHO T283
% Voids in Mineral Aggregates (VMA)	Minimum percent voids in mineral aggregates (VMA) for Grading-1 BC for maximum particle size 19 mm for Design Air Void percent of 3,4 and 5% are 12, 13and 14 respectively			

1.8 Binder Content

The binder content shall be optimised to achieve the requirements of the mix set out in Table 1.3 as per traffic conditions. The Marshall method is used for determining the optimum binder content. The optimum binder content can be calculated as follows:

Determination of Optimum Binder Content:

Determination of optimum binder content for the mix design of Bituminous Concrete is calculated by taking the average value of following three bitumen contents found form the graphs obtained from the experimental work which are as follows:

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

1.9 Various Additives used in the Bituminous Mixes

When various additives are used in the bituminous mixes, these are known as bitumen modifiers. The additives like polymers, rubber or the blend of the two or more should be selected in such a way that they should have the following properties (IS 15462 – 2004):

a) Additives should be compatible with the bitumen.
b) Can resist degradation at various mixing temperatures.
c) Should capable of being processed by ordinary or conventional mixing & laying machinery.
d) Should maintain properties like penetration, ductility, viscosity etc during application, in-service and storage.
e) Produce required coating viscosity at application temperature.

1.9.1 Polymer Modified Bitumen (PMB)

Classification of Polymer Modified Bitumen (IS 15462 - 2004)

The polymer and crumb rubber modified bitumen are classified into different four categories which are as follows:

a) Type A PMB (P) - Plastomeric Thermoplastics
b) Type B PMB (E) - Elastomeric Thermoplastics
c) Type C NRMB - Natural Rubber and Latex Based.
d) Type D CRMB - Crumb Rubber/ Treated Crumb Rubber.

Type-A, Type-B and Type-C for modified bitumen can be further classified into three different grades according to their penetration value as follows:

GRADES OF PMB (P)

- **PMB (P) 120**: PMB (P) 120 means that Type A PMB (P) with penetration value in between 90 to 150.
- **PMB (P) 70:** PMB (P) 70 means that Type A PMB (P) with penetration value in between 50 to 90.
- **PMB (P) 40:** PMB (P) 40 means that Type A FMB(P) with penetration value in between 30 to 50.

GRADES OF PMB (E)

- **PMB (E) 120:** PMB (E) 120 means that Type B PMB (E) with penetration value in between 90 to 150.
- **PMB (E) 70:** PMB (E) 70 means that Type B PMB (E) with penetration value in between 50 to 90.
- **PMB (E) 40:** PMB (E) 40 means that Type B PMB (E) with penetration value in between 30 to 50.

GRADES OF NRMB

- **NRMB 120**: NRMB 120 means that Type C NRMB with penetration value in between 90 to 150.
- **NRMB70**: NRMB 70means that Type C NRMB with penetration value in between 50 to 90.
- **NRMB 40**: NRMB 40means that Type C NRMB with penetration value in between 30 to 50.

1.9.2 POLYMERS

Polymers are the substances having large molecule size and high molar masses and are composed of large number of repeating structural units. There are both naturally occurring as well as synthetic polymers with a large variety of properties. Polymers mainly include plastics, proteins, starches, cellulose and elastomers, which, mainly include the natural and synthetic rubber. Natural rubber is an example of natural polymer made from latex found in plants.

1.9.2 (a) Crumb Rubber Modified Bitumen (CRMB)

CRMB is based on a unique technology that permits homogeneity, stability and consistent properties of the binder throughout. This can be achieved by adding special stabilising additives to form a high performance bituminous binder having unique properties. As the road structures are deteriorating more rapidly due to increase in the traffic density and vehicular loads, so to minimise the damage to the pavement surface, Crumb Rubber Modified Bitumen is designed to maximise the resistance to permanent deformation (rutting) and reduce fatigue cracking of asphalt mixtures that are used in the most demanding locations. In order to improve the road pavement performance properties, the modification of bituminous binder has to be done. There are various types of additives such as styrene-butadiene styrene (SBS), ethylene-vinyl acetate (EVA), styrene butadiene rubber (SBR) & crumb rubber modifier (CRM) which greatly enhances the binder performance, improves elasticity, reduced temperature susceptibility. The use of these commercial polymers in pavement construction increases the cost of construction as these are highly expensive materials. However, CRMB is used as an alternative material which is formed from waste tyre rubbers and is environmentally beneficial and relatively less expensive.

In recent years, CRMB bitumen binders have reported many advantages which includes improved rutting resistance due to its high viscosity, high softening point, better resilient modulus, reduction in fatigue/cracking, increase in durability and reduced maintenance cost. Due to these reasons CRMB is suited for use in heavy load traffic lanes, air fields etc.

Different types or Grades of CRMB (Type – D)

Type - D Polymer Modified Bitumen can be classified into three types based on the softening values given below:

- **CRMB 50:** CRMB 50 means CRMB Type D bitumen having minimum softening point value of 50.
- **CRMB 55:** CRMB 55 means CRMB Type D bitumen having minimum softening point value of 55.
- **CRMB 60:** CRMB 60 means CRMB Type D bitumen having minimum softening point value of 60.

1.9.2 (b) Plastic Waste

Plastic is a very common material used in day-to-day life. In present day, every vital industry uses plastic like PVC pipes, furniture industry, food, packaging and automobile because it is a very cheap and effective raw material. As plastic is a non-biodegradable material, it remains unchanged for thousands of years; so its disposal is a major problem in present time as it is a threat to human body and environment. Due to its improper disposal many problems can arise; For example, it may be mistaken as is food by the animals. It may cause reproductive problems in humans, causes breast cancer, genital abnormalities and much more. The risk of family health & safety would increase further and above all, the environment burden would be numerous.

Due to these reasons, the government has made it mandatory for road developers to use waste plastic material along with the bituminous mixes for the construction of the roads to overcome to the problem of the growing waste plastic disposal. The road developers will now have to use the waste plastic material along with the hot mix asphalt for the construction of roads within 50 km of periphery of any city which has a population of over five lakh.

Role of Polyethylene in Bituminous Pavements

Use of polythene in bituminous pavements is not new. These days it is mandatory to use waste polythene in the construction of bituminous pavements. Waste plastic or polythene is added to hot mix asphalt mixture and the process of laying mixture on the surface of road is similar to a normal tar road. Plastic roads consists mainly of waste plastic carry bags, water bottles, soft drink bottles, and disposal cups. All this raw material is collected from the municipal waste dump which is helpful in the construction of asphalt pavements by using waste raw material. By adding these polymers, modifications are done in the design mix of the bituminous concrete pavements which causes reduction in the rutting, thermal cracking in the pavement and improves the fatigue life of the pavement. Rheological studies are commonly used to improve the characteristic property of the polymer modified bitumen. So, using the waste polythene which enhances the properties of HMA mixes not only produces stronger and better pavements but is a beneficial way of disposing the large amount of waste plastic and makes environment healthy and pure.

Advantages of using Polythene/Waste Plastic as a Modifier (IRC SP:98-2013)

- Higher resistance to deformation.

- Improved stability & strength.
- Has binding property; hence it is used as a binder.
- High resistance to water induced damages.
- It increases durability & improves fatigue life.
- Coating of aggregates can be easily done.
- Material is locally available and its use makes the environment safer.

Processes for Manufacturing of Bituminous Mix Using Waste Plastic

There are mainly two important processes which are used for manufacturing of bituminous mixes used in construction of flexible pavement. These are explained as follows:

- **Dry Process:** For Flexible Pavements, hot aggregates at 170˚C are mixed with hot bitumen at 160˚C and the mix is used for laying of the roads. In this process, waste plastic is cut into smaller pieces and are coated over the surface of the aggregates. After heating to a temperature of 170˚C, plastic coated aggregates are mixed with hot bitumen and are laid on the surface of roads.
- **Wet Process:** In Wet Process, waste plastic is converted into powdered form. In this process, firstly waste plastic is blended with hot bitumen and the homogenous mixture of hot bitumen with melted plastic is mixed with aggregates.

1.10 Organisation of Thesis:

This research has the following structure:

- Chapter 1 gives an introduction and a discussion on the various types of binders, materials and additives used the Marshall Mix method.
- Chapter 2 provides an insight on the relevant literature needed to conduct this research.
- Chapter 3 covers the details on the various materials used, methodology and explains the tests adopted to carry out this research.
- Chapter 4 discusses the detailed test results and achievements of the objectives.
- Chapter 5 discusses if the test results are in acceptance with objectives set initially. Conclusions are made and future scope of work is discussed.

Chapter – 2

Literature Review

2.1 General

In this chapter, a review of previous research studies conducted to study the effect of various additives used in the bituminous concrete mixtures with the use of different type of asphalt binders is presented and discussed. Based on this review, a gap was identified in the existing literature; suitable research area was decided for this study.

2.2 Use of VG-30 Bitumen in Bituminous Mixes

Dhara et al (2016) calculated the strength of different mixes of bituminous concrete using Marshall test method. Asphalt binder used in this case was VG-30 & VG-10 and their properties were compared. The optimum bitumen content for VG-10 and VG-30 are 6.0%, and 5.05% respectively. Stability of VG 30 at optimum bitumen content 5.05% of 2 % Epoxy Resin was higher than VG-10 at Bitumen content 6.0% of 3% Epoxy Resin and Flow was decreased. In case of VG-30 bitumen, maximum stability value i.e. 1490.55 kg was attained at 5% of bitumen, where as in case of VG-10 bitumen, Maximum stability i.e. 1650.6 kg was attained at 6% of bitumen. In this, it is also observed that Epoxy Resin was used as Modifier and shows improved results.

Singh and Gupta (2015), evaluated the mix properties of bituminous mixes made by the use of different grading of bitumen binders like VG10, VG30 and VG40 and different grading of aggregates. Bituminous mix testing was done on these materials and their stability values, flow values were compared with each other and their optimum asphalt binder content was compared i.e. for VG10 (6%), VG30 (5.8%) and VG40 (5.6%) OBC was calculated and their stability value comes out to be i.e. for VG10 1650.6 kg, VG30 1867.6 kg and VG40 1993.5 kg.

Bhargav and Gautam (2013), tried to find the optimum temperature by which the bituminous mix temperature was reduced by the warm mix asphalt technology. Rediset organic additive was used as an adhesive with the bitumen binder VG-30. There was significant difference in properties of mix with addition of additive with VG-30 asphalt binder. With addition of 2%, Rediset stability at 120˚C was calculated to be 1656 kg and at 2.5% Rediset at 120˚C, it reduces to 1272 kg. Results shows that there was a (30-40) °C reduction in mixing & compaction temperature of bituminous mixes by adding 2% of additive which satisfies all the volumetric requirement for both the asphalt binders resulting in better performance of the bituminous mixes at the lower temperature.

2.3 Use of Waste Plastic (Polyethylene) in Bituminous Mix

Kazmi and Rao (2015) investigated the use of waste plastic material (Polyethylene Bags) [LDPE] in the shredded form which is used as a binding agent in the construction of Flexible Pavements. In this study, polyethylene was used as a binding agent with bitumen VG-30 grade as a replacement of bitumen with different proportions 5, 7, 9 and 11% and properties of mix is carried out. There was substantially increase in the stability value of blended material in comparison to normal VG-30 asphalt binder. The results showed that the waste plastic materials can be incorporated as a binding agent for the construction of flexible pavements. Addition of 9% LDPE was found to be the optimum binder proportion. Marshal stability with addition of 9% of LDPE comes out to be 1590.2 kg and it was 32.5% greater than the standard value of a minimum 1200 kg. The flow range of 2.9 - 3.0 was also well within the required range.

Ahmad (2014) used Low Density Poly-Ethylene (LDPE) plastic waste from kitchens and carry bags as an additive for the modification of bituminous concrete mixes. In this study, the main purpose of using waste plastic was to construct better roads which can resist increased traffic loads and can reduce cracking in the pavement surface. In this paper, Dense Bituminous Macadam (DBM) mix was prepared by using normal bitumen VG-30 as a control specimen and bitumen was mixed with waste plastic polyethylene (LDPE) in different proportions of 2, 4, 6, 8, 10 and 12% by weight of bitumen. The average values of all vital parameters were taken out of the three replicate tests specimens of most significant percentages (8, 10 and 12%) of plastic waste. The Marshall tests were conducted on DBM mixes. It was observed that the plastic waste modified bitumen mix show better binding property, stability, and is more resistant to water. The addition of LDPE (PW) reduces the air voids which prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in enhancement of Marshall Stability value. Hence, the latest technology not only provides strength to the roads but also increases the road life and will help to improve the surrounding environment. The results are shown in Table 2.1

Table 2.1 Results of DBM Mixes for varying Percentage of LDPE

S. No	LDPE Waste (%)	Bitumen Content (%)	Marshall Stability Value (kg)	Flow Value (mm)	Bulk Density of Mix(gm/cc)	Air Voids (%)	VMA (%)	VFB (%)
1	0.0	4.5	889.0	3.46	2.01	5.65	14.2	64.8
2	8.0	4.5	945.0	2.60	2.25	4.83	16.9	69.7
3	10.0	4.5	970.5	2.41	2.35	4.20	19.8	71.6
4	12.0	4.5	1012	2.30	2.51	3.17	20.5	73.9

It has been observed that the stability values of mixes modified with plastic waste have been increased significantly upto 14% at 12% waste as compared to mix prepared with plain bitumen. This shows the enhancement in strength of the mix due to addition of plastic waste which signifies that the inclusion of plastic waste increases the density of the mix.

Akinpelu et al (2013) used Polyethylene as a binder modifier. In this six different proportions of waste plastic by weight of optimum binder content was selected i.e. 2.5, 5.0, 7.5, 10.0, 12.5 and 15%. The waste plastic was incorporated using wet process as a replacement and various properties were tested like Bulk Density, Stability and Flow. The results showed the increased stability value, reduced density and slightly reduced flow value for all percentages. The optimum proportion of modifier was obtained at 12.5% by the weight of optimum binder content (OBC). The improvement in stability value of the modified asphalt binder using polyethylene is mainly due to an increase in adhesion and cohesion properties of the asphalt binder which will enhance the higher fatigue resistance value and reduce thermal cracking and rutting.

Prasad et al (2012) used waste plastic bottles as a modifier in Marshall Test. In this test, bitumen was blended with waste plastic bottles in shredded form to form modified blended bitumen with the help of wet process with different grades of asphalt binder. The results showed that the maximum value of stability was attained at 8% waste plastic i.e. 1552 kg by the weight of bitumen and flow is 6 mm and voids filled with bitumen (VFB) was 74.238 % with 60/70 grade asphalt binder. The maximum stability of 1963 kg was attained at 8% waste plastic by the weight of bitumen and associated flow was 4.7 mm and VFB is 71.942%. Results are shown in Table 2.2 which is as follows:

Table 2.2 Results of Marshall Stability Test for BC Grade –1 for varying Waste Plastic %

S. No.	Waste Plastic (%)	Bitumen (%)	Marshall Stability (kg)	Flow Value in 0.25(mm)	Air Voids (%)	VMA (%)	VFB (%)
1	0	5.2	1231	5.7	7.7	19.477	60.46
2	2	5.2	1272	6	7.5	19.326	60.86
3	4	5.2	1291	6	5.3	17.201	68.93
4	6	5.2	1300	6	5.5	17.273	67.82
5	8	5.2	1552	6	4.0	15.786	74.23
6	10	5.2	1525	6	3.7	15.446	75.54
7	12	5.2	1258	5.7	2.6	14.283	81.38

Swami et al (2012) used waste plastic bags collected from dump site, garbage etc. The shredded waste plastic were added in the hot bitumen having temperature (160˚C - 170˚C) and blended properly. The results showed that with the increase in polymer content, the penetration value was decreased i.e. the modified asphalt binder gets softer with the addition of polymers. The polymer blended bitumen shows better resistance towards water also, due to better binding property of polymer and bitumen. Also, plastic has the property of absorbing sound, which helps in reducing sound pollution caused due to heavy traffic.

2.4 Use of CRMB in Bituminous Mixes

Sahu and Joshi (2015) used Crumb Rubber Modified Bitumen (CRMB-60) blended with normal asphalt binder VG-30 with various different percentages of crumb rubber in different proportions with constant optimum binder content i.e. 5% which shows improved characteristics when compared with regular bitumen. The density of the mix was also increased by 25% with the addition of CRMB as compared with normal VG-30 asphalt binder and also cost analysis had done in accordance with 12 years. The cost analysis was performed for both the asphalt binders i.e. VG-30 and CRMB-60 including 12 years maintenance cost. The cost for Bituminous course for CRMB-60 came out to be Rs 68.23 Lacs per Km which was 20.81% economical than the bituminous work done by normal VG-30 bitumen. Following are the results shown in Table 2.3.

Table 2.3 Mix Design values of Crumb Rubber Modified Bitumen

S. No.	Crumb Rubber (%)	Bitumen (%)	Marshall Stability (kg)	Flow Value (mm)	Bulk Density (g/cc)	Air Voids (%)	VMA	VFB (%)
1	8	5	883.86	2.4	2.48	3.90	14.84	73.66
2	9	5	988.39	2.67	2.49	3.74	14.63	74.38
3	10	5	1049.59	2.93	2.49	3.67	14.53	74.74
4	11	5	1122.36	3.23	2.49	3.56	14.40	75.25
5	12	5	1230.78	3.57	2.50	3.22	14.07	77.05
6	13	5	1155.65	3.83	2.51	3.19	13.84	76.91
7	14	5	1137.97	4.03	2.52	2.85	13.48	78.79
8	MORTH & IRC Specifications		1200	2.5–4.0	2.0-3.0	3.0-5.0	Min.12	65-78

Anwar (2014) prepared two specimens of different sizes i.e. 100 mm and 150 mm diameter and with different mix design methods. These specimens were tested for properties such as Stability, Flow and Indirect Tensile Strength test (ITS) using crumb rubber as in dense graded bituminous macadam with varying percentages i.e. 10, 15, 20, 25 and 30% respectively of CRMB bitumen. In two different design methods, mix formed by Modified Marshall method shows better results in comparison with simple Marshall method.

Teppala et al (2014) conducted Modified Marshall test using Crumb Rubber Modified asphalt binder (CRMB-55) with and without addition of chemical Zycosoil in small doses i.e. 0.03%, 0.04% and 0.06% added by the weight of bitumen. The results showed that with the addition of chemical Zycosoil the penetration value gets decreases and material becomes stiff. With 0.04 % dosage of Zycosoil chemical, the change with elastic recovery is also noted indicating more flexibility to the binder and to increase the life of pavement at low temperature. The Marshall Mix design using CRMB 55 with 0.04 % Zycosoil chemical, reflects the significant rise in stability, unit weight and flow values for better compaction and enhancing the workability conditions.

2.5 Indirect Tensile Strength Test on Bituminous Mixes

Archana et al (2014) investigated the Marshall test and Indirect Tensile Strength test. In this 60/70 asphalt grade bitumen and waste plastic was used in semi dense bituminous concrete mix and was prepared by Dry Process i.e. waste plastic was added along with the heated aggregates and the mix was prepared. Indirect Tensile Strength test is conducted on both with and without plastic samples in accordance with both Dry sample and Conditioned samples. As a result, Indirect Tensile Strength test (ITS) for SDBC (Semi Dense Bituminous Concrete) mixes at optimum binder content was lower when compared with modified SDBC mix modified with waste plastic. The SDBC mixes with 8% plastic exhibited better results as compared to non-modified SDBC mixes.

Anwar (2014) prepared two specimens of different sizes i.e. 100 mm and 150 mm diameter and with different mix design methods. These specimens were tested for properties such as Stability, Flow and Indirect Tensile Strength test (ITS) using crumb rubber as in dense graded bituminous macadam with varying percentages i.e. 10%, 15%, 20%, 25% and 30% respectively of CRMB bitumen. In two different design methods, mix formed by Modified Marshall method shows better results in comparison with simple Marshall method.

Panda et al conducted laboratory investigations on the bituminous concrete mixes using waste polyethylene. The polyethylene was added in the form of milk pouches from OMFED (Odisha Milk Federation) in various percentages with 80/100 grade asphalt binder . Optimum binder content was fixed i.e. 5% and polyethylene percentages were varied in the bituminous mix. Indirect Tensile Strength test (ITS) has been carried out as per ASTM D-6931 standards at 25˚C. Results showed that ITS value increases with the increase in concentration of plastic content upto 4% and decreases thereafter with addition of more plastic and is showed graphically in Figure 2.1

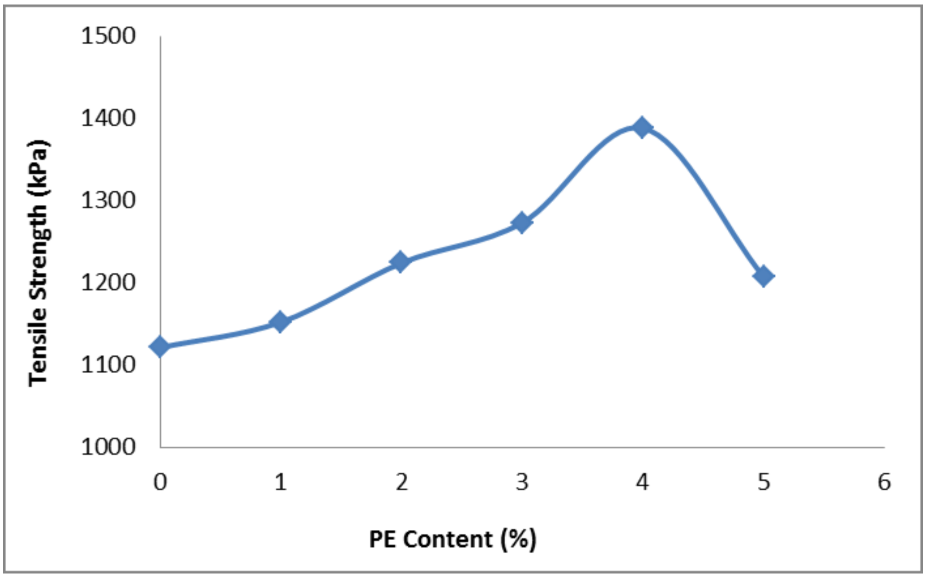

Figure 2.1 Variation of Tensile Strength with Polyethylene

2.6 Dynamic Shear Rheometer (DSR) Testing on Various Bituminous Mixes

Joshi et al (2013) conducted Dynamic Shear Rheometer (DSR) test on re-acclaimed asphalt binder from four year old pavement stretch to study the rheological properties of the bitumen binder such as Complex modulus (G*), Phase angle, Rutting and Fatigue parameters. Rutting is caused mainly due to permanent deformation of the mix where as fatigue is related to energy absorbed during repeated application of loads to the pavement. After testing values of G* should be in the range of (500 – 6000 Pa) where as Phase Angle should be in the range of (52.54˚ - 77.35˚). Larger the phase angle, more viscous the material will be. The results indicated that the asphalt binder extracted from the stretches was stiff enough to resist rutting & fatigue failure. Out of six different sections of roads i.e. C1, C2, C3, C4, C5 and C6, The section C4 has the least resistance to rutting 31.936 kPa and fatigue 30.34 while section C1 has the highest resistance to rutting i.e. 402.90 kPa and fatigue 253.80 kPa. But, the values for all the sections are within the permissible limits.

Ramprasad et al (2013) investigated the behaviour of bitumen grade 60/70 using both unmodified and modified bitumen with crumb rubber. The various Marshall properties and Indirect tensile strength (ITS) were compared for the specimens of bituminous mixes prepared at optimum binder content (OBC) for grade-2 bituminous concrete (BC). CRMB showed higher Marshall Stability value, reduced flow value, higher ITS value and improved rheological properties only in terms of rutting. The results also showed that the variation of Complex Modulus (G*) with the temperature; In general, the complex modulus (G*) of plain bitumen is less when compared with CRMB 55 and CRMB 60. Amongst this, CRMB 55 shows higher complex modulus value at lower temperature and it was clearly observed that the virgin bitumen fails i.e. (value of complex modulus is less than 1 kPa) at temperature 64˚C, but CRMB 55 and CRMB 60 bitumen fails at higher temperature of 70˚C. This clearly indicates that CRMB bitumen grades are less susceptible to temperature changes as compared to plain bitumen.

Pareek et al (2012) conducted an experimental study on Marshall Test using conventional bitumen 60/70 grade and Polymer modified bitumen (PMB). In this study various parameters such as rutting resistance, indirect tensile strength and resilient modulus were calculated and compared for both the mixes. For conventional bitumen 60/70 grade, the optimum binder content came out to be 4.74% and for PMB-70 was 5.02%. The stability of bituminous concrete mix using PMB-70 came out to be 23.50 kN where as in case of 60/70 grade bitumen is 18.55 kN i.e. for PMB mix Marshall Stability was increased by 27%. The Rutting parameter for 60/70 grade bitumen for different temperatures 45, 55, 65˚C was 28.84, 7.50, 1.73 kPa respectively and for PMB-70 was 73.14, 18.86, 6.32 kPa respectively. The indirect tensile strength of conventional 60/70 grade bitumen and polymer modified bituminous concrete mixes were found to be 492 kPa and 591 kPa respectively. It shows that the tensile strength of PMB mix was 20% higher than the conventional bituminous mix.

Mahrez et al (2010) investigated the visco-elastic behaviour of asphalt bitumen binder modified with waste plastic bottles as compared to the ordinary 80/100 asphalt binder. The percentage of waste plastic bottle modifier was varied to examine its effects on the rheological properties of the plastic waste modified binders. The effect of waste plastic modifiers influenced the rheological properties of asphalt binder by increasing its complex modulus (G*) value and decreasing phase angle. The results showed that all the specimens exhibited a decrease in complex modulus (G*) values with addition of waste plastic. Further with the increase in temperature, phase angle also increased. In General, the waste plastic modified bitumen showed slightly higher complex modulus (G*) values throughout the test temperature range as compared to the original asphalt binder. The high complex modulus value indicates that binder strength had increased which further shows higher rutting resistance value.

Nanda et al examined the comparative performance of asphalt binder of grade 60/70 with two types of modified bitumen i.e. Crumb Rubber Modified Bitumen (CRMB-60) and Polymer Modified Bitumen (PMB-70). The rheological properties of both modified and base bitumen were studied using Dynamic Shear Rheometer (DSR) to examine the visco-elastic behaviour before & after ageing for both the asphalt binders. The effect of ageing of asphalt binder on the rheological properties and Marshall properties such as stability and flow was studied. The Marshall properties of bituminous mixes were compared at optimum binder content (OBC) for bituminous concrete. Results showed the higher Marshall Stability value, reduced flow value, improved tensile strength & improved rheological properties for the modified bitumen when compared to the base bitumen. PMB-70 and CRMB-60 shows higher complex modulus value (G*) when compared to base bitumen at the temperature range between 50-70˚C.

CHAPTER - 3

MIX DESIGN & TESTING ON BITUMINOUS MIXES

3.1 Marshall Test for Bituminous Concrete Grade-1

Marshall Mix design method is a design methodology which is adopted worldwide for determining the strength and flow characteristics of the bituminous paving mixes. It is generally used for design of bituminous mixes which can withstand with heavy traffic loads even under adverse climatic conditions by fulfilling the requirements of the pavement surface characteristics. It is a very popular method in India for characterization of bituminous mixes and also used to calculate Optimum Binder Content (OBC) for different mixes and for studying the various Marshall Characteristics such as Marshall Stability value, Flow value, VMA, VFB, Unit Weight in a mixture etc. Further, the Marshall properties such as stability value, flow value, unit weight are calculated to determine the optimum binder content (OBC). The main objective of the design of bituminous mix is used to determine an economical blend through various trial mixes. The resulting mix should satisfy the following conditions:

(i) Sufficient binder should be used to ensure a strong and tough pavement by providing a water proofing coating on the surface of aggregate particles & binding them together under the suitable compaction.

(ii) Provide sufficient stability for resistance to deformation under repeated loads. This resistance in the mixture is obtained from aggregate interlocking and cohesion which generally develops due to binder in the mix.

(iii) Sufficient flexibility should be provided to withstand deflection and the bending without cracking. So, to obtain desired flexibility, it is necessary to have proper grade of bitumen.

3.2 Objective

To determine the optimum binder content (OBC) of Bituminous Mix by the Marshall Method of mix design using various additives such as VG-30 bitumen, using waste plastic and waste tyre tube rubber.

3.3 Test Procedure and Set up is as per ASTM D6927-06 Standard Test:

a) Compaction mould having cylindrical shape of diameter 101.6 mm and of height 63.5 mm height, extension collar and a base plate. Both ends of the cylindrical mould are interchangeable and can be placed on the round circular base plate.

b) A mechanical compaction hammer with a flat, circular tamping face with a nominal diameter of 98.4 mm and a hammer of weight 4.54 kg which can be lifted and released to obtain free fall of 457 mm.

c) Compaction pedestal and mould holder, consists of a wooden block capped with a steel plate to hold the mould assembly in position during compaction; also a mould holder with spring tension device to hold the compaction mould in place on the compaction pedestal.

d) An oven for heating the bituminous mixture & specimen mould assembly at certain required temperature.

e) Hot plates for heating compaction hammer having circular plate at bottom, spoon and spatula.

f) A flat steel spatula is required with blade having size 25 mm wide and should be of length 150 mm and stiff enough to penetrate the entire bituminous mixture.

g) Thermometer is essentially required to for determining the temperature of the hot bituminous mixtures. It should preferably be a dial type having temperature range of 10 to 200˚C.

h) A balance or weighing machine for measuring the weight of the mix. The sensitivity of the balance should be at least one gram.

i) Trowels for making the bituminous mix and for placing the bituminous mix in the mould assembly.

j) A specimen extractor suitably fitted with a jack or compression machine, for extruding the compacted specimen from the mould. Testing head consists of upper & lower cylindrical segments of test head with an inside radius of 51 mm. The lower segment is mounted on the base having two vertical guide rods which facilitates insertion in the holes of upper test head.

    - The Marshall Stability testing machine consists of a motorized loading unit provided with a gear system to lift the base plate upward at the specified rate. It consists of calibrated proving ring of 10 tons capacity fitted with a dial gauge. The strain controlled loading machine produces a movement of the base plate at the rate of 50.8 mm/ min. at 60˚C

- A water bath of sufficient depth is required for the complete immersion of samples. The samples are thermostatically controlled so as to maintain the water bath at 60±1°C.

Plate 3.1 Specimen Extractor

The plate 3.1 shows the specimen extractor, which is provided with the jack, which makes the extraction of sample easier from the mould.

3.4 Preparation of Test Specimen

1) Prepare a mix of coarse aggregate, fine aggregate and mineral filler material in such a proportion that the final mix after blending should have the gradation within the specified range.
2) 1200 grams aggregates blended in the desired proportions is measured correctly and then heated in a oven to the mixing temperature of 175˚C to 190˚C.
3) Before placing in the mould, the temperature of the mixture and a mould assembly (base plate, mould and collar) was approximately 143°C. The face of the compaction hammer was thoroughly cleaned and heated on a hot plate set at approximately143°C.

The temperature of the laboratory during compaction of the specimens was between 20˚C and 30°C.

4) The bitumen binder is heated to a temperature of 120˚C to 165˚C (depending upon the type and grade of the binder used). The required quantity of bitumen is calculated as per the percentage binder by the weight of the total mineral aggregates specified in the mix design or the job mix formula. The weighed quantity of the heated bitumen is added to the heated aggregate and the mixture is thoroughly mixed at the specified mixing temperature of 160˚C, using a mechanical mixture or by hand mixing with trowel.
5) The mixing is done thoroughly such that the surfaces of the aggregates are uniformly and fully coated with the binder. It is necessary to maintain the specified compacting temperature of the mix. The recommended compacting temperature is about 138˚C for VG 10 grade asphalt binder and about 149˚C for VG 30 grade asphalt binder. If necessary, the mixture and mould shall be returned to an oven at the required temperature for the minimum time necessary to achieve the required Compaction temperature.
6) Apply the calibrated number of blows (approximately 75) with the mechanical compaction hammer. Compaction should be performed at a minimum rate of 30 blows per minute. The compaction hammer shall apply only one blow with each fall, i.e. there shall not be a rebound impact. Remove the base plate and the collar, and reverse and reassemble the mould. Apply the calibrated number of compaction blows to the face of the reversed specimen.
7) Remove the collar, base plate and allow the specimen to cool down. Cooling may be done at the room temperature in 25°C air bath. The sample shall be kept in the mould for a minimum period of 24 hours to allow it to cool down, stiffen and gain strength.
8) Extrude the specimen from the mould. Proper care should be taken while extruding the specimen from the mould, so as not to develop tensile stresses in the specimen or tear the sides of the specimen.
9) The compacted specimen should have a thickness of 63.5$\pm$1.5 mm.

3.5 Specimen Testing

Following is the procedure for the testing of specimens prepared above**:**

a) Measure the height of the specimens to the nearest 0.1 mm. Prior to measurement to height, the excess material should be brushed out from the edges of the specimens. The diameter of the compacted specimens should be 101.6 mm and 63.5 mm height are prepared.

b) Each specimen prepared is weighed in air and the average diameter and thickness of the cylindrical specimen is obtained by taking measurements at three or four locations of the specimen. The weights of the specimen in air and its apparent weight by suspending it in water are also noted to determine the density or specific gravity of each compacted bituminous mix specimen.

c) Calculate the bulk density of the specimen from weight and volume.

d) The specimens to be tested are kept immersed under water in a thermostatically controlled water bath maintained at 60 ± 1˚C for 30 to 40 minutes. Prior to testing, it should be assured that inside of the test heads are clean, and the guide rods are properly lubricated so that the upper test head slides freely over other.

Plate 3.2 - Samples Extracted from Marshall Mould

Plate 3.2 shows the compacted specimens consists of different percentages of bitumen.

e) The breaking head temperature is maintained between 21˚C to 38°C, using a water bath when required. Remove the specimen from the water bath, quickly towel dry the specimen and place it in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine.

f) Apply the load on the specimen at a constant rate of 50.8±2.5mm/min. until the maximum load is reached and the load starts decreasing. The maximum load is defined as the last point in the load/time curve before the load decreases. The elapsed time for the test from removal of the test specimen from water bath to placement in the test assembly shall not exceed 30 seconds.

g) The maximum load value expressed in KN is recorded as the 'Marshall Stability' value of the specimen. The vertical deformation of the test specimen corresponding to the maximum load, expressed in 0.25 mm units is recorded as the 'Flow Value'.

h) If the initial thickness of the specimen was exactly 63.5 mm, it is not necessary to apply the correction factor. If there was a deviation in thickness, it is necessary to apply the appropriate correction factor to the maximum load value or Marshall Stability value recorded for each test specimen.

3.6 Volumetric Analysis

Fundamentally, the mix design is meant for the determination of the volume of asphalt binder and aggregates necessary to form a mixture of bituminous concrete with the desired properties. In Marshall Mix design method, each of the compacted specimen undergoes the following analysis:

- Theoretical Specific Gravity (G_t)
- Bulk Specific Gravity of the mix (G_m)
- Percent Air Voids (V_v)
- Percent Volume of Bitumen (V_b)
- Percent Void in mixed aggregate (VMA)
- Percent Voids Filled with Bitumen (VFB)

S as to understand these terms, a phase diagram is plotted in the Plate 3.4

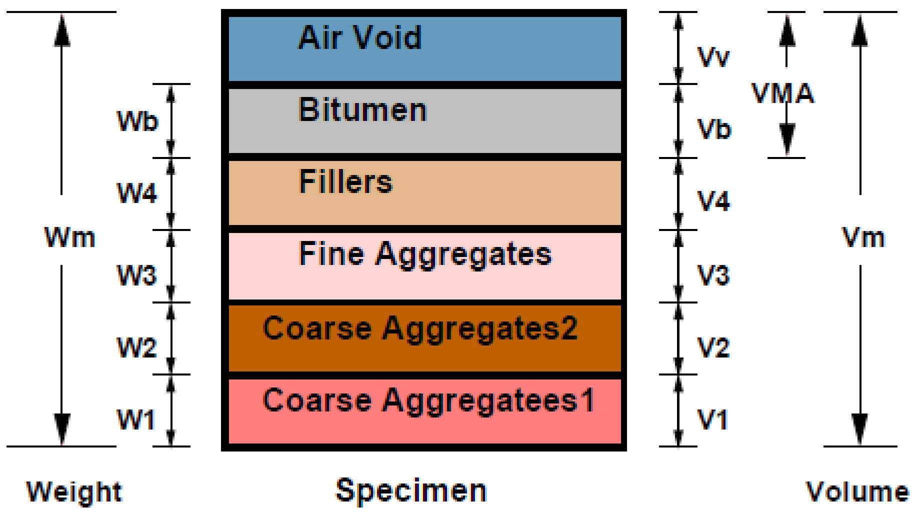

Plate 3.3 - Phase diagram of Bituminous Mix

3.6.1 Theoretical specific Gravity of the Mix (G_t)

Theoretical specific gravity G_t of the mix is the specific gravity without taking into account of air voids, and is mainly given by:

$$G_t = \frac{W1 + W2 + W3 + W4 + Wb}{\left(\frac{W1}{G1} + \frac{W2}{G2} + \frac{W3}{G3} + \frac{W4}{G4} + \frac{Wb}{Gb}\right)}$$

where, W_1 is the weight of coarse aggregates-1 in the total mix,

W_2 is the weight of coarse aggregates-2 in the total mix

W_3 is the weight of fine aggregates in the total mix

W_4 is the weight of filler

W_b is the weight of bitumen in the total mix

G_1 is the apparent specific gravity of coarse aggregate-1

G_2 is the apparent specific gravity of coarse aggregate-2

G_3 is the apparent specific gravity of filler

G_b is the apparent specific gravity of bitumen

3.6.2 Bulk specific gravity of the mix (G_m)

The bulk specific gravity of the mix Gm is the actual specific gravity, considering air voids and is calculated by:

$$G_m = \frac{Wm}{Wm - Ww}$$

Where, W_m is weight of mix in air

W_w is weight of mix in water, [(W_m - W_w) gives the volume of the mix]

3.6.3 Air voids percent (V_v)

Air voids V_v is the percentage of air voids by volume in the specimen and is calculated by:

$$V_v = \frac{(Gt - Gm)100}{Gt}$$

Where, G_t is theoretical specific gravity of the mix.

G_m is the bulk or actual specific gravity of the mix.

3.6.4 Percent volume of bitumen (V_b)

The volume of bitumen V_b is the percent of volume of bitumen to the total volume of the mix and given by:

$$V_b = \frac{\frac{Wb}{Gb}}{\left(\frac{W1+W2+W3+W4}{Gm}\right)}$$

Where, W_1 is the weight of coarse aggregates-1 in the total mix,

W_2 is the weight of coarse aggregates-2 in the total mix

W_3 is the weight of fine aggregates in the total mix

W_4 is the weight of filler

W_b is the weight of bitumen in the total mix

G_1 is the apparent specific gravity of coarse aggregate-1

G_2 is the apparent specific gravity of coarse aggregate-2

G_3 is the apparent specific gravity of filler

G_b is the apparent specific gravity of bitumen

G_m is the bulk specific gravity of the mix.

3.6.5 Voids in mineral aggregate (VMA)

Voids in mineral aggregate VMA is the volume of the voids in the aggregates and is sum of air voids and the volume of bitumen and is given by:

$$VMA = V_v + V_b$$

3.6.6 Voids filled with bitumen (VFB)

Voids filled with bitumen VFB are the voids in the mineral aggregates filled with the bitumen and is given by:

$$VFB = \frac{Vb \times 100}{VMA}$$

Where, V_b is the percentage of bitumen content in the mix.

3.7 Tests on Bitumen

There are various of tests to calculate the properties of asphalt binders. The following tests were conducted to evaluate the different properties of asphalt binder which are to be used.

3.7.1 Penetration Test [IS: 1203 - 1978]

Penetration test measures the hardness or softness of bitumen or asphalt binder by measuring the depth in tenths of a mille meter (mm) to which a standard loaded needle penetrates vertically in 5 seconds. The test was performed as per recommendations of Indian Standards (IS). The penetrometer consists of a needle assembly with a total weight of 100g of bitumen and a device for releasing and locking in any position. The bitumen is softened so that it can be poured easily, stirred thoroughly and poured into containers. The test should be conducted at a particular temperature of 25˚C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred.

3.7.2 Specific Gravity Test [IS: 1202 - 1978]

In paving jobs, density property is of great use to classify a binder. In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly influenced by its chemical composition. Increase in aromatic type mineral impurities cause an increase in specific gravity .The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27˚C. The specific gravity can be measured using Pycnometer as shown in the Plate 3.5. The specific gravity of bitumen varies from 0.97 to 1.02.

Plate 3.4 Specific Gravity Test

3.7.3 Softening point test [IS: 1205 – 1978]

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using the Ring and Ball apparatus. Equipment consists of a brass ring containing test sample of bitumen and is suspended in liquid like water or glycerine at a specified temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 50˚C per minute. The temperature at which the softened bitumen touches the metal plate which is at a specified distance below is noted. Generally, higher softening point indicates the lower temperature susceptibility and is preferred in hot climates.

3.7.4 Viscosity Test [IS: 1206 – 1978]

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, Bitumen resists the compactive effort; thereby resulting mix is heterogeneous, hence low stability values. At low viscosity instead of providing a uniform bending film over aggregates, bitumen will lubricate the aggregate particles, thereby reducing the stability values.

Plate 3.5 - Rotational viscometer (Alcometer)

A rotational viscometer gathers data on a material’s viscosity behaviour under different conditions. The rotational viscometer basically consists of two parts – a head unit with a motor and a spindle that is driven by the motor. The viscosity is determined by measuring the resistance of a spindle rotating in the sample. Rotational viscometers can be used for the accurate measurement of viscosity for both Newtonian and non-Newtonian fluids. Newtonian fluids are those that are affected by temperature, such as water, kerosene, mineral oils etc. Non-Newtonian fluids are those that change viscosity when stirred, shaken or otherwise agitated. These include paint, gels, inks, milk, ketchup etc. The apparatus of rotational viscometer is shown in plate 3.6.

3.8 Aggregate Testing

Aggregates are principle constituents of pavement. Additionally, they are often used in each of layer in the pavements as either stabilized or as un-stabilized base or sub-base courses. They consist of the majority of pavement volume but only account for a minority of total pavement material costs. Therefore, knowledge of aggregate properties is crucial to design a good quality pavement.

Following tests were conducted on the aggregates which are listed as follows:

- Impact Test
- Water absorption Test
- Specific Gravity Test
- Blending of aggregates to achieve required gradation for BC mix Grade-1

3.9 Indirect Tensile Strength Test (IDT) [ASTM: D6931-12]

The main use of IDT is to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both moisture conditioned and unconditioned samples.

In this test, a compressive load is applied on a cylindrical Marshall mix specimen by loading the cylindrical specimen in a direction across its vertical diametrical plane at a specified rate of deformation i.e. 50 mm/min. The specimen was kept in a controlled water bath maintained at the required temperature for minimum 30 minutes before test for the conditioned sample; The peak load at failure is recorded from the dial gauge of the proving ring and is used to calculate the Indirect Tensile Strength (ITS) of the specimen. The values of ITS is used to calculate the relative quality of the bituminous mixes in conjunction with the laboratory mix design testing and also for estimating the rutting and fatigue potential. The results can be used to determine the potential for field pavement moisture damage when results are obtained on both moisture conditioned and unconditioned samples.

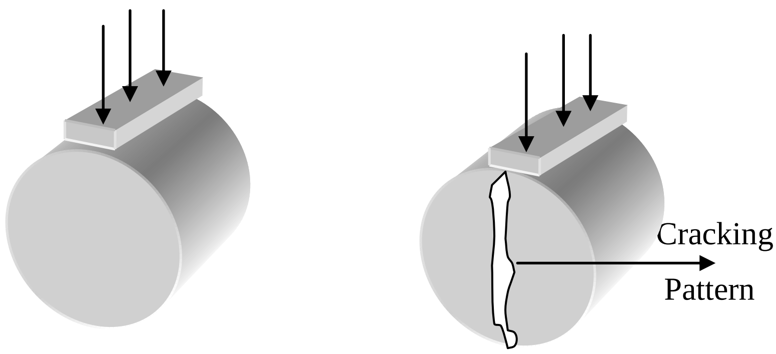

Plate 3.6 – Loading Configuration of Indirect Tensile Strength Test

Following is the equation used for the calculation of Indirect Tensile Strength:

$$S_T = \frac{2 \times P}{\pi \times D \times T}$$

Where,

S_T = Indirect Tensile Strength, kPa

P = Maximum Load, kN

T = Height of test specimen before testing, mm

D = Specimen Diameter, mm

Plate 3.7 - Indirect Tensile Strength Test

Plate 3.8 Indirect Tensile Strength Test of Bituminous Concrete Mixes

Chapter 4

RESULTS AND DISCUSSIONS

4.1 General

This chapter presents and discusses the results obtained from the laboratory testing of the Bituminous Concrete (BC) mixes designed using Marshall Mix method with and without the addition of various additives in certain proportions as the replacement of the asphalt binder. All the prepared Marshall mix specimens were subjected to compaction of 75 blows on each face to obtain the required density. The results were calibrated to determine the Optimum Binder Content (OBC) by performing the Stability-Flow analysis and Volumetric analysis for the prepared specimens. In addition to Marshall Mix method, other test was also conducted such as Indirect Tensile Strength Test on various asphalt binders to calculate the Resilient Modulus values.

4.2 Sieve Analysis

Sieve analysis test was carried out for determining the gradation of aggregates preparation of the Marshall specimen. Through this sieve analysis test, the proportioning of aggregates such as coarse aggregates, fine aggregate and stone dust is determined by ensuring the proper blending of aggregates to satisfy the gradation limit as specified in MORTH for BC Grade 1. The sieve analysis test results on aggregates are presented in the Table 4.1.

Table 4.1 Sieve Analysis Results

Sieve Size	% Passing 20mm	% Passing 10mm	% Passing 4.75mm	% Passing Stone Dust
26.5	100	100	100	100
19	93.87	100	100	100
9.5	15	55.13	100	100
4.75	10	23.23	89.33	100
2.36	0.54	5.19	70.66	100
0.300	0.54	1.06	30	96
0.075	0.54	1.06	10	35.5

The MORTH’S gradation of BC Grade-1 is shown in Table 4.2. The blending proportion of materials selected for the gradation of the bituminous concrete mixes BC-Grade 1 is shown in Table 4.3 and the combined gradation table for BC mix is shown in Table 4.4.

Table 4.2 Gradations for Bituminous Concrete Mix MORTH, (Clause 507.2.5)

MORTH Specified Gradation For Bituminous Concrete		
Grading	1	2
Nominal Aggregate Size	19 mm	13.2mm
Layer Thickness	50 mm	30-40 mm
IS Sieve, mm	Cumulative % by weight of total aggregate passing	
26.5	100	-
19	90-100	100
13.2	59-79	90-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10
Bitumen content % by mass of total mix	Min 5.2*	Min 5.4**

Table 4.3 Percentage of aggregate size taken

Calculated Blending for BC mix Grading-1				
20 mm	**10 mm**	**4.75 mm**	**Stone Dust**	**Total**
25	40	25	10	100

Table 4.4 Combined Gradation of the Sample taken

Required sieve	**Percentage Passing 20mm**	**Percentage Passing 10mm**	**Percentage Passing 4.75mm**	**Percentage Passing Stone Dust**	**Combined Gradation**	**Limit As per MORTH Specification**	
26.5	25	40	25	10	100	100	100
19	23.47	40	25	10	98.47	79	100
9.5	3.75	22.05	25	10	60.80	52	72
4.75	2.5	9.29	22.33	10	44.12	35	55
2.36	0.14	2.08	17.67	10	29.88	25	44
0.300	0.14	0.42	7.5	9.6	17.66	10	20
0.075	0.14	0.42	2.5	3.55	6.61	2	8

4.3 Aggregate Testing

Aggregate testing was done to check the various specified properties of the mineral aggregates and the test results were compared with MORTH'S specifications allowable values as shown in Table 4.5

Table 4.5 Test results of the Ingredient Aggregates.

Property	**Results**	**Permissible Limit**
Aggregate Impact Value,% (20mm)	18	Maximum 27
Aggregate Impact Value,% (10mm)	20	Maximum 27
Abrasion Value	19	Maximum 35
Specific Gravity	2.81	Maximum 3.0

4.4 Bitumen Testing

Various tests were conducted on the asphalt binder sample like penetration test, viscosity test, specific gravity value test etc. The penetration test and viscosity test were conducted to obtain the consistency of asphalt binder at some specified temperature and assign the grade of asphalt while softening point test is used to obtain temperature for the bitumen melt. The test results for these different properties of bitumen tests are shown in Table 4.6.

Table 4.6 Test Results of Bitumen Asphalt Binder

Test Results for Bitumen Asphalt Binder		
Property	**Test Results**	**Specified Limits as per BIS : 73-1992**
Penetration at 25ºC/100 gm /5 sec, mm	65	60 -70
Softening Point, ºC	50.8	40 – 55
Specific Gravity, at 27ºC	1.01	>0.99
Viscosity at 60ºC, Poise	1036	1000±200

4.5 Results of BC Mix Design Grade - 1 without using any Additive

To decide the optimum binder content (OBC), Marshall Mix samples were prepared by varying the percentage of 60/70 asphalt binder without using any additive or modifier. Stability-Flow laboratory analysis and Volumetric analysis were performed for the Marshall mix samples with bitumen content varying from 4.5% to 5.5%. The test values were obtained and plotted graphically. The output results of stability and flow values are shown in Table no. 4.7 and Figure 4.1 to 4.6. From the graphs plotted in Figure 4.1 to 4.6, the optimum binder content comes out to be 5.0 percent by the weight of aggregates using stability-flow values.

Table 4.7 Comparison of Stability-Flow for bitumen binder 60/70

Test	**Bitumen Content By Wt of Mix (%)**	**Bulk Density (gm/cc)**	**Air Voids (%)V_v**	**Voids in Mineral aggregate (%)VMA**	**Voids Filled With Bitumen (%)VFB**	**Corrected Stability (kN)**	**Flow (mm)**
1	4.5	2.49	4.244	14.863	71.44	8.6	2.25
2	5.0	2.530	4.899	16.474	70.26	13.6	3.48
3	5.5	2.435	4.966	17.537	71.679	10.8	3.88

The above table signifies that the maximum Marshall Stability comes out to be 13.6 kN at bitumen content 5 percent and with addition of more, the stability value starts getting decreasing.

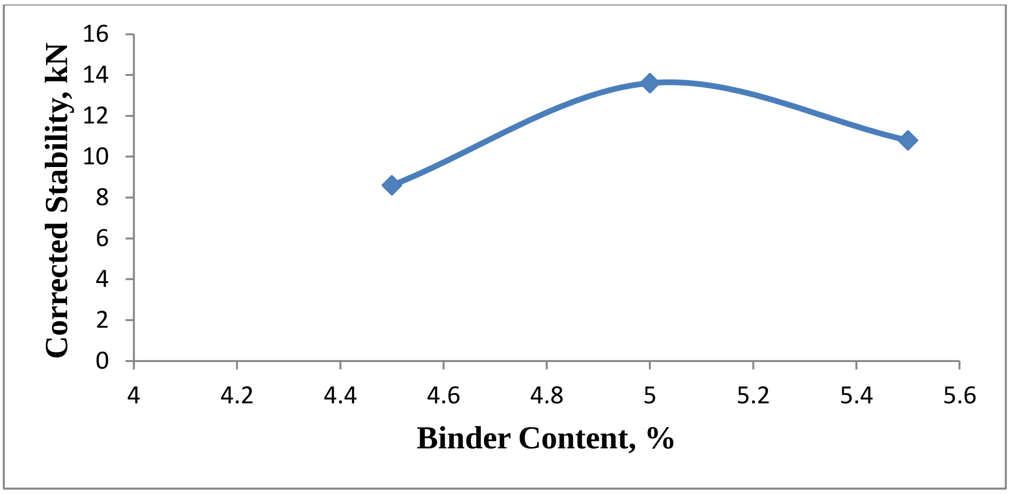

Figure 4.1 Variation of Corrected Stability with Binder Content

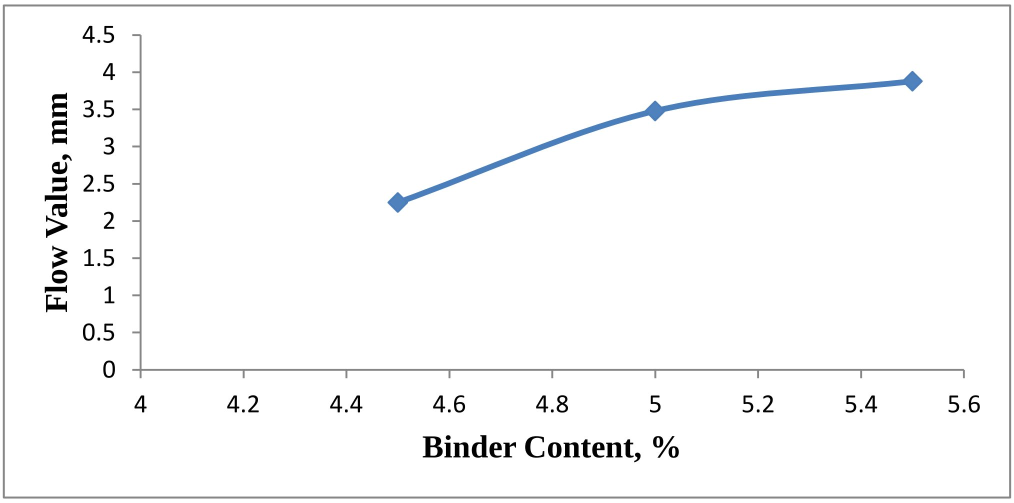

Figure 4.2 Variation of Flow Value with Binder Content

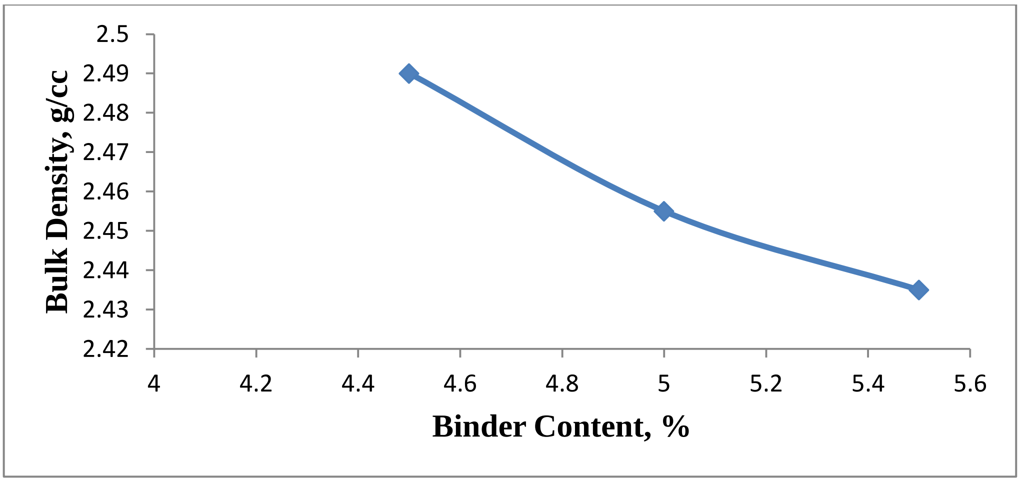

Figure 4.3 Variation of Bulk Density with Binder Content

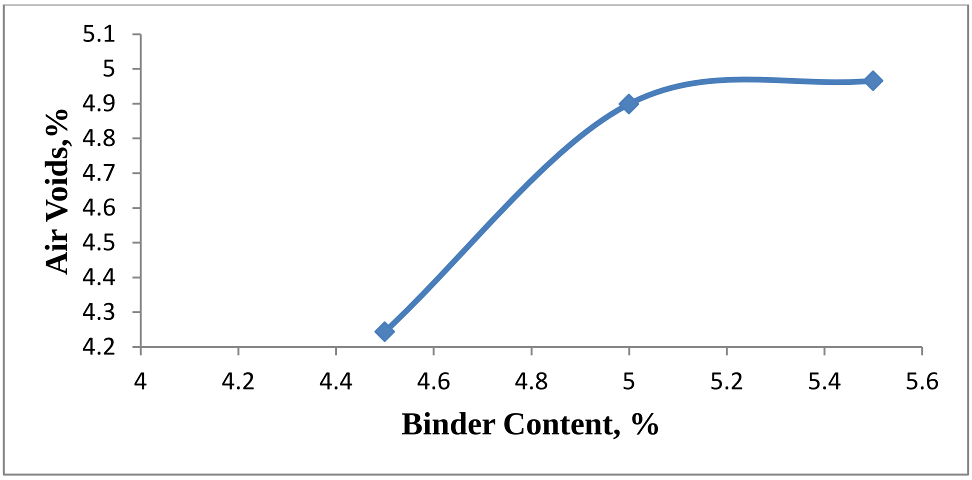

Figure 4.4 Variation of Air Voids with Binder Content

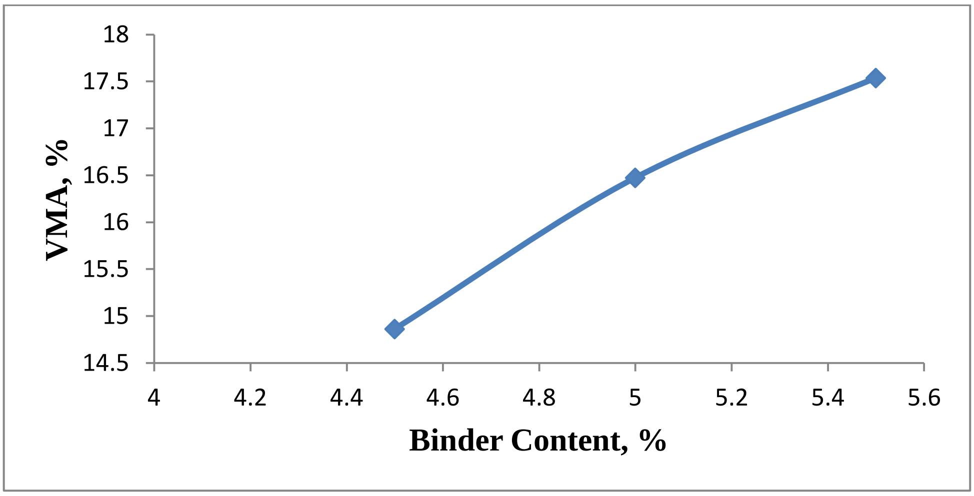

Figure 4.5 Variation of VMA with Binder Content

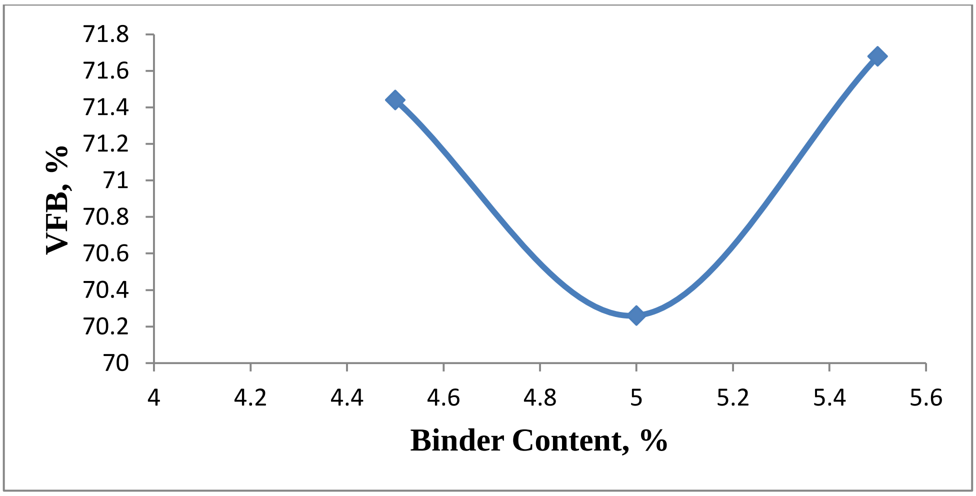

Figure 4.6 Variation of VFB with Binder Content

From the above graphs obtained, the Optimum Binder Content (OBC) is calculated as follows:

- Max stability = 5 percent bitumen content
- Max G_m = 5 percent bitumen content.
- 4% percent air void = 4.67 percent bitumen content

The optimum bitumen extent is the average of above = 4.9 percent (nearly equal to 5 percent)

The result shows the Optimum Binder Content at 5%. This value is further used for evaluating the effect of various additives used such as waste plastic, waste tyre rubber etc in different proportions.

4.6 Results of BC Mix Design Grade – 1 using Polymer Modified Bitumen (PMB 40)

To calculate the optimum binder content (OBC) of Polymer Modified mix, Marshall Mix samples were prepared by varying the percentages of PMB 40 asphalt binder. Stability-Flow laboratory analysis and Volumetric analysis were carried out for the Marshall Mix samples prepared with bitumen content varying from 4.5% to 5.5%. The test values were obtained and are plotted graphically. From the graphs plotted in Figure 4.7 to 4.12, the optimum binder content comes out to be 5.2 percent by the weight of aggregates using stability-flow values. The output results of stability and flow values are shown in Table no 4.8 and Figure 4.7 to 4.12

Table 4.8 Stability - Flow values for different percentages of PMB 40

Test	**Bitumen Content By Wt of Mix (%)**	**Bulk Density (gm/cc)**	**Air Voids (%)V_v**	**Voids in Mineral aggregate (%)VMA**	**Voids Filled With Bitumen (%)VFB**	**Corrected Stability(kN)**	**Flow (mm)**
1	4.5	2.466	5.15	15.65	67.09	16.112	2.20
2	5.0	2.50	4.69	16.28	71.19	18.40	3.48
3	5.5	2.463	4.16	16.87	75.34	15.13	3.63

The Result shows that the maximum Stability value of 18.40 kN is attained at 5% of Polymer Modified Bitumen (PMB) and with addition of more, the stability value starts getting decreasing and maximum Bulk Density is 2.50 at 5% bitumen content.

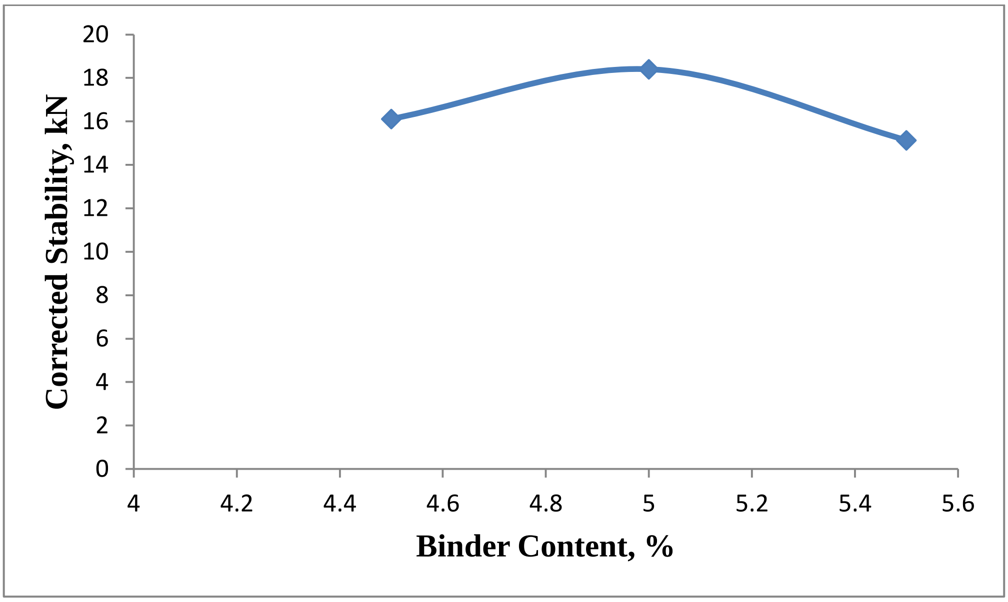

Figure 4.7 Variation of Corrected Stability with Binder Content

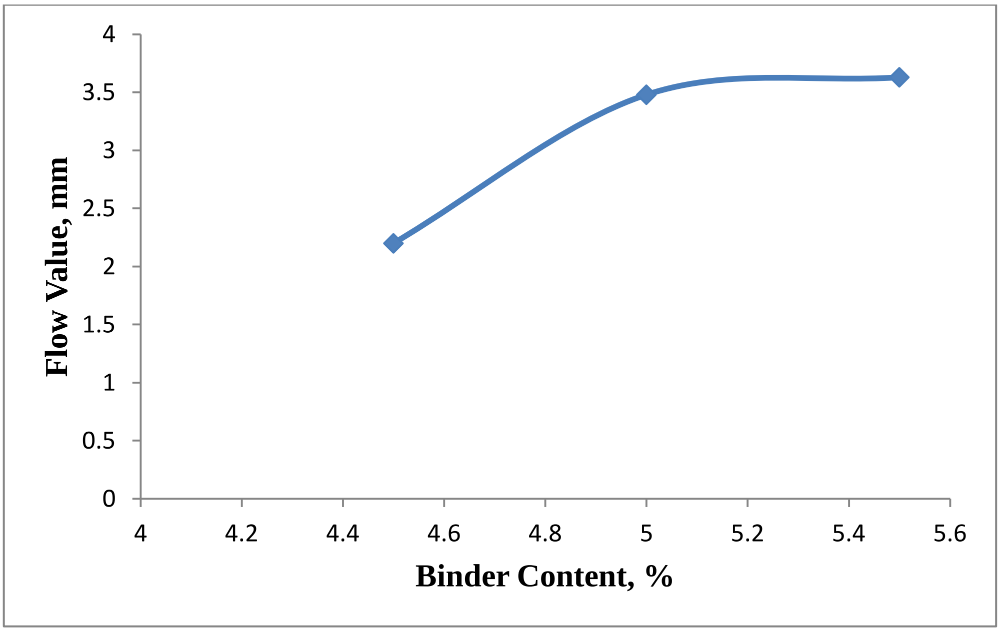

Figure 4.8 Variation of Flow Value with Binder Content

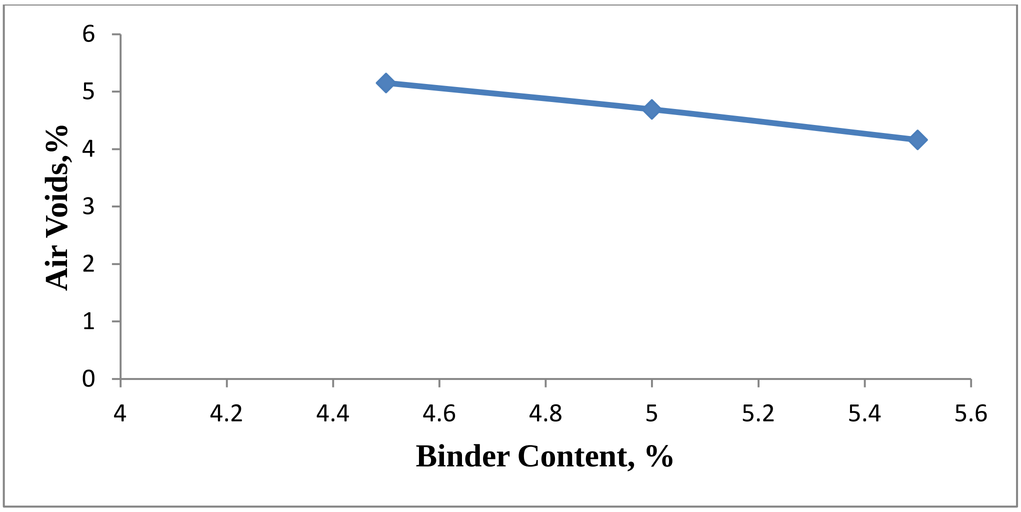

Figure 4.9 Variation of Air Voids with Binder Content

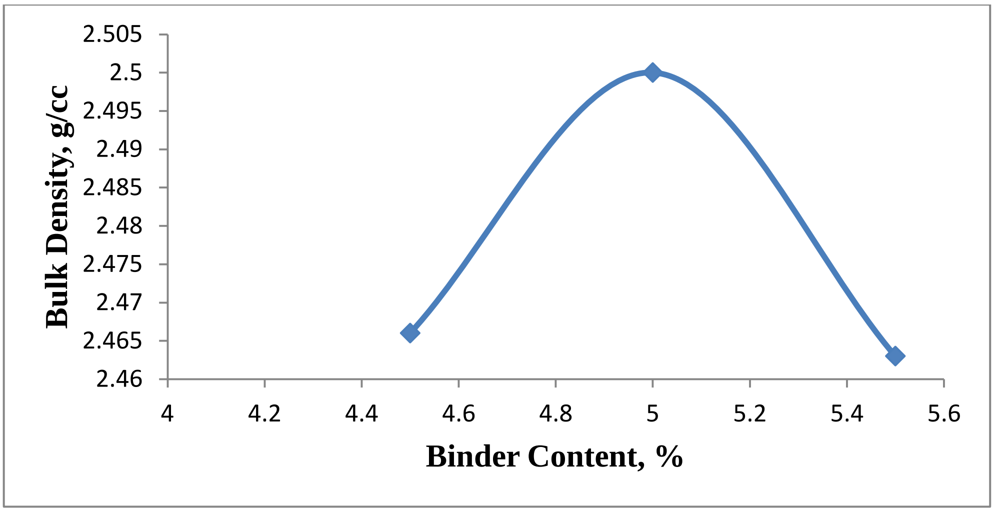

Figure 4.10 Variation of Bulk Density with Binder Content

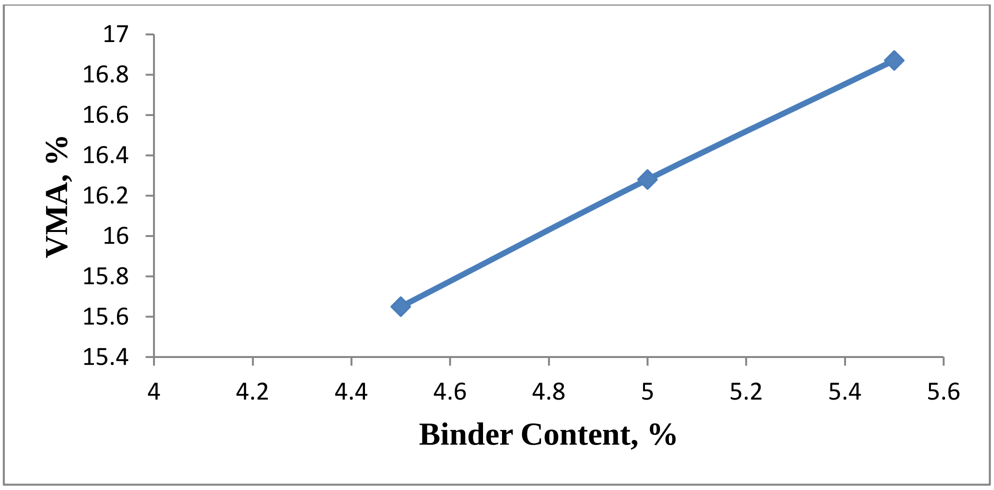

Figure 4.11 Variation of VMA with Binder Content

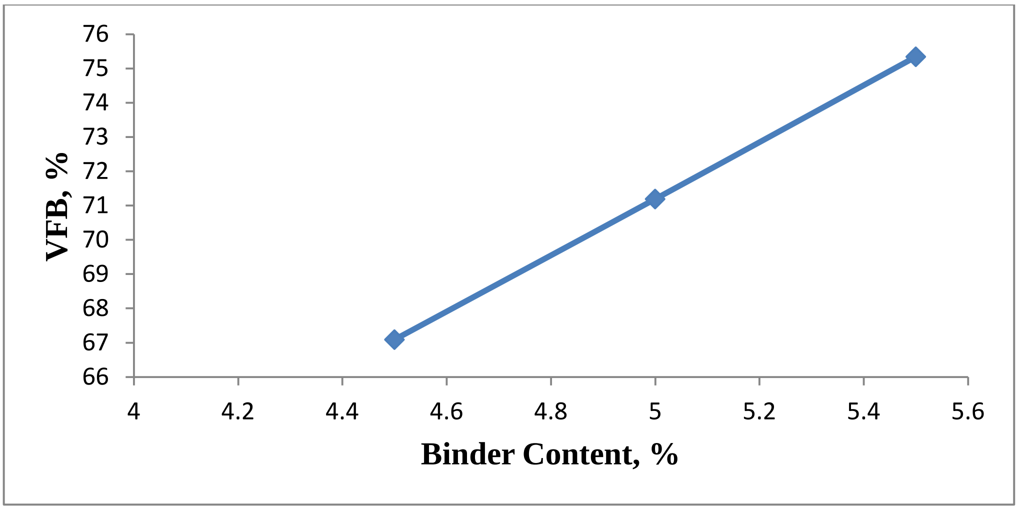

Figure 4.12 Variation of VMA with Binder Content

From the above graphs obtained, the Optimum Binder Content (OBC) is calculated as follows:

- Max stability = 5 percent bitumen content
- Max G_m = 5 percent bitumen content.
- 4% percent air void = 5.5 percent bitumen content

The optimum bitumen extent is the average of above = 5.2 percent

4.7 Results of BC Mix Design Grade – 1 using Crumb Rubber Modified Bitumen (CRMB 60)

To calculate the optimum binder content (OBC), Marshall Mix samples were prepared by varying the percentages of Crumb Rubber Modified Bitumen (CRMB 60) asphalt binder. Stability-Flow laboratory analysis and Volumetric analysis were carried out for the prepared Marshall Mix samples with bitumen content varying from 4.5% to 5.5%. The test values were obtained and plotted graphically. From the graphs plotted in Figure 4.13 to 4.18, the optimum binder content comes out to be 5.2 percent by the weight of aggregates using stability-flow values. The output results of stability and flow values are shown in Table no 4.9 and Figure 4.13 to 4.18.

Table 4.9 Stability-Flow values for different percentages of CRMB 60

Test	Bitumen Content By Wt of Mix (%)	Bulk Density (gm/cc)	Air Voids (%)Vv	Voids in Mineral aggregate (%)VMA	Voids Filled With Bitumen (%)VFB	Corrected Stability(kN)	Flow (mm)
1	4.5	2.421	6.88	17.20	60.0	15.504	2.96
2	5.0	2.513	6.27	17.67	64.516	17.17	3.55
3	5.5	2.449	5.05	17.69	71.45	13.98	3.92

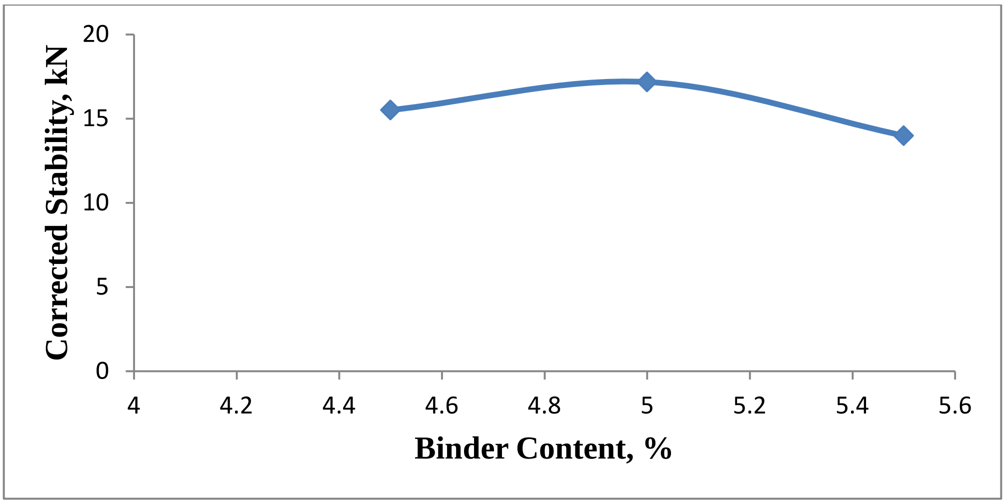

Figure 4.13 Variation of Corrected Stability with Binder Content

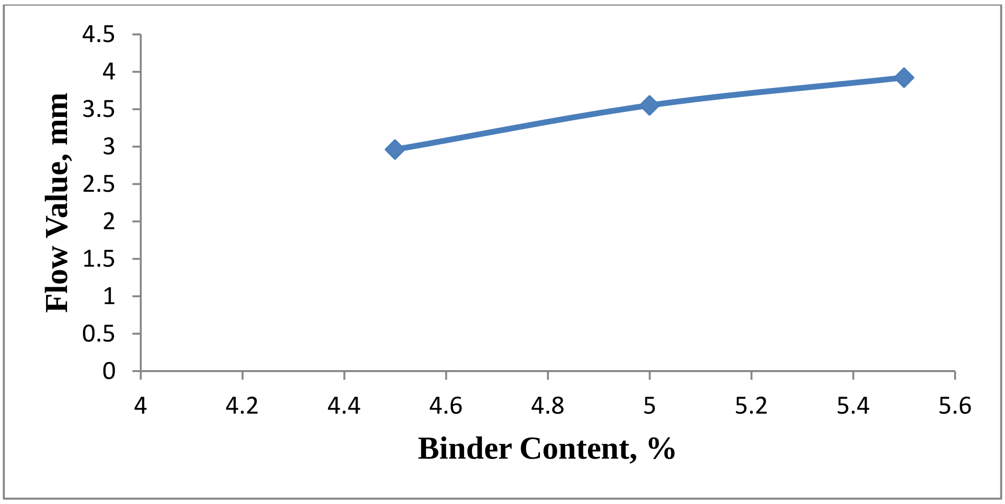

Figure 4.14 Variation of Flow values with Binder Content

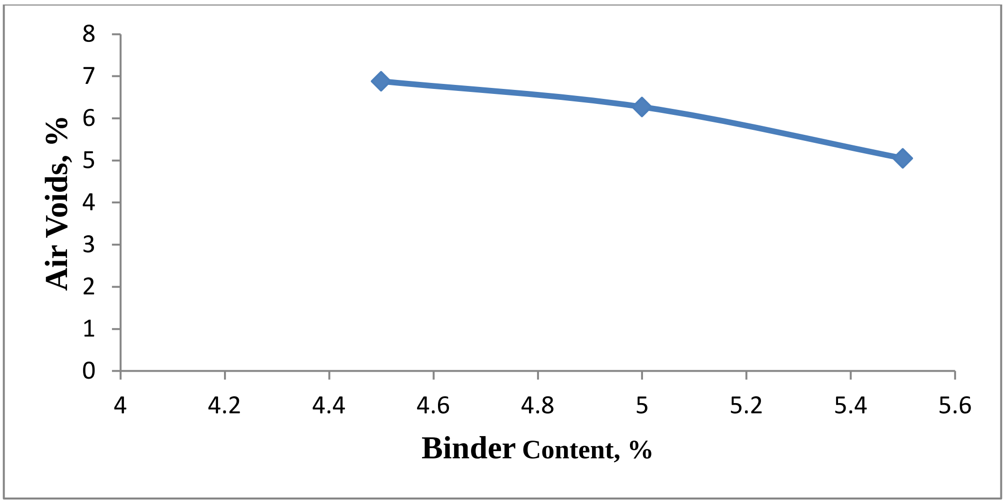

Figure 4.15 Variation of Air Voids with Binder Content

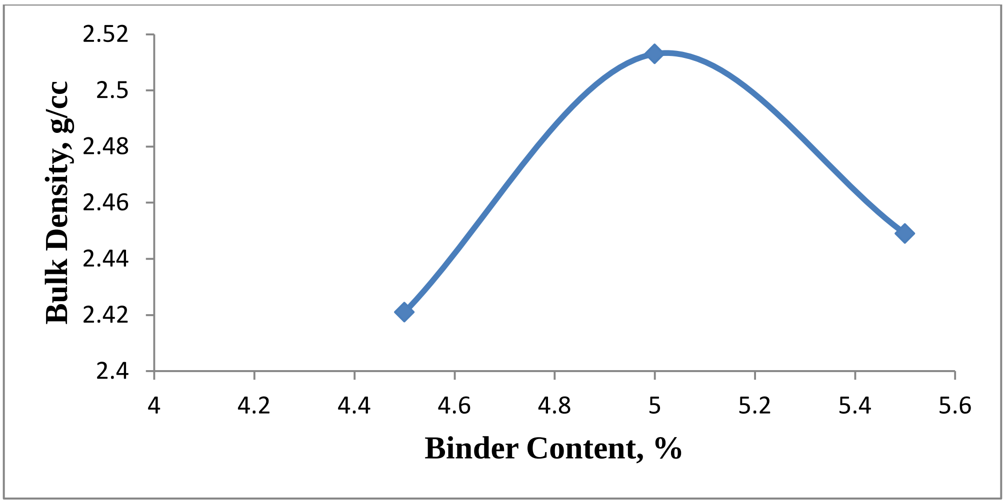

Figure 4.16 Variation of Bulk Density with Binder Content

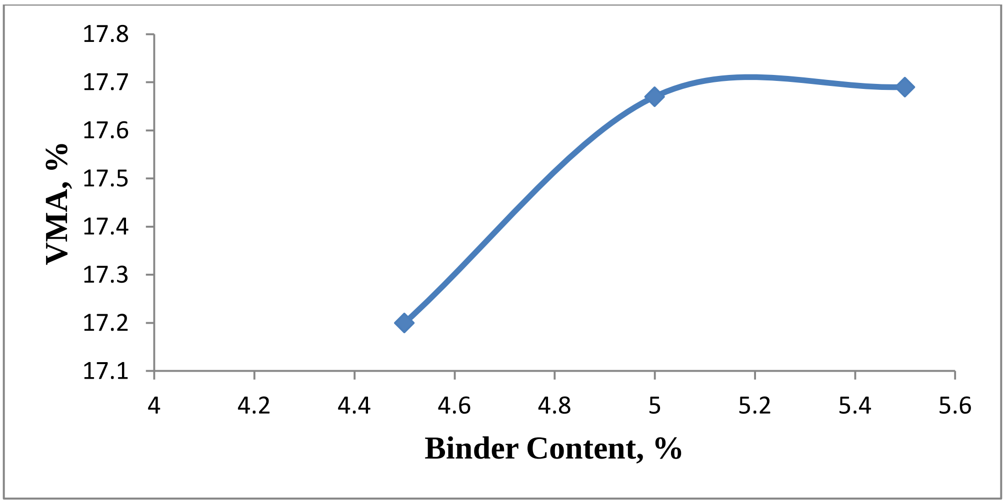

Figure 4.17 Variation of VMA with Binder Content

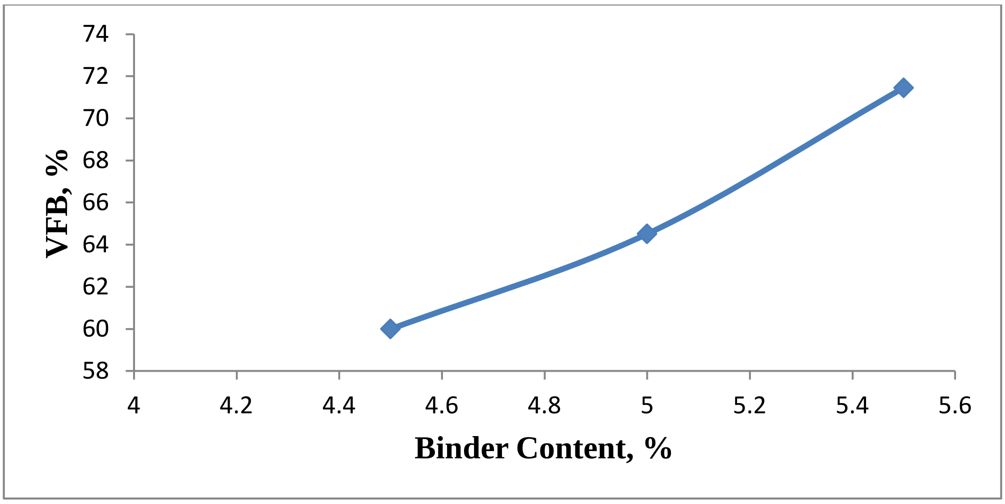

Figure 4.18 Variation of VFB with Binder Content

From the above graphs obtained, the Optimum Binder Content (OBC) is calculated as follows:

- Max stability = 5 percent bitumen content
- Max G_m = 5 percent bitumen content.
- 4% percent air void = 5.5 percent bitumen content

The optimum bitumen extent is the average of above = 5.2 percent

4.8 Results of BC Mix Design Grade – 1 using Waste Plastic as a Modifier

In this study, the bituminous concrete mix of Grade-1 was modified with the addition of the waste milk pouches obtained from H-Hostel mess, Thapar University. The waste milk pouches shown in Plate 4.1 were cut into smaller pieces as shown in Plate 4.2 and added to the BC Grade-1 mix The optimum binder content (OBC) of 5% was replaced with various percentages of waste plastic content of 2, 4, 6, 8, 10, and 12% by weight of for the determination of stability and Flow characteristics using the modified bitumen mix. Stability and Flow analysis was carried out using Marshall Mix design method. The output results of stability and flow values are shown in Table no 4.10 and Figure 4.19 to 4.20 which are as follows:

Plate 4.1 Waste Milk Pouches

Plate 4.2 Small Pieces of Milk Pouches

Table 4.10 Stability - Flow values for different percentages of Waste Plastic

Replacement of OBC with Plastic% (by weight of OBC)	Corrected Stability (kN)	Flow (mm)
2	19.9	3.88
4	23.12	3.56
6	25.67	3.47
8	26.50	3.36
10	24.79	2.86
12	21.97	2.72

The Result shows that the maximum Stability value of 26.50 kN is attained at 8% of waste plastic as a replacement of bitumen and with addition of more plastic, the stability value starts getting decreasing.

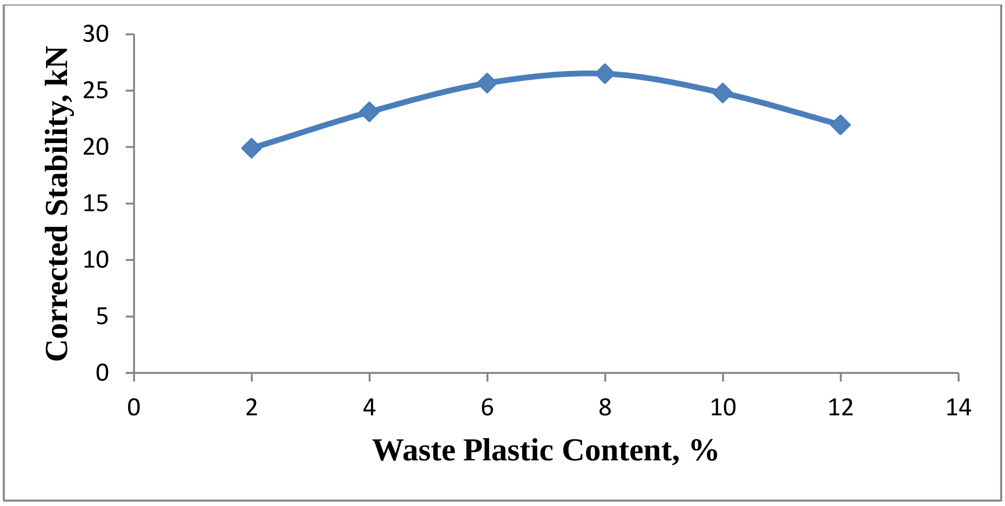

Figure 4.19 Variation of Corrected Stability with Waste Plastic Content

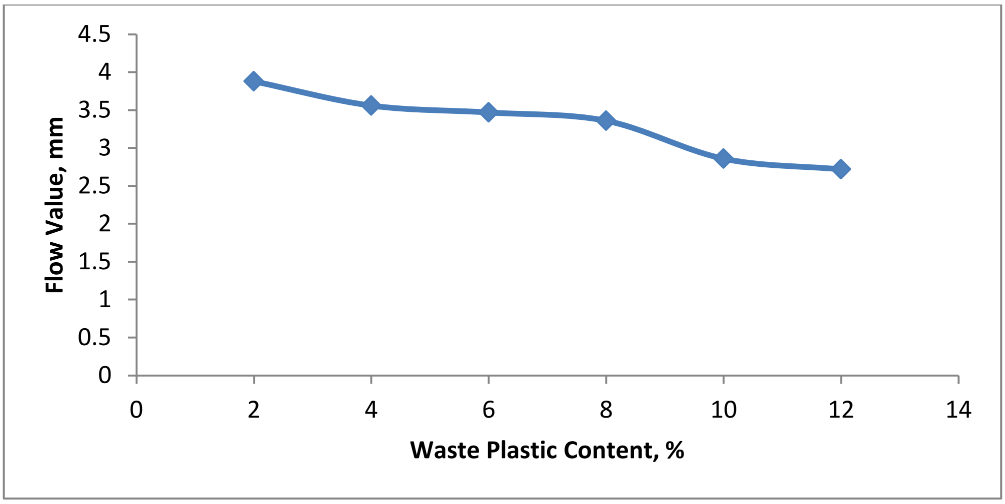

Figure 4.20 Variation of Flow Value with Waste Plastic Content

4.9 Results of BC Mix Design Grade – 1 using Waste Tyre Tube as a Modifier

In this study, the Bituminous Concrete Mix was modified with the addition of waste tyre tubes obtained from local sources. The waste tyre tube shown in Plate 4.3 were cut into smaller pieces as shown in Plate 4.4 and added to BC Grade-1 mix. The optimum binder content (OBC) of 5% was replaced with various percentages of waste tyre tube of 6%, 9%, 12%, 15% by weight of OBC for the determination of stability and Flow characteristics using the modified bitumen mix. Stability - Flow analysis was carried out using Marshall Mix design method. The output results of stability and flow values are shown in Table no 4.11 and Figure 4.21 to 4.22.

Plate 4.3 Waste Tyre Tube

Plate 4.4 Mixing of Waste Tyre Tube

Table 4.11 Stability - Flow values for different percentages of Waste Tyre Tube

Replacement of OBC with Waste Tyre Tube%	**Corrected Stability (kN)**	**Flow (mm)**
6	10.64	2.53
9	15.96	3.14
12	19.0	3.78
15	17.48	3.97

The Result shows that the maximum Stability value of 19.0 kN is attained at addition of 12% waste tyre tube and with addition of more, the stability value starts getting decreasing.

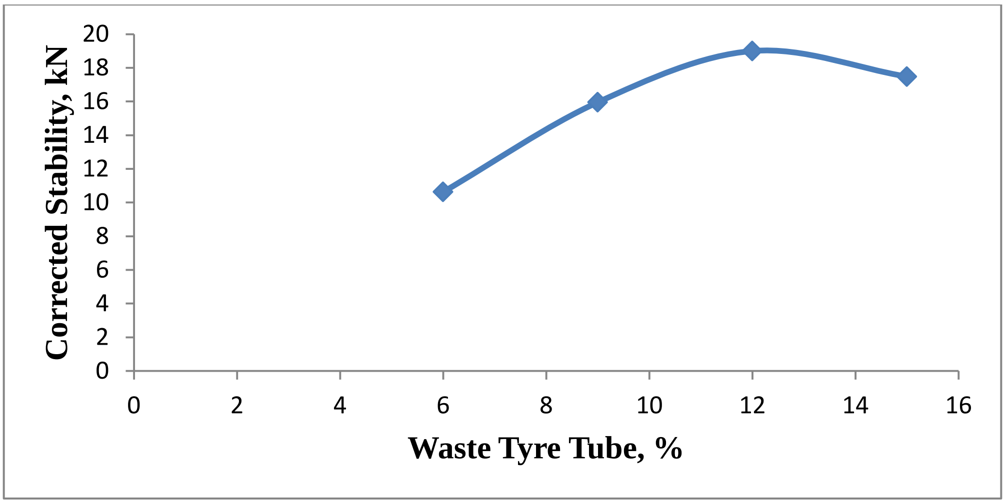

Figure 4.21 Variation of Corrected Stability with Waste Rubber Content

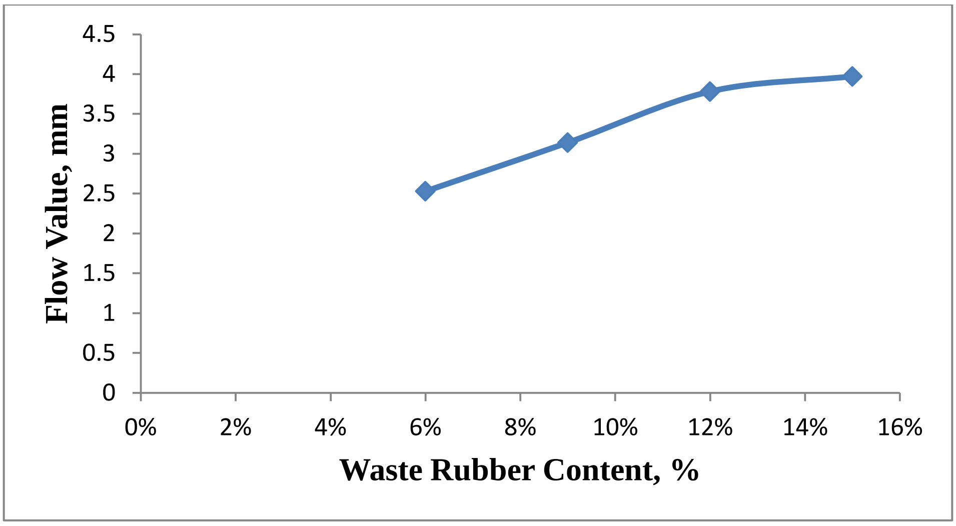

Figure 4.22 Variation of Flow Value with Waste Rubber Content

The Result shows that the maximum Stability value of 19.0 kN is attained at addition of 12% waste tyre tube and with addition of more, the stability value starts getting decreasing.

4.10 Calculation of Indirect Tensile Strength (ITS):

The Indirect Tensile Strength test was conducted on various bituminous mixtures like mixtures made of using asphalt binder VG 30, CRMB 60, PMB40, using Waste plastic (8%), Waste tyre tube (12%) by keeping constant optimum binder content (OBC) i.e. 5% and ITS test was conducted on these specimens at room temperature. The Indirect Tensile Strength of the test specimen was calculated according to ASTM D 6931-12 From the failure load is recorded from the dial gauge of the proving ring, the ITS was calculated by the followed equation:

$$S_T = \frac{2 \times P}{\pi \times D \times T}$$

Where,

S_T = Indirect Tensile Strength, kpa

P = Maximum Load on the Proving Ring, kN

T = Original Height of test specimen before testing, mm

D = Specimen Diameter, mm

Plate 4.5 shows the apparatus for ITS test. Plate 4.6 shows some of the tested specimens. It can be seen that the samples split into two parts along the diameter as in split Tensile Strength Test.

Plate 4.5 Indirect Tensile Strength Test

Plate 4.6 ITS test conducted on different Samples

Table 4.12: Calculation of ITS & Resilient Modulus values

S. No.	**Type of Binder**	**ITS (MPa)**	**Es (MPa)**
1	VG 30	1.21	1230.585
2	CRMB 60	1.29	1314.474
3	PMB 40	1.38	1409.029
4	Waste Plastic (8%)	1.42	1451.109
5	Waste Tyre Tube (12%)	1.49	1524.845

Table 4.1 shows the results of Indirect Tensile Strength test for different types of binders. The ITS value was calculated at the OBC's of all the asphalt binders i.e. for VG-30 at 5%, for CRMB at 5.2%, PMB at 5.2%, Waste Plastic at 8% and Waste Tyre Tube at 12%. Further from ITS value Resilient Modulus values were calculated.

Calculation of Resilient Modulus:

Resilient Modulus of bituminous mix can be calculated using this empirical relation (Adedare S.Adedimi1a, Thomas W. Kennedy)

$$\mathbf{Log\ (E_s) = 2.94 + 1.03\ log\ (ITS)}$$

Where,

Es is Resilient Modulus in psi

ITS is Indirect tensile strength in psi

4.11 Design of Flexible Pavements

4.11.1 Vehicle Damage Factor:

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the axle configuration, axle loading, terrain, type of road and from region to region. The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions. These equivalency factors can be taken from IRC:37 2012. The exact VDF values are arrived after extensive field surveys.

The equations for computing equivalency factors for single, tandem and tridem axles given below should be used for converting different axle load repetitions into equivalent standard axle load repetitions. [IRC 37:2012 Clause 4.4.3]

Single axle with single wheel on either side = $\left(\frac{axle\ load\ in\ KN}{65}\right)^4$

Single axle with dual wheel on either side = $\left(\frac{axle\ load\ in\ KN}{80}\right)^4$

Tandem axle with dual wheel on either side = $\left(\frac{axle\ load\ in\ KN}{148}\right)^4$

Tridem axle with dual wheel on either side = $\left(\frac{axle\ load\ in\ KN}{224}\right)^4$

VDF is derived carefully by carrying out specific axle load surveys on the existing roads. Minimum sample size for survey is given in Table 4.13 shown below. Axle load survey is carried out without any bias for loaded or unloaded vehicles. On some sections, there may be significant difference in axle loading in two directions of traffic. In such situations, the VDF is evaluated direction wise. Each direction can have different pavement thickness for divided highways depending upon the loading pattern.

Table 4.13 Sample size for Axel Load Survey (IRC 37:2012)

Total number of Commercial Vehicles per day	**Minimum Percentage of Commercial Traffic to be surveyed**
<3000	20%
3000 to 6000	15%
>6000	10%

4.11.2 Calculated VDF for different classes of vehicles:

Table 4.14 VDF for different vehicle type

(Four Laning of National Highway from Rajkot to Somnath)

S. No.	Vehicle Type	Number of Vehicles	VDF
1	1	87	3.2120
2	2	102	9.0378
3	3	12	5.1943
4	4	21	8.384
5	5	3	15.661
6	6	94	1.4036
7	7	58	0.397

Weighted Average VDF=

$$\frac{[(87*3.2120)+(102*9.0378)+(12*5.1934)+(21*8.384)+(3*15.661)+(94*1.4036)+(94*1.4036)+(58*0.397)]}{377}$$

Weighted Average VDF = 4.3543

4.11.3 Computation of Design Traffic

The design traffic is calculated in terms of the cumulative number of standard axles to be carried during the design life of the road. It should be computed using the following equation as per [IRC 37:2012 Clause 4.6.1]

$$N = (365 \times [(1+r)^n - 1])/r \times A \times LDF \times VDF$$

Where,

N = Cumulative number of standard axles to be catered for in the design in terms of msa.

A =Initial traffic in the year of completion of construction in terms of the number of Commercial Vehicles Per Day (CVPD).

LDF = Lane Distribution Factor

VDF = Vehicle Damage Factor

n = Design life in years.

r = Annual growth rate of commercial vehicles in decimal (e.g., for 7.5% annual growth rate = 0.075

The traffic in the year of completion is estimated using the following formula:

$$A = P(1+r)^x$$

Where,

P = Number of commercial vehicles as per last count.

x = Number of years between the last count and the year of completion of construction i.e. 2 years.

Calculations:-

1. No. of commercial vehicles per day as per the last count (P) in one direction = 4170

2. As the construction period is 2 years, the no. of commercial vehicles per day at present assuming growth rate to be 7.5% per year = 4818

3. The design life of the pavement is taken up as 15 years.

4. As the highway is 4 lane and divided so the LDF = 0.75 [IRC 37:2012 Clause 4.5.1]

5. VDF = 4.3543

6. Cumulative number of standard axles that will pass through the pavement in the design life

(N) = 150msa.

4.11.4 Design of Pavement:

Design Principle:

A flexible pavement is modelled as an elastic multilayer pavement structure. The stresses and strains are computed at critical locations using a linear layered elastic modelling. The Stress analysis software IIT-PAVE has been used for the computation of stresses and strains in flexible pavements. Tensile strain (ε_t), at the bottom of the bituminous layer and the Vertical sub-grade strain (ε_v) on the top of the sub-grade are conventionally considered as critical parameters for pavement design to limit cracking and rutting in the bituminous layers and non-bituminous layers respectively. The computation also indicates that tensile strain near the surface close to the edge of a wheel can be sufficiently large to initiate longitudinal surface cracking followed by transverse cracking much before the flexural cracking of the bottom layer if the mix tensile strength is not adequate at higher temperatures.

Fatigue:

The number of load repetitions in terms of standard axles that cause fatigue denotes the fatigue life of the pavement. In the guidelines according to IRC 37:2012, cracking in 10 percent area has been considered.

$$N_f = 2.021 * 10^{-04} \text{ x } [1/\varepsilon_t]^{3.89} * [1/M_R]^{0.854}$$

Where,

N_f = Fatigue Life in number of standard axles

ε_t = Tensile Strain in the bituminous layer

M_R = Resilient Modulus

Rutting:

Rutting is the permanent deformation in pavement usually occurring longitudinally along the wheel path. The rutting may partly be caused by deformation in the sub-grade and other non-bituminous layers which would reflect to the overlying layers making them deformed shape. The bituminous mixes also may undergo rutting due to secondary compaction and shear deformation under heavy traffic load and higher temperature. Excessive rutting greatly reduces the serviceability of the pavement and therefore, according to IRC 37:2012, it has to be limited to a certain reasonable value. In these guidelines the limiting rutting is recommended as 20 mm.

$$N_r = 1.41 \times 10^{-8} \times [1/\varepsilon_v]^{4.5337}$$

Where,

N = Rutting life in number of cumulative standard axles
ε_v = Vertical strain in the sub grade
ε_t **=** Tensile strain in the bituminous layer

Design Methodology:

- First of all Million standard axles are calculated from the traffic survey data.
- We took 5 different types of binders VG-30, CRMB, PMB, VG-30 with 8% waste plastic, VG-30 with 12% of waste tyre tube.
- All the properties related to these binders were calculated like Stability, Indirect Tensile strength, Resilient Modulus etc. (Table 4.12)
- Varying these properties, pavement was designed by changing the thickness of the bituminous mix layers assuming other layers fixed.
- Allowable strains are calculated using equations of rutting and fatigue as written above (in section 4.10.4)
- Then actual strains are calculated corresponding to each thickness of the bituminous mix layers using IIT-PAVE.
- Then thickness of pavements is calculated corresponding to these allowable strains.
- This calculated thickness is considered as design thickness.

4.12 Design of Flexible Pavement Using VG 30

The design of flexible pavement is carried out using VG 30 grade bitumen. In the following Table 4.15 Design components are shown which are further used in the designing of a Flexible Pavement.

Table 4.15 Data considered in design for VG-30 Asphalt Binder

CBR of sub-grade	10%
Traffic	150msa
Granular sub base thickness	200mm
Granular base thickness	250mm
Elastic modulus of sub-grade	76.8MPa
Resilient Modulus of Granular Layer	240MPa
Poisson Ratio of Sub grade	0.35
Poisson Ratio of Granular layer	0.35
Poisson Ratio of Bituminous Layer	0.35
Tyre pressure	0.56MPa
c/c spacing of dual wheel	310mm
Single wheel load	20000N

Calculations:

- The elastic modulus of sub-grade is calculated using the following formula [IRC 37:2012 Clause 5.3]

$E_{subgrade}$ (MPa) = 10*CBR, For CBR 5

= $17.6*(CBR)^{0.64}$, For CBR > 5

$E_{sub\text{-}grade}$ = Resilient modulus of sub-grade soil

<u>For CBR 10%</u>,

Value of $E_{Subgrade}$ = 76.8 MPa

- The elastic modulus of Granular layer is calculated using the following formula:

  $E_{granular\ layer} = 0.2(h)^{0.45} \times E_{sub\text{-}grade}$

  $E_{granular\ layer}$ = 240 MPa

The Allowable fatigue and allowable rutting strain is calculated by using following formula [IRC 37:2012 Clause 6.2.2]

- $N_f = 2.021 * 10^{-04}$ x $[1/\varepsilon_t]^{3.89} * [1/M_R]^{0.85}$
- $N_r = 1.41$ x 10^{-8} x $[1/\varepsilon_v]^{4.5337}$

The strain corresponding to various thickness of the bituminous mix layers has been calculated using IIT-PAVE software at bottom of bituminous layer and at the top of sub-grade. The strains have been calculated for three different bitumen content for which corresponding peak load was calculated by Marshall Stability Test. Indirect Tensile Strength was calculated and the corresponding modulus were obtained.

The strains corresponding to various thickness of bituminous mixes layer has been calculated using IIT- PAVE software at bottom of bituminous layer and at the top of sub-grade.

The following Table 4.16 shows the design parameters for VG 30 grade bitumen having OBC at 5%, which are used in the designing of a pavement section.

Table 4.16 Design Parameters for VG-30 at 5%

TYPE OF ASPHALT BINDER	**VG 30**	
BITUMEN CONTENT	**5%**	
MARSHALL STABILITY (kN)	**13.6**	
INDIRECT TENSILE STRENGTH (MPa)	**1.21**	
STATIC MODULUS (Es) (MPa)	**1230.585**	
BITUMINOUS LAYER THICKNESS	**DESIGN PARAMETERS**	
130mm	Ɛ(µT)	283.4
	Ɛ®(µ)	346
	Fatigue Life	29.24 msa
	Rutting Life	69.184 msa
140 mm	Ɛ(µT)	267.5
	Ɛ®(µ)	332.1
	Fatigue Life	36.67 msa
	Rutting Life	83.31 msa
150 mm	Ɛ(µT)	253.1
	Ɛ®(µ)	318.9
	Fatigue Life	45.48 msa
	Rutting Life	100.13 msa
160 mm	Ɛ(µT)	238.7
	Ɛ®(µ)	306.4
	Fatigue Life	57.116 msa
	Rutting Life	120.04 msa

170 mm	Ɛ(μT)	225.1
	Ɛ®(μ)	294.4
	Fatigue Life	71.757 msa
	Rutting Life	143.848 msa
180 mm	Ɛ(μT)	212.6
	Ɛ®(μ)	283.1
	Fatigue Life	89.616 msa
	Rutting Life	171.81 msa
190 mm	Ɛ(μT)	200.8
	Ɛ®(μ)	272.4
	Fatigue Life	113.63 msa
	Rutting Life	205.97 msa
200 mm	Ɛ(μT)	190.1
	Ɛ®(μ)	262.3
	Fatigue Life	138.47 msa
	Rutting Life	242.83 msa
210 mm	Ɛ(μT)	179.9
	Ɛ®(μ)	252.6
	Fatigue Life	171.608 msa
	Rutting Life	288.07 msa
220 mm	Ɛ(μT)	170.5
	Ɛ®(μ)	243.5
	Fatigue Life	211.45 msa
	Rutting Life	340.21 msa
230 mm	Ɛ(μT)	161.8
	Ɛ®(μ)	234.8
	Fatigue Life	259.22 msa
	Rutting Life	401.22 msa
Allowable Horizontal Tensile Strain (Ɛt)μ	178	
Allowable Vertical Compressive Strain (Ɛv)μ	370	
Minimum Bituminous Layer Thickness	**217 mm**	

For **E = 1230.585MPa**, the thickness of bituminous layer has been interpolated between 200mm and 210mm corresponding to allowable fatigue and allowable rutting strain to permit total traffic of 150msa. So the recommended thickness of bituminous layer is **217 mm.**

The below graph shows the variation of Fatigue and Rutting life with varying thickness of bituminous layer.

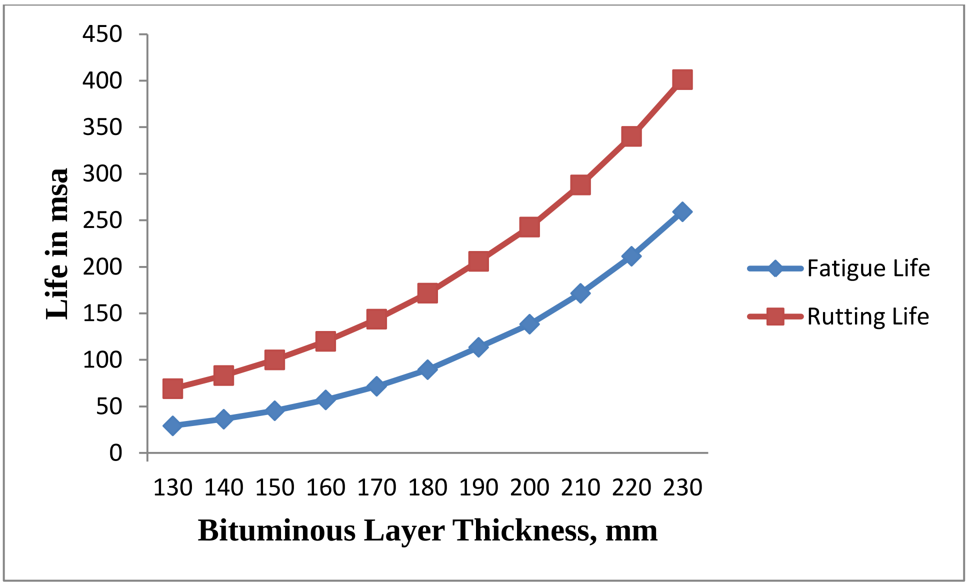

Figure 4.23 Life of pavement v/s Bituminous Layer thickness for VG 30 at 5%

4.13 Design of Flexible Pavement Using CRMB

In the following Table 4.17 Design components are shown which are further used in the designing of a Flexible Pavement.

Table 4.17 Data considered in design for CRMB as Asphalt Binder

CBR of sub-grade	10%
Traffic	150msa
Granular sub base thickness	200mm
Granular base thickness	250mm
Elastic modulus of sub-grade	76.8MPa
Resilient Modulus of Granular Layer	240MPa
Poisson Ratio of Sub grade	0.35
Poisson Ratio of Granular layer	0.35
Poisson Ratio of Bituminous Layer	0.35
Tyre pressure	0.56MPa
c/c spacing of dual wheel	310mm
Single wheel load	20000N

The strains corresponding to various thickness of bituminous mixes layer have been calculated using IIT- PAVE software at bottom of bituminous layer and at the top of subgrade.

The following Table 4.18 shows the design parameters for CRMB modified bitumen having OBC at 5%, which are used in the designing of a pavement section.

Table 4.18 Design Parameters for CRMB at 5.2%

TYPE OF ASPHALT BINDER	**CRMB 60**	
BITUMEN CONTENT	**5.20%**	
MARSHALL STABILITY (kN)	**17.17**	
INDIRECT TENSILE STRENGTH (MPa)	**1.29**	
MODULUS (Es) (MPa)	**1314.474**	
BITUMINOUS LAYER THICKNESS	**DESIGN PARAMETERS**	
130 mm	Ɛ(µT)	276.9
	Ɛ®(µ)	342.9
	Fatigue Life	30.305 msa
	Rutting Life	72.066 msa
140 mm	Ɛ(µT)	261.1
	Ɛ®(µ)	328.9
	Fatigue Life	38.087 msa
	Rutting Life	87.058 msa
150 mm	Ɛ(µT)	246.7
	Ɛ®(µ)	315.6
	Fatigue Life	47.491 msa
	Rutting Life	104.974 msa
160 mm	Ɛ(µT)	232.6
	Ɛ®(µ)	303
	Fatigue Life	59.708 msa
	Rutting Life	126.271 msa
170 mm	Ɛ(µT)	219.2
	Ɛ®(µ)	291
	Fatigue Life	75.210 msa
	Rutting Life	151.659 msa
180 mm	Ɛ(µT)	206.7
	Ɛ®(µ)	279.6
	Fatigue Life	94.509 msa
	Rutting Life	181.783 msa

190 mm	Ɛ(µT)	195
	Ɛ®(µ)	268.9
	Fatigue Life	118.553 msa
	Rutting Life	216.962 msa
200 mm	Ɛ(µT)	185
	Ɛ®(µ)	258.7
	Fatigue Life	145.495 msa
	Rutting Life	258.538 msa
210 mm	Ɛ(µT)	175
	Ɛ®(µ)	249.1
	Fatigue Life	180.604 msa
	Rutting Life	306.888 msa
220 mm	Ɛ(µT)	165.8
	Ɛ®(µ)	239.9
	Fatigue Life	222.824 msa
	Rutting Life	363.979 msa
230 mm	Ɛ(µT)	157.2
	Ɛ®(µ)	231.2
	Fatigue Life	274.123 msa
	Rutting Life	430.336 msa
Allowable Horizontal Tensile Strain (Ɛt)µ	178	
Allowable Vertical Compressive Strain (Ɛv)µ	370	
Minimum Bituminous Layer Thickness	**207 mm**	

For **E = 1314.474MPa**, the thickness of bituminous layer has been interpolated between 200mm and 210mm corresponding to allowable fatigue and allowable rutting strain to permit total traffic of 150msa. So the recommended thickness of bituminous layer is **207 mm.**

The below graph shows the variation of Fatigue and Rutting life with varying thickness of bituminous layer.

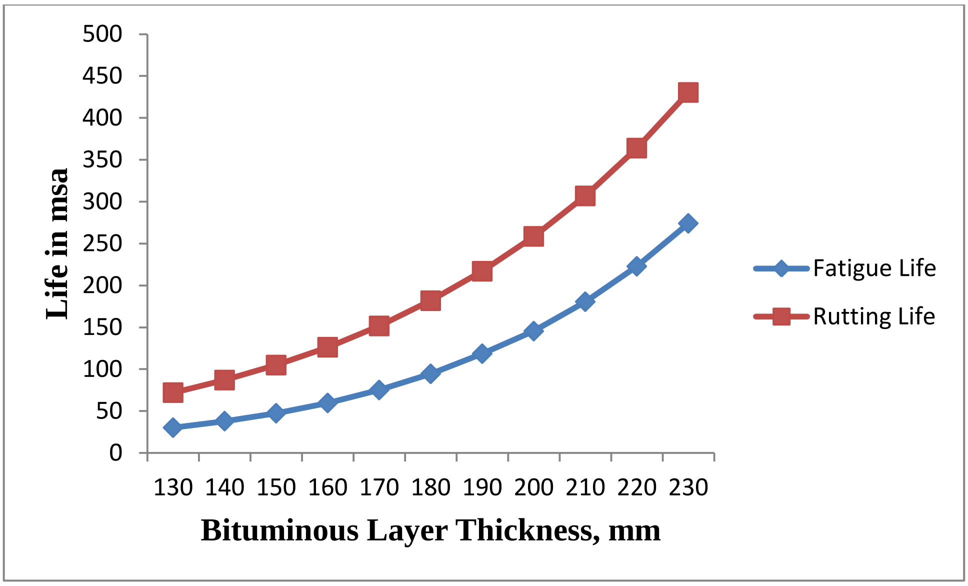

Figure 4.24 Life of pavement v/s Bituminous Layer thickness for CRMB 60 at 5.2%

4.14 Design of Flexible Pavement Using PMB 40

In the following Table 4.19 Design components are shown which are further used in the designing of a Flexible Pavement.

Table 4.19 Data considered in design for PMB as Asphalt Binder

CBR of sub-grade	10%
Traffic	150msa
Granular sub base thickness	200mm
Granular base thickness	250mm
Elastic modulus of sub-grade	76.8MPa
Resilient Modulus of Granular Layer	240MPa
Poisson Ratio of Sub grade	0.35
Poisson Ratio of Granular layer	0.35
Poisson Ratio of Bituminous Layer	0.35
Tyre pressure	0.56MPa
c/c spacing of dual wheel	310mm
Single wheel load	20000N

The strains corresponding to various thickness of bituminous mixes layer have been calculated using IIT- PAVE software at bottom of bituminous layer and at the top of subgrade.

The following Table 4.20 shows the design parameters for PMB modified bitumen having OBC at 5.2%, which are used in the designing of a pavement section.

Table 4.20 Design parameters for PMB at 5.2%

TYPE OF ASPHALT BINDER	**PMB 40**	
BITUMEN CONTENT	**5.20%**	
MARSHALL STABILITY (kN)	**18.4**	
INDIRECT TENSILE STRENGTH (MPa)	**1.38**	
MODULUS (Es) (MPa)	**1409.029**	
BITUMINOUS LAYER THICKNESS	**DESIGN PARAMETERS**	
130 mm	Ɛ(μT)	270
	Ɛ®(μ)	339.6
	Fatigue Life	31.505 msa
	Rutting Life	75.296 msa
140 mm	Ɛ(μT)	254.5
	Ɛ®(μ)	325.5
	Fatigue Life	39.652 msa
	Rutting Life	91.257 msa
150 mm	Ɛ(μT)	240.1
	Ɛ®(μ)	312.1
	Fatigue Life	49.735 msa
	Rutting Life	110.418 msa
160 mm	Ɛ(μT)	226.2
	Ɛ®(μ)	299.4
	Fatigue Life	62.721 msa
	Rutting Life	133.302 msa
170 mm	Ɛ(μT)	213.1
	Ɛ®(μ)	287.3
	Fatigue Life	79.104 msa
	Rutting Life	160.717 msa

180 mm	Ɛ(µT)	201
	Ɛ®(µ)	275.9
	Fatigue Life	99.301 msa
	Rutting Life	193.100 msa
190 mm	Ɛ(µT)	189.5
	Ɛ®(µ)	265.2
	Fatigue Life	124.879 msa
	Rutting Life	231.028 msa
200 mm	Ɛ(µT)	179.5
	Ɛ®(µ)	254.9
	Fatigue Life	154.198 msa
	Rutting Life	276.478 msa
210 mm	Ɛ(µT)	169.8
	Ɛ®(µ)	245.3
	Fatigue Life	191.395 msa
	Rutting Life	329.039 msa
220 mm	Ɛ(µT)	160.8
	Ɛ®(µ)	236.1
	Fatigue Life	236.557 msa
	Rutting Life	391.304 msa
230 mm	Ɛ(µT)	152.5
	Ɛ®(µ)	227.4
	Fatigue Life	290.716 msa
	Rutting Life	463.915 msa
Allowable Horizontal Tensile Strain (Ɛt)µ	178	
Allowable Vertical Compressive Strain (Ɛv)µ	370	
Minimum Bituminous Layer Thickness	**201.54 mm**	

For **E = 1409.029MPa**, the thickness of bituminous layer has been interpolated between 200mm and 210mm corresponding to allowable fatigue and allowable rutting strain to permit total traffic of 150msa. So the recommended thickness of bituminous layer is **201.54 mm.**

The below graph shows the variation of Fatigue and Rutting life with varying thickness of bituminous layer.

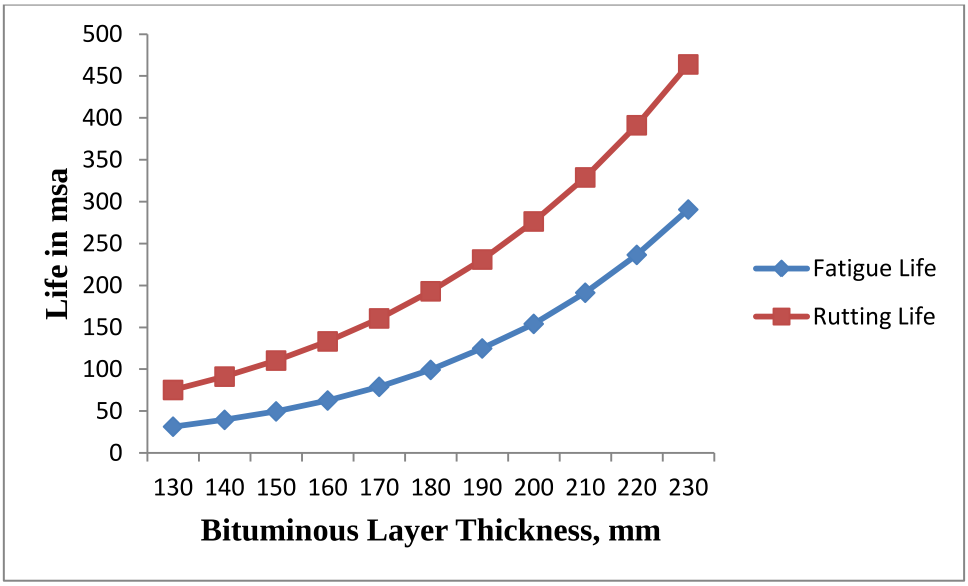

Figure 4.25 Life of pavement v/s Bituminous Layer thickness for PMB 40 at 5.2%

4.15 Design of Flexible Pavement Using Waste Plastic

In the following Table 4.21 Design components are shown which are further used in the designing of a Flexible Pavement.

Table 4.21 Data considered in design of pavement using Waste Plastic in VG-30 as Asphalt Binder

CBR of sub-grade	10%
Traffic	150msa
Granular sub base thickness	200mm
Granular base thickness	250mm
Elastic modulus of sub-grade	76.8MPa
Resilient Modulus of Granular Layer	240MPa
Poisson Ratio of Sub grade	0.35
Poisson Ratio of Granular layer	0.35
Poisson Ratio of Bituminous Layer	0.35
Tyre pressure	0.56MPa

c/c spacing of dual wheel	310mm
Single wheel load	20000N

The strains corresponding to various thickness of bituminous mixes layer has been calculated using IIT- PAVE software at bottom of bituminous layer and at the top of sub-grade.

The following Table 4.22 shows the design parameters for designing of a pavement section using Waste Plastic in the VG 30 bitumen.

Table 4.22 Design parameters for Waste Plastic in VG-30 at 5%

TYPE OF ASPHALT BINDER	**Waste Plastic**	
BITUMEN CONTENT	**5%**	
MARSHALL STABILITY (kN)	**26.5**	
INDIRECT TENSILE STRENGTH (MPa)	**1.42**	
MODULUS (Es) (MPa)	**1451.109**	
BITUMINOUS LAYER THICKNESS	**DESIGN PARAMETERS**	
130 mm	Ɛ(μT)	266.9
	Ɛ®(μ)	338.2
	Fatigue Life	32.13 msa
	Rutting Life	76.71 msa
140 mm	Ɛ(μT)	251.5
	Ɛ®(μ)	324
	Fatigue Life	40.49 msa
	Rutting Life	93.18 msa
150 mm	Ɛ(μT)	237.4
	Ɛ®(μ)	310.6
	Fatigue Life	50.58 msa
	Rutting Life	112.85 msa
160 mm	Ɛ(μT)	223.4
	Ɛ®(μ)	297.8
	Fatigue Life	64.20 msa
	Rutting Life	136.57 msa

170 mm	Ɛ(µT)	210.5
	Ɛ®(µ)	285.8
	Fatigue Life	81.60 msa
	Rutting Life	164.57 msa
180 mm	Ɛ(µT)	198.4
	Ɛ®(µ)	274.4
	Fatigue Life	101.86 msa
	Rutting Life	197.92 msa
190 mm	Ɛ(µT)	187.1
	Ɛ®(µ)	263.6
	Fatigue Life	127.96 msa
	Rutting Life	237.44 msa
200 mm	Ɛ(µT)	177.2
	Ɛ®(µ)	253.3
	Fatigue Life	158.104 msa
	Rutting Life	284.47 msa
210 mm	Ɛ(µT)	167.6
	Ɛ®(µ)	243.7
	Fatigue Life	196.35 msa
	Rutting Life	338.94 msa
220 mm	Ɛ(µT)	158.7
	Ɛ®(µ)	234.5
	Fatigue Life	242.78 msa
	Rutting Life	403.54 msa
230 mm	Ɛ(µT)	150.5
	Ɛ®(µ)	225.8
	Fatigue Life	298.43 msa
	Rutting Life	478.99 msa
Allowable Horizontal Tensile Strain (Ɛt)µ	178	
Allowable Vertical Compressive Strain (Ɛv)µ	370	
Minimum Bituminous Layer Thickness	**199.1 mm**	

For **E = 1451.109MPa**, the thickness of bituminous layer has been interpolated between 190mm and 200mm corresponding to allowable fatigue and allowable rutting strain to permit total traffic of 150msa. So the recommended thickness of bituminous layer is **199.1 mm.**
The below graph shows the variation of Fatigue and Rutting life with varying thickness of bituminous layer.

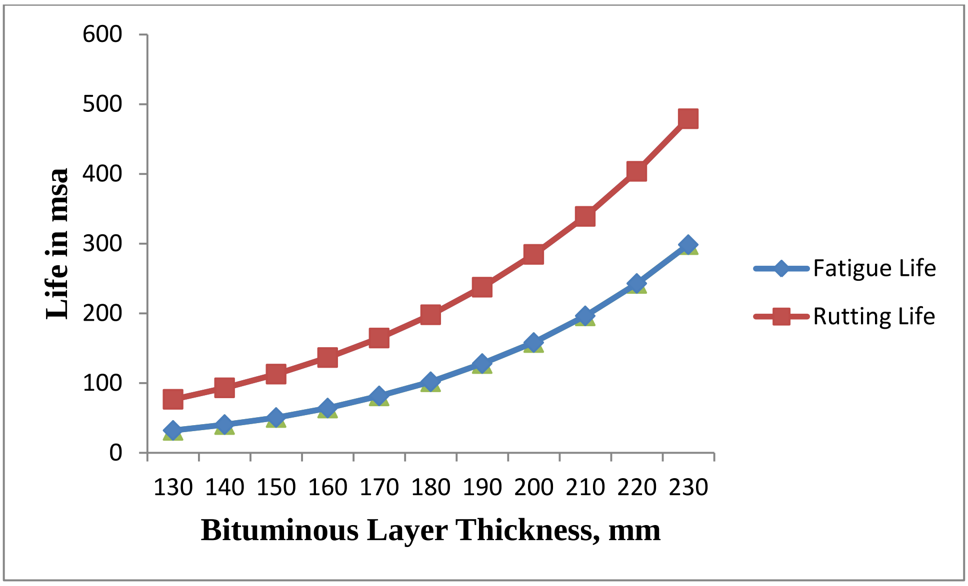

Figure 4.26 Life of pavement v/s Bituminous Layer thickness using Waste Plastic

4.16 Design of Flexible Pavement Using Waste Tyre Tube

In the following Table 4.25 Design components are shown which are further used in the designing of a Flexible Pavement.

Table 4.23 Data considered in design for Waste Tyre Tube in VG-30 as Asphalt Binder

CBR of sub-grade	10%
Traffic	150msa
Granular sub base thickness	200mm
Granular base thickness	250mm
Elastic modulus of sub-grade	76.8MPa
Resilient Modulus of Granular Layer	240MPa
Poisson Ratio of Sub grade	0.35

Poisson Ratio of Granular layer	0.35
Poisson Ratio of Bituminous Layer	0.35
Tyre pressure	0.56MPa
c/c spacing of dual wheel	310mm
Single wheel load	20000N

The strains corresponding to various thickness of bituminous mixes layer has been calculated using IIT- PAVE software at bottom of bituminous layer and at the top of sub-grade.

The following Table 4.24 shows the design parameters for designing of a pavement section using Waste Tyre Tube in the VG 30 bitumen.

Table 4.24 Design parameters for Waste Tyre Tube in VG-30 at 5%

TYPE OF ASPHALT BINDER	**Waste Tyre**	
BITUMEN CONTENT	**5%**	
MARSHALL STABILITY (kN)	**19**	
INDIRECT TENSILE STRENGTH (MPa)	**1.49**	
MODULUS (Es) (MPa)	**1524.845**	
BITUMINOUS LAYER THICKNESS	**DESIGN PARAMETERS**	
130 mm	Ɛ(µT)	262
	Ɛ®(µ)	335.8
	Fatigue Life	33.10 msa
	Rutting Life	79.23 msa
140 mm	Ɛ(µT)	246.7
	Ɛ®(µ)	321.5
	Fatigue Life	41.83 msa
	Rutting Life	97.19 msa
150 mm	Ɛ(µT)	232.5
	Ɛ®(µ)	308
	Fatigue Life	52.68 msa
	Rutting Life	117.23 msa
160 mm	Ɛ(µT)	218.9
	Ɛ®(µ)	295.2

	Fatigue Life	66.60 msa
	Rutting Life	142.12 msa
170 mm	Ɛ(µT)	206
	Ɛ®(µ)	283.1
	Fatigue Life	84.35 msa
	Rutting Life	171.81 msa
180 mm	Ɛ(µT)	194.3
	Ɛ®(µ)	271.7
	Fatigue Life	105.90 msa
	Rutting Life	207.00 msa
190 mm	Ɛ(µT)	183.4
	Ɛ®(µ)	260.8
	Fatigue Life	132.568 msa
	Rutting Life	249.22 msa
200 mm	Ɛ(µT)	173.4
	Ɛ®(µ)	250.6
	Fatigue Life	164.84 msa
	Rutting Life	298.64 msa
210 mm	Ɛ(µT)	163.9
	Ɛ®(µ)	240.9
	Fatigue Life	205.28 msa
	Rutting Life	357.17 msa
220 mm	Ɛ(µT)	155.2
	Ɛ®(µ)	231.7
	Fatigue Life	253.80 msa
	Rutting Life	426.12 msa
230 mm	Ɛ(µT)	147.1
	Ɛ®(µ)	223.1
	Fatigue Life	312.64 msa
	Rutting Life	505.84 msa
Allowable Horizontal Tensile Strain (Ɛt)µ	178	

Allowable Vertical Compressive Strain (Ɛv)µ	370	
Minimum Bituminous Layer Thickness	**195.4 mm**	

For **E = 1524.845MPa**, the thickness of bituminous layer has been interpolated between 190mm and 200mm corresponding to allowable fatigue and allowable rutting strain to permit total traffic of 150msa. So the recommended thickness of bituminous layer is **195.4 mm.**
The below graph shows the variation of Fatigue and Rutting life with varying thickness of bituminous layer.

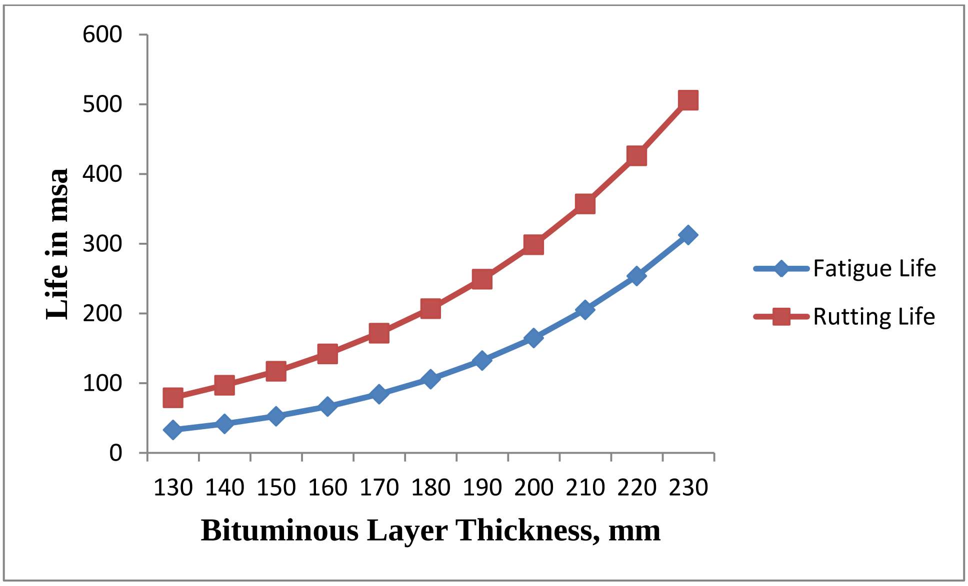

Figure 4.27 Life of pavement v/s Bituminous Layer thickness using Waste Plastic

4.17 Discussions of Results:

4.17.1 Effect of Asphalt binder VG-30 on the Stability-Flow analysis of Bituminous Concrete Grade-1

In the case of VG-30 asphalt binder, different percentage viz. 4.5%, 5% and 5.5% of bitumen were used to calculate the optimum binder content for the BC mix GRADE-1. Table 4.7 and Figs. 4.1 to 4.6 show the variation of stability, flow, bulk Density, air voids, VFB, VMA etc. for different percentages of bitumen. It is observed that the flow criteria of 2 to 4 mm for BC grade 1 [*MORTH – clause 505.3.1]* was satisfied for the entire range of bituminous mixes having 4.5%, 5% and 5.5% bitumen. On analysis, it was observed that the optimum binder content comes out to be 5%.

4.17.2 Effect of the use of PMB on the Stability-Flow analysis of BC mix Grade-1

In this case, different percentages of PMB 4.5%, 5% and 5.5% content were added to find out the optimum PMB content for the BC mix GRADE-1. Table 4.8 and Figs. 4.7 to 4.12 show the variation of stability, flow, bulk density, air voids, VFB, VMA etc. for different percentages of PMB content. It is observed that the maximum stability value i.e. 18.40 KN occurs at 5% bitumen content of PMB. The stability value decreases with the increase in bitumen content (5.5%). It is also observed that the flow criteria of 2 to 4 mm for BC grade 1 [*MORTH – clause 505.3.1]* was satisfied for the entire range of bituminous mixes having 4.5%, 5% and 5.5% bitumen. Result analysis showed that the optimum binder content comes out to be 5.2%

4.17.3 Effect of the use of CRMB on the Stability-Flow analysis of BC mix Grade-1

In this case, different percentages of CRMB 4.5%, 5% and 5.5% content were used to find out the optimum CRMB content for the BC mix GRADE-1. Table 4.9 and Figs. 4.13 to 4.18 show the variation of stability, flow, bulk density, air voids, VFB, VMA etc. for different percentages of CRMB content. It is observed that the maximum stability value i.e. 17.17 KN occurs at 5% bitumen content of CRMB. The stability value decreases to 13.98 KN with the increase in bitumen content (5.5%). It is also observed that the flow criteria of 2 to 4 mm for BC grade 1 [*MORTH – clause 505.3.1]* was satisfied for the entire range of bituminous mixes having 4.5%, 5% and 5.5% bitumen. Analysis of results showed that the optimum binder content comes out to be at 5.2% CRMB.

4.17.4 Effect of Waste Plastic on the Stability-Flow analysis of BC mix Grade-1

Waste milk pouches were used in the bituminous mixes in the bituminous concrete layer for the calculation of optimum binder content. Different percentages of plastic content were added to the bituminous mixture by the replacement of bitumen at optimum binder content. Waste plastic was added as replacement for bitumen in the varying percentages i.e. 2, 4, 6, 8, 10 and 12% by weight of bitumen. Table 4.10 and Figs. 4.19 and 4.20 show the variation of stability and flow of BC mix with percentage replacement of OBC by waste plastic. The maximum stability of 26.50 KN is observed at addition of 8% waste plastic. It is also observed that the flow criteria of 2 to 4 mm for BC grade 1 [*MORTH – clause 505.3.1]* was satisfied for the entire range of bituminous mixes having varying proportion of bitumen and waste plastic content. With the addition of 8% waste plastic, the stability value is increased by 48.6% over normal VG 30 bitumen.

4.17.5 Effect of Waste Tyre Tubes on the Stability-Flow analysis of BC mix Grade-1

The optimum binder content is calculated for the BC mix grade-1 with bitumen replaced with 6, 9, 12 and 15% of discarded tyre tube by weight of bitumen. Table 4.11 and Figs. 4.21 and 4.22 shows the variation of stability and flow of BC mix with percentage replacement of OBC by the waste tyre tubes. The maximum stability is observed at 12% of waste tyre tube. With this replacement, the stability value comes out to be 19 KN i.e. increase in stability value with 12% addition of waste tyre tube with 12 % is 39.7% and it is also observed that the flow criteria of 2 to 4 mm for BC grade 1 [*MORTH – clause 505.3.1]* was satisfied for the entire range of bituminous mixes having varying proportion of bitumen and waste tyre tube content.

4.17.6 Calculation of Indirect Tensile Strength

The Indirect Tensile Strength Test was conducted on various bituminous mixtures like mixtures made of using asphalt binder VG-30, CRMB, PMB, using Waste plastic (8%), Waste tyre tube (12%) by keeping constant optimum binder content (OBC) i.e. 5% and ITS test was conducted as per ASTM D 6931-12 on these specimens at room temperature. The results are shown in the following Table 4.27

Table 4.25 Calculation of ITS & Resilient Modulus values

S. No.	Type of Binder	ITS (MPa)	Es (MPa)
1	VG-30	1.21	1230.585
2	CRMB	0.836	840.842
3	PMB	1.03	1042.478
4	Waste Plastic (8%)	1.42	1451.109
5	Waste Tyre Tube (12%)	1.49	1524.845

4.17.7 Design of Pavement

From the results we can conclude that rutting and fatigue life for **waste tyre tube** is more than **all the other four binders** for the same thickness of bituminous layer. So, to provide same fatigue and rutting life we require less thickness of bituminous layer. Due to reduction in thickness required for bituminous layer there is a considerable reduction in construction cost. Though maintenance studies need to be carried out in order to study the actual behaviour of pavement under different loading and climatic conditions.

Chapter – 5

CONCLUSION

5.1 GENERAL

The major conclusions drawn from the study carried out on stability-flow analysis of BC mix (Grade-1) by using different additives are as follows:

1. Initially, normal asphalt binder VG-30 is tested at different percentages for the BC mix grade -1 and optimum binder content (OBC) is calculated .The OBC occurs at 5% and flow values are in the limits specified as per MORTH.
2. The stability values for the BC grade-1 mix increase with the replacement of OBC up to 8% of waste plastic but it decreases further with the addition of waste plastic. This waste plastic only indicates that this percentage is the only suited level of replacement.
3. For the addition of discarded tyre tubes, the stability values for the BC grade-1 mix increase with the replacement of OBC (5%) upto 12% of discarded tyre tubes with optimum binder content of 5% but decreases with the addition of tyre tube. However, the stability and flow values lie within the limits specified by MORTH for all % replacements of tyre tubes.
4. The OBC of CRMB and PMB used in BC Grade-1 is 5.2%.
5. Out of the various materials used, replacement of OBC by 12% discarded tyre tube has the highest stability value.
6. The Indirect Tensile Strength (ITS) test was conducted on all the conditioned samples prepared i.e. for VG-30 bitumen, PMB, CRMB, with waste plastic and with discarded tyre tube at constant loading rate of 50.8mm/min and the results comes out to be 1.21, 1.29, 1.38, 1.42, 1.49 respectively and further Elastic Modulus were calculated w.r.t each binder and pavement is designed using IIT PAVE.

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