BE CIVIL ENGINEERING

PROJECT REPORT

PERFORMANCE EVALUATION OF ANTISTRIPPING MODIFIED CONCRETE USING A NANO-PRODUCT, “ZYCOSOIL”.

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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MILITARY COLLEGE OF ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY

RISALPUR CAMPUS, PAKISTAN

(2015)

This to certify that the

BE Civil Engineering Project entitled

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Has been accepted towards the partial fulfillment of the requirements for

BE Civil Engineering Degree

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Dr. Muhammad Jawed Iqbal, PhD

Syndicate Advisor

Syndicate members with Advisor

Dedication

Special dedication to our parents
Our supervisor, our beloved friends,

And all faculty members

For all support, encouragement and believe in us. Thank you so much.

ACKNOWLEDGEMENT

First of all thanks to Allah for his blessings, this has enabled me to complete my final year project. **Maj. Dr. Muhammad Jawed Iqbal**, our syndicate DS, was the driving force behind this research. He contributed valuable ideas and his reception of our ideas and suggestions has always been extremely encouraging. Through his exemplary guidance and leadership, we were able achieve the objectives of this research.

We are honored to have had the renowned instructor **Colonel Dr. Shahid Iqbal** as our chief instructor. His ceaseless support and valuable guidance always shone through like an invigorating ray of sunlight.Our profound gratitude also goes to **Lt Col Dr. Sarfaraz** for his intuitive and innovative insights. He has been guiding us on every easy and difficult time. He helped greatly in execution of our project. Lab demonstrators Mr. Mugheera and Mr. Arshad always a bulwark of support for transportation graduate students, thank you for your vital guidance. We appreciate the support extended to us by Lt **Col. Dr. Muhammad Bilal Khurshid** of NUST H12 campus.

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EXECUTIVE SUMMARY

The rapidly increasing urban population of Pakistan with prompt rise in industrialization coupled with high increase of road vehicles engaging in rapidly growing cities to fit the evolving needs of the economy, demands good quality of roads to cope up the increasing pressure of road traffic. It becomes the responsibility of researchers, scientists, contractors to improve the riding quality while maintaining the economy for the developing country like ours. In this project the investigations are carried out to determine engineering properties of locally available crushed stones, fillers and 60/70 grade bitumen for mix design and zycosoil is added to the mix to compare its behavior with the conventional mix.

Marshall Method of mix design was adopted to find out the optimum bitumen content. In order to arrive at homogenous mix with required standards, mix with obtained 4% optimum bitumen content is taken into consideration for Modified Marshall Mix design by addition of 1.5% and 2% dosage of zycosoil chemical is prepared and tested to determine the key properties as per the codal provision. The tests indicated the desire to opt for chemically modified mix is it shows better results as compared to conventional mix hence it is suggested to use for the construction of Flexible pavement.

Marshall Mix design was used, first to determine the optimum binder content and then further to test the modified mixture properties. In total 29 samples were prepared of which 5 samples were used to determine the optimum asphalt binder content and the remaining samples were used to investigate the effect of modifying the conventional asphalt mix with zycosoil and lime. The optimum asphalt content was found out to be 4%. Two proportions of viscous zycosoil by weight of the optimum binder content were selected to be tested (i.e. 1.5% and 2%). The proportion of lime was selected to be 2% by weight of asphalt binder content. The tests include the determination of bulk density, stability and flow. The optimum proportion of the modifier is found to be 1.5% by the

weight of bitumen content. All the results of different samples containing different modifiers were compared with each other.

Rutting is the major cause of road failure in Pakistan due to violation of axle load limits, improper design practices and exposure to high tire pressure and high temperatures. Rutting test was performed to measure the relative rutting resistance of controlled samples, zycosoil and lime modified samples. Zycosoil modified mix exhibited better rutting resistance compared to conventional mix as a whole addition of Zycosoil and lime in asphalt mix is found to increase the Marshall stability, reduce the density and reduce the rutting susceptibility. The results showed that zycosoil modified asphalt mix exhibited better performance compared to lime modified asphalt mix and conventional asphalt mix. Economic analysis showed that addition of zycosoil in asphalt mix lead to a saving of **Rs. 19, 448** per lane km in comparison to using conventional (unmodified) asphalt mix in road construction.

The analysis and results of this research can effectively be used to greatly improve and economize the road construction and to introduce *state-of-the-art* products to the asphalt pavements.

CHAPTER 1

INTRODUCTION

1.1 General

Growth of good road infrastructure is the backbone of the transportation system and is the key element of economy of country. The significant evolution is observed owing to strong domestic arcades, increasing purchasing power and corporate governance laws. Roads have to meet the ever increasing load carrying capacity to meet the demand of users and should show enhanced performance of pavement. Scientists and researchers are constantly concentrating to improve the pavement with desirable quality, stability and proper lifetime. Bituminous Mixes are most commonly used all over the world in pavement construction

The complicated microstructure of asphalt concrete is related to the gradation of aggregate, the properties of aggregate-binder interface, the void size distribution, and the interconnectivity of voids. For special applications where traffic is extremely heavy, stiffer mixes are required. Keeping these facts in minds it was felt that efforts can be made to use some chemical additives and study the various parameters of bitumen and bituminous mixes. As a result, the fatigue property of asphalt mixtures is very complicated and sometimes difficult to predict. Understanding the ability of an Asphalt pavement to resist fractures from repeated loading condition is essential for developing superior HMA pavement designs. Previous studies have been conducted to understand the occurrence of fatigue and how to extend pavement life under repetitive traffic loading. However, reaching a better understanding of fatigue behavior of asphalt pavements continues to challenge researchers worldwide, particularly as newer materials with more complex properties are being used in the field.

1.2 Problem Statement:

Increase in road traffic during the last two decades in combination with an insufficient degree of maintenance due to shortage in funds, has caused an accelerated and continuous deterioration of the road network in Pakistan. To alleviate this process, several measures may be effective, such as, securing additional funds for maintenance, improved and innovative roadway design, use of better quality of materials and the use of cost-effective construction methods. With this perspective, this research is aimed at exploring the potential prospects of adding Zycosoil and Lime into asphalt pavements. Objectives of this research also include determining the best method of adding zycosoil in asphalt mix. A comparative analysis will then be carried out to identify the best method for utilization of zycosoil in asphalt mix in Pakistani environments. Marshall Mix design method is planned to be used to determine the optimum bitumen content. A comparative analysis of various HMA performance parameters such as stability, rutting resistance, and load bearing capacity, etc of modified and conventional HMA will be carried out. Lastly economic analysis will also be carried out to ascertain the cost-effectiveness of various modifiers in comparison to conventional HMA. Then comparative analysis of modified and unmodified HMA will be carried out, which is the main focus of our project. The analysis and results of this research are expected to effectively contribute in improving and economizing the road construction

1.3 Research Objectives

Research objectives of this study include:

- To study basic properties of aggregates and plain bitumen
- Study the effect of adding zycosoil & Lime in hot mix asphalt (HMA) as modifier.
- To compare the performance parameters of conventional HMA and modified HMA through testing matrix.
- To determine the optimum content of modifiers to be used in bituminous mixes in Pakistani environment.
- To evaluate the engineering properties and Optimum bitumen Content for the mix with and without Zycosoil.

1.4 Scope of Project

Basic aim of this project is to evaluate the performance of adding zycosoil modified bituminous mix and its potential to improve the binding properties of the mix, Marshall Stability value, flow, penetration resistance, temperature susceptibility and rutting resistance of asphalt concrete wearing course. Also included in the scope of the research is to analyze the economy achieved by this process.

1.5 Overview of Study Approach

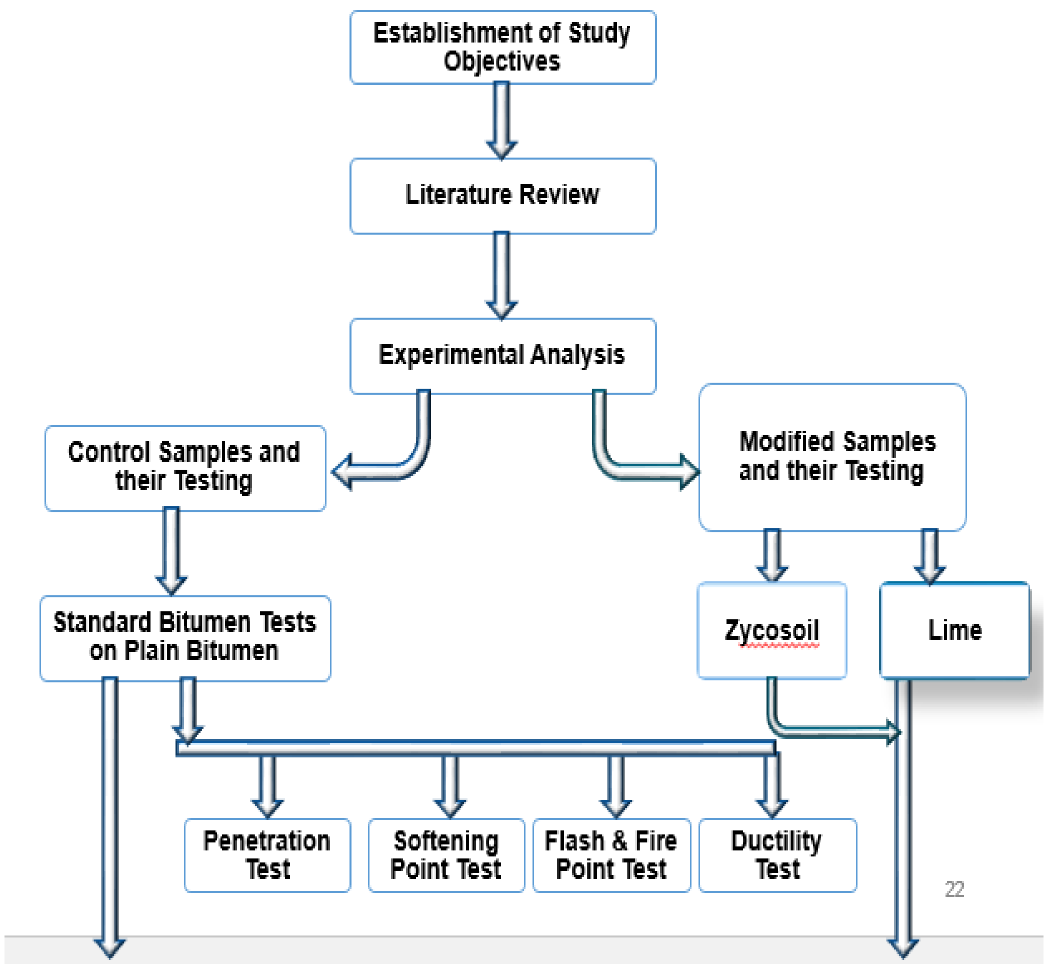


Figure 1.1 Overview of study approach

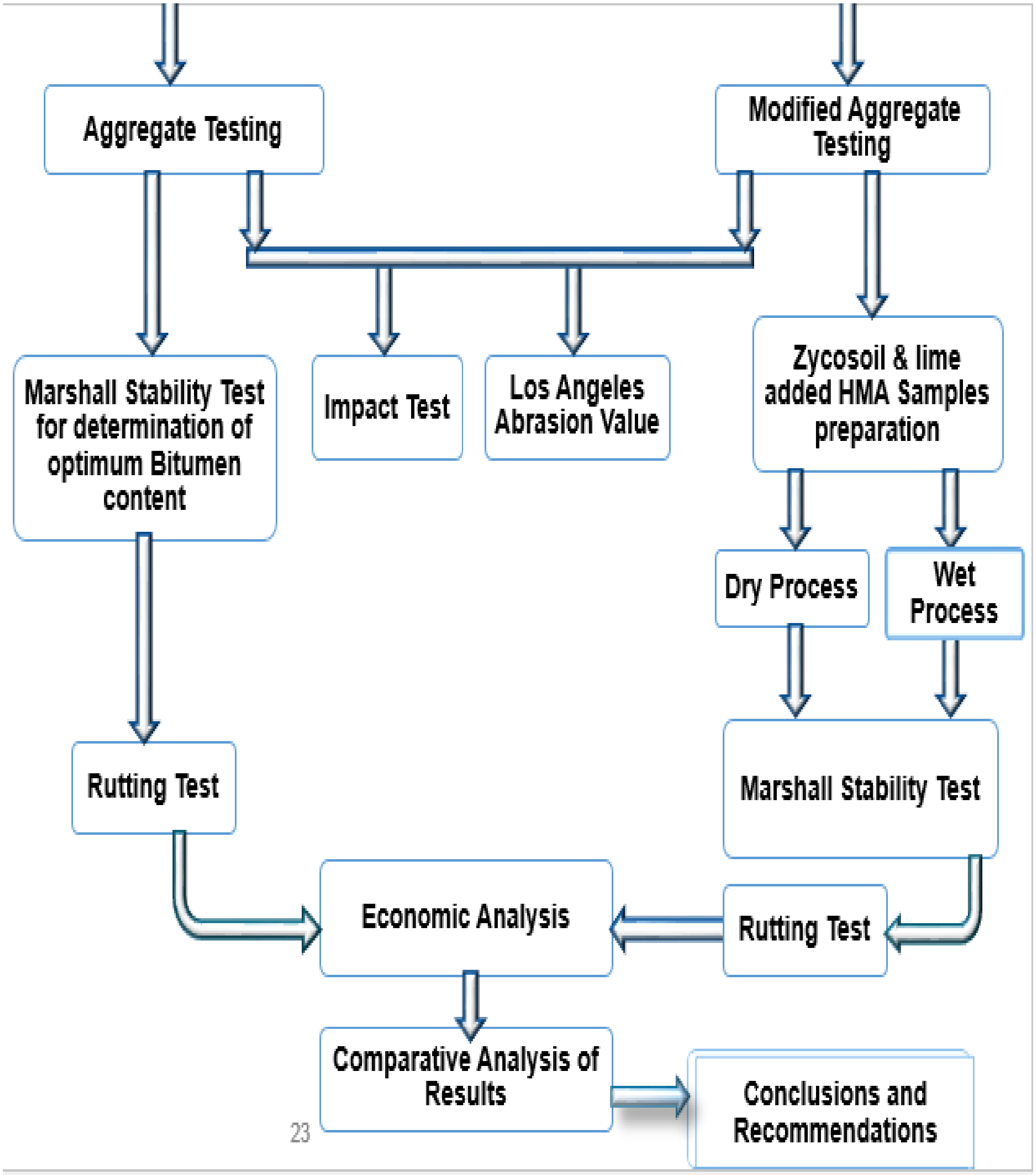


Figure 1.1 Overview of study approach (continued)

CHAPTER 2

LITERATURE REVIEW

2.1 Pavement Problems

Flexible pavements can perform from 5 to 25 years according to their design life. But there are many issues and distresses that hinder the performance of pavements. Some factors that cause problems in pavements are:

- Temperature
- Moisture
- Poor construction
- Drainage issues
- Overloading

These are just a few of the factors that can cause many problems in pavements. Some of the common distresses are:

- Alligator cracking
- Block Cracking
- Reflection Cracking
- Rutting
- Bleeding
- Stripping

Although there are many distresses and many pavement performance issue. Some of them can be addressed by adding additives like zycosoil to the asphalt mix (e.g. Rutting etc.). Bitumen is a useful binder for road construction. Different grades of bitumen like 30/40, 60/70, and 80/100 are available on the basis of their penetration values. The steady increase in high traffic intensity in terms of commercial vehicles, the increase in overloading of trucks and the significant variation in daily and seasonal temperature demand improved road characteristics. Any improvement in the property of the binder is the need of the hour.

2.2 Water- the great destroyer

Moisture damage is caused by a loss of adhesion, commonly referred to as "stripping" aggregate surface or a loss of cohesion within the binder itself, resulting in a reduction in stiffness. Heavy traffic on a moisture-weakened pavement can result in premature rutting or fatigue cracking. The presence of moisture can also accelerate the formation of potholes

2.3 Types of water repellents:

Film formers: These film formers have a particle size greater than 100 nm, which will not allow them to penetrate inside the pores of the building materials but instead form a film covering and protecting the surface from water absorption. Failure of film formers: -

- Blocks breathability
- Life of only 2 – 5 years

Penetrants: They are solvent based, soluble monomeric materials less than 6 ηm in size which can easily penetrate inside the pores and sub-branches of the pores. Failure of penetrants: –

- Flammability
- High cost
- Toxic VOC solvents

2.4 What Is Nanotechnology?

Today is the day of modernization and advancements. Earlier developments indicate the use of polymers to enhance the properties of asphalt binder. The introduction of nanotechnology to the field of asphalt pavements is new. Though there are certain materials like Staffanes, but this world is full of potential to be uncovered.

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering. The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled “There’s Plenty of Room at the Bottom” by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (Caltech) on December 29, 1959, long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultra-precision machining, Professor Norio Taniguchi coined the term nanotechnology. It wasn't until 1981, with the development of the scanning tunneling microscope that could "see" individual atoms that modern nanotechnology began.

2.5 Earlier Studies and Historical Developments

Development of distresses in the pavements with the conventional mixes reveals the need for use of improved materials and techniques for design specifications based on performance tests. The present investigation was carried out to propose the use of chemical. Chemical were mixed to bituminous concrete by wet process to get modified mix. Marshall Method of mix design was adopted to find out the optimum bitumen content. Marshall specimen were prepared for bitumen content of 5.0,5.5,6.0,6.5 and 7.0 per cent by weight of aggregate with 0.1% of chemical by weight of bitumen. Bulk density, Marshall Stability, Flow, Air Voids (Vv), Voids in Mineral Aggregates (VMA), voids filled with bitumen (VFB), Retained stability, Indirect Tensile Strength and Tensile Strength Ratio (TSR), Stripping, Fatigue life and deformations were determined and compared with neat bituminous concrete mixes. The Marshall Stability, Retained stability, Indirect Tensile Strength (ITS), Tensile strength ratio, fatigue life values for modified mix was increased, similarly stripping of bitumen and rutting deformation decreased considerably as compared to conventional mix.

Tests were conducted to study the effect of waste polymer modifier (nitrile rubber and polythene) on various mechanical properties of the bituminous concrete mixtures. Results showed significant improvements in various properties of the bituminous concrete mixture. The higher values of Marshall Stability and retained stability indicated increased strength and low moisture susceptibility.

- Anil Kumar S (2014) studied that the development of distresses in the pavements with the conventional mixes reveals the need for use of improved materials and techniques for design specifications based on performance tests. The present investigation was carried out to propose the use of chemical. Chemical were mixed to bituminous concrete by wet process to get modified mix. Marshall Method of mix design was adopted to find out the optimum bitumen content. Marshall specimen were prepared for bitumen content of 5.0,5.5,6.0,6.5 and 7.0 per cent by weight of aggregate with 0.1% of chemical by weight of bitumen. Bulk density, Marshall Stability, Flow, Air Voids (Vv), Voids in Mineral Aggregates (VMA), voids filled with bitumen (VFB), Retained stability, Indirect Tensile Strength and Tensile Strength Ratio (TSR), Stripping, Fatigue life and deformations were determined and compared with neat bituminous concrete mixes. The Marshall Stability, Retained stability, Indirect Tensile Strength (ITS), Tensile strength ratio, fatigue life values for modified mix was increased, similarly stripping of bitumen and rutting deformation decreased considerably as compared to conventional mix.
- Goutham Sarang(2014)carried out on Stone Matrix Asphalt (SMA) - a gap graded bituminous mixture with high concentration of coarse aggregates and high mastic content. In this investigation SMA mixtures were prepared by Marshall Compaction (MC) and also in Super pave Gyratory Compactor (SGC) and their performances in laboratory were compared. The mixtures were prepared using

Viscosity Graded (VG)–30 bitumen and a chemical named Zycosoil was used as a stabilizing additive. Volumetric properties, Marshall Characteristics, behavior to moisture action etc. were determined in laboratory. From the results it is seen that gyratory compaction is the suitable method to prepare SMA mixtures.

- Sandhya Dixit (2013) showed that the properties of bitumen such as penetration, softening point improved with the addition of the waste fiber. There is a significant decrease in penetration values for modified blends, indicating the improvement in their temperature susceptibility resistant characteristics. From the Marshall Test results, it is concluded that the Marshall Stability value increases with an increase in bitumen content from 5% to 5.5% then it decreases. Also higher value of Marshall Stability was found for a modified mix as compared to an unmodified mix.
- Sangita et al. (2011) studied the effect of waste polymer modifier (nitrile rubber and polythene) on various mechanical properties of the bituminous concrete mixtures was evaluated. Various test results on 60/70 bitumen and aggregate satisfied the specified limits. Marshall Stability and retained stability tests confirmed the optimum WPM content to be 8%. The WPMB mix containing 8% WPM showed significant improvements in various properties of the bituminous concrete mixture. The higher values of Marshall Stability and retained stability indicated increased strength and low moisture susceptibility.
- Taher M.A. Al-Ani (2009) studied that adding the Rubber-Silicone to asphalt binder have the following effects on the performance of asphalt mixture: Increasing the Marshal stability, air voids, and reducing the flow and bulk density compared with the original mix. Increasing the flexibility properties of the mix and this appears from reducing the permanent deformation at test temperature (600C), the reduction percentage is about (30% to 70%) compared with the original mix without adding Rubber-Silicone. Study the effect of Rubber-Silicone on the performance of asphalt mixture at low temperature.

2.6 What Is Zycosoil?

Zycosoil is chemically reactive antistrip nanotechnology. Zycosoil reacts with aggregates to form 'asphalt-loving' non-polar hydrophobic aggregate surfaces at HMA processing temperatures. Zycosoil eliminates de-bonding of asphalt mixes caused due to inadequate and incomplete coating, coupled with moisture ingress, to enhance durability of asphalt pavements. Chemical nanotechnology allows water proofing of soils and aggregate surfaces permanently and acts as a bonding agent to asphalt. This is the most significant development in the last 50 years which will improve the quality of road building with reduced maintenance cost.

2.7 Zycosoil Benefits

Following are the key benefits of using Zycosoil:

- Improves mix tensile strength and Marshall Stability, maintaining flow value
- Higher compaction on field by 1-1.5 %
- Odorless work environment
- Cleaner equipment
- Non corrosive

2.8 Eliminates stripping by Chemical Bonding

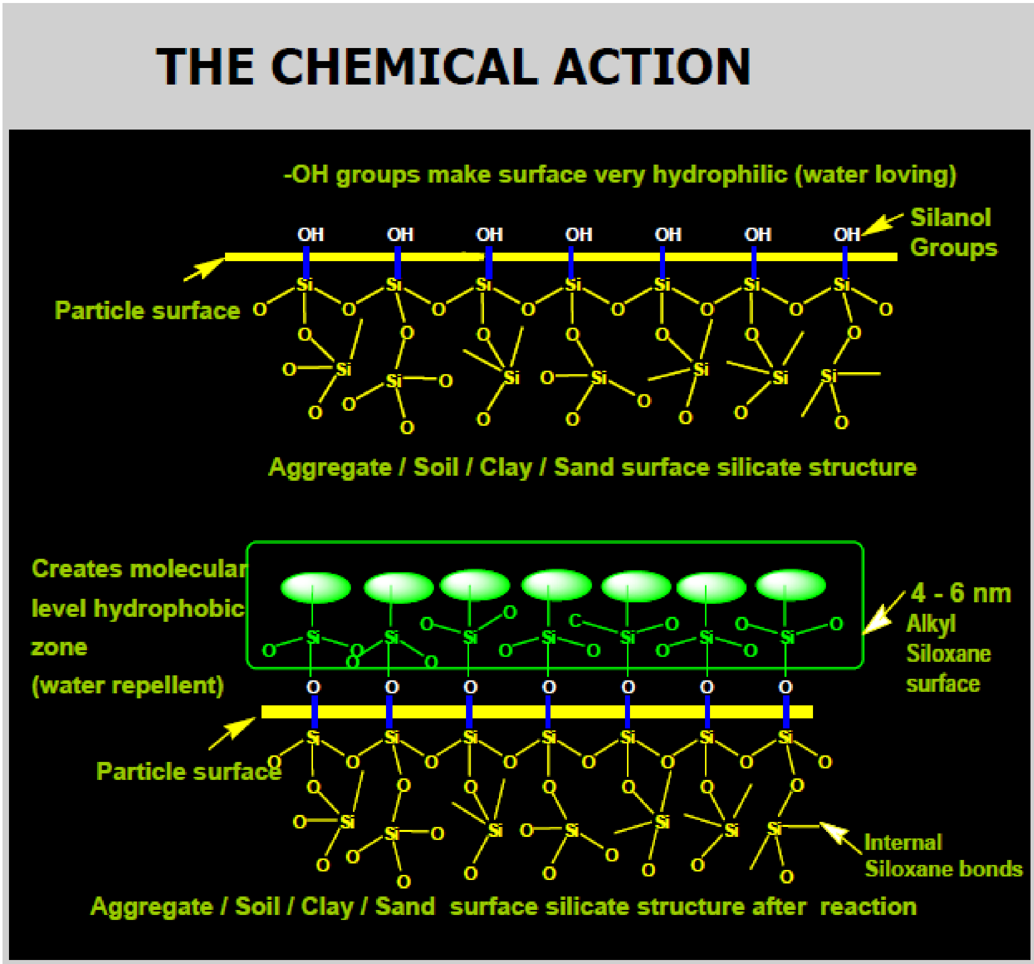


Fig 2.1 Chemical reaction

2.9 Zycosoil Features

Zycosoil is a water soluble reactive organo-silicon compound. It forms Si-OH silanol groups upon hydrolysis. These silanols are reactive and can form Si-O-Si siloxane bonds with surface silanol groups of inorganic substrates. Zycosoil nanotechnology offers:

- Permanent water repellent nano layer on all types of soil, aggregates & other inorganic road construction materials

- Reaction leads to permanent nano siliconization of the surfaces by converting the water loving silanol groups to water repellent siloxane bonds

- The Si-O-Si Siloxane bond is Mother Nature's strongest bond which survives for centuries

- Has ultraviolet and thermal stability for 20 plus years

- Is non-leachable as it chemically binds to surfaces permanently Zycosoil reactive bonding with the aggregates and asphalt helps to reduce incompatibility with aggregates:

- Minimum loss of compressive strength and flexibility of asphalt concrete under wet conditions

- Stripping and hydraulic scouring due to bond failure of asphalt binder with aggregates under wet condition

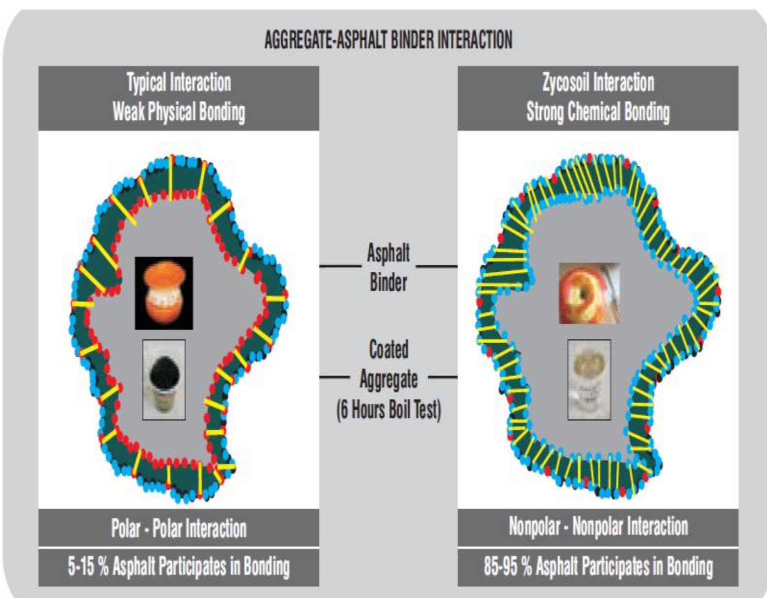


Fig 2.2 Chemical bonding

- Zycosoil can enable a reduction in asphalt binder for maintaining same stability strength without compromising flow values. Addition of 0.1 % Zycosoil in asphalt binder resulted in approx. 40 % increase in compressive strength of asphalt concrete mixture with 5.1 % asphalt binder. Results indicated that 0.1 % Zycosoil addition at 4 % asphalt binder content matched the compressive strength of the controlled with 5.1 % asphalt binder content concrete mix.

2.10 Technical Specifications

- Color Clear to pale yellow
- Solid content 41 +/- 2 %
- Solvent Ethylene glycol
- Flash Point 80° C
- Viscosity (25° C) 200-800 cps
- Solubility Soluble in asphalt

2.11 Application Process

- 1 Kg Zycosoil is mixed with 1 MT of Asphalt (0.1%)
- The Hot Molten asphalt is mixed with circulating pump for 20-30 min.
- The modified hot molten asphalt binder is mixed with aggregates by a spray technique as needed.

2.12 Impact

- Favorable Economics for Cost negative at Capex with inbuilt insurance for future
- Moisture Damage for Chemically bonded asphalt binders to aggregates, eliminates de-bonding due to moisture

- Cracking & Rutting for Longer life durable pavements
- Crew & Equipment 4 Odor free, No fumes, Cooler hot mix & Cleaner equipment's
- Materials (aggregates / asphalt binder) 4 Resolves aggregate & binder issues for high performance HMA / WMA
- Binder Optimization4 Uniform coating and distribution of asphalt binder in fines below 75microns. This usually results in 0.2-0.3% lower bitumen content for the same voids at designcompaction load
- RAP / RAS4 Thorough coating and improved workability/ compaction eliminate construction limitations of high RAP/ RAS content mixes
- Jet Black Look

2.13 Eliminates Stripping

- Chemical bonding eliminates aggregates moisture susceptibility aggregates by converting silanols to siloxane bonds
- Wet / moist aggregates fed for WMA mixes is a serious concern for aggregate asphalt de-bonding, usually requiring anti-strip additives
- Aggregates water/moisture with Zycosoil acts as a catalyst and promotes reactivity of asphalt binder with aggregate to achieve chemical bonding
- Retains 95% coating in 6 hours ASTM D3625 boil test

2.14 **Limitations of Zycosoil**

- Adverse effects of the solvent used- ethylene glycol
- A lot of precautions to be takem
- More effective on pre-existing cracks than cracks which occur after the application
- It cannot be applied if:

    1. Ambient temperature is below 10º C or above 50ºC
    2. Rain is expected within 2 hours following the application.

- Precipitation has occurred within 24 hours prior to application.

CHAPTER 3

EXPERIMENTAL DESIGN AND METHODOLOGY

The experimental phase of this research started with the preparation of control samples, which basically represent unmodified/conventional HMA and modified samples of zycosoil and lime. Having found the optimum asphalt content in conventional mix which came out to be 4.0%, Zycosoil optimum content was added in percentages of 1.5% and 2%, according to the weight of binder and 2% of lime, according to weight of bitumen. A comparative analysis of all three samples was carried out on the basis of stability, flow and deformation

3.1 Materials Used

3.1.1 Asphalt Content: Asphalt binder 60/70 was used in this research

Table 3.1 Specifications of 60/70 Bitumen

SPECIFICATIONS	BITUMEN 60/70
Gravity @25/25 °C	1.01/1.06
Penetration @ 25 ° C	60/70
Softening Point ° C	49/56
Ductility @ 25 ° C CMS	100 cm
Loss on Heating (wt.)%	0.5 MIN

Drop in Penetration After Heating %	20 MAX
Flash Point °C	250 MIN
Solubility in CS@ (wt.)%	99.5 MIN
Spot Test	NEGATIVE
Density @25° C	1.01/1.06

3.1.2Aggregates

Fine and coarse aggregates were crushed limestone

3.1.3 Modifier

In this investigation, zycosoil in 1.5% and 2% and lime 2% (by the weight of bitumen) were used as modifiers.

Zycosoil

Lime

3.3 Quality Tests on Aggregate

3.3.1 Penetration Test

The penetration test is an empirical test used to measure the consistency of asphalt cement. Generally, the penetration of a bituminous substance may be defined as distance in hundredths to which a standard needle penetrates the material under known conditions of time, loading and temperature. This test is used for evaluating the consistency of asphalt material before and after heating. Hence the softer the bitumen, the greater will be its number of penetration units. (80/100, 60/70, 40/50) This is the most widely used method of measuring the consistency of a bituminous material at a given temperature. It is a means of classification rather than a measure of quality. (The engineering term consistencyis an empirical measure of the resistance offered by a fluid to continuous deformation when it is subjected to shearing stress). Penetration is related to viscosity ASTM D5 gives the test procedure for measuring penetration at **77 °F (25 °C)** and lower temperatures. Specimens are prepared in sample containers exactly as specified (ASTM D5-97) and placed in a water bath at the prescribed temperature of test for **1 to 1.5 hours** before the test. For normal tests the precisely dimensioned needle, loaded to **100 ± 0.05 g**, is brought to the surface of the specimen at right angles, allowed to penetrate the bitumen for **5 ± 0.1 s**, while the temperature of the specimen is maintained at **25 ± 0.1 °C.** The penetration is measured in tenths of a millimeter. At least three determinations are made on the specimen. A clean needle is used for each determination.

Figure 3.1 Apparatus for Bitumen Penetration Test

3.3.2 Softening Point

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test**.** The softening point of bitumen is usually determined by Ring and Ball test. It is also an indirect measure of viscosity or, rather, the temperature at which a given viscosity is evident. Generally higher softening point indicates lower temperature susceptibility and is preferred in warm climates.

Two horizontal disks of bitumen, cast in shouldered brass rings, are heated at a control rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall a distance of 25 mm. Samples of asphalt loaded with steel balls are confined in brass rings suspended in a beaker of water and glycerin or ethylene glycol at 25 mm (1 inch) above a metal plate. The liquid is then heated at a prescribed rate. As the asphalt softens, the balls and the asphalt gradually sink toward the plate. At the moment the asphalt touches the plate, the temperature of the water is determined, and this is designated as ring and ball (RB) softening point of asphalt. Specimens are prepared exactly as specified (ASTM D36-95.

Figure 3.2 Apparatus for Determining Softening Point of Aspha

3.3.3 Flash and Fire Point

The studies of flash and fire points of the zycosoil bitumen blend helps to understand the inflammability nature of the blend.

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And this volatile catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade.

Flash point "the flash point of a material is the lowest temperature at which the vapor of a substance momentarily takes fire in the form of a flash under specified condition of test". **Fire point** "the fire point is the temperature at which the material gets ignited and burns under specified conditions of test".

3.3.4 Ductility

It is important that the binders form ductile thin films around the aggregate. Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27 °C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc.

Figure 3.4 Ductilometer

Table 3.2 Summary of Bitumen Quality Tests Without zycosoil and lime.

TESTS	ACTUAL VALUE	SPECIFICATIONS
Penetration Value	6.8mm	60-70
Softening Point	55 °C	43°C min
Flash Point	232 °C	232 °C
Fire Point	255 °C	242 °C
Ductility	101 cm	100 cm

3.4 Quality tests On Aggregates

3.4.1 Los Angeles Abrasion Test:

The Los Angeles (L.A.) abrasion test (Figure 3.7) is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA.

Los Angeles abrasion test studies all possible reasons causing wear. In the L.A. abrasion machine Attrition, Abrasion, and crushing are all present as follows:

- **Attrition:** By the friction between the aggregate particles.
- **Abrasion:** By the friction between the steel balls and the aggregates.
- **Crushing:** By hitting the walls of the testing machine.

Figure 3.3 Los Angeles Abrasion Apparatus

The standard L.A. abrasion test subjects a coarse aggregate sample (**retained on the No. 12 (1.70 mm) sieve)** to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres.

After being subjected to the rotating drum, the weight of aggregate that is retained on a No. 12 aggregate weight that has broken down and passed through the No. 12 (1.70 mm) sieve. Therefore, an L.A. abrasion loss value of 30 indicates that 30% of the original sample passed through the **No. 12 (1.70 mm) sieve**

Table 3.3(ASTM C 535 Sample Grading)

Sieve Size		**Mass of Indicated Sizes, g.**			
Passing mm inch	**Retained** mm inch	**Grading**			
		A	**B**	**C**	**D**
37.5 1.5	25.0 1.0	1250 ±25			
25.0 1.0	19.0 3/4	1250 ±25			
19.0 3/4	12.5 1/2	1250 ±25	2500 ±10		
12.5 1/2	9.5 3/8	1250 ±25	2500 ±10		
9.5 3/8	6.3 1/4			2500 ±10	

6.3 1/4	4.75 #4			2500 ±10	
4.75 #4	2.63 #8				**5000 ±10**
Total		**5000 ±10**	**5000 ±10**	**5000 ±10**	**5000 ±10**

Table 3.4 (ASTM C 535 Sample Grading)

Sieve Size		**Mass of Indicated Sizes, g.**		
Passing inch	**Retained inch**	Grading		
		1	**2**	3
3.0	2.5	2500 ±50		
2.5	2.0	2500 ±50		

2.0	1.5	5000 ±50	5000 ±50	
1.5	1.0		5000 ±25	5000 ±25
1.0	¾			5000 ±25
Total		10000 ±100	10000 ±75	10000 ±50

Table 3.5 Selection of Number of Steel Balls and Mass of Charge

Test Method -- Grading	Number of Spheres	Mass of Charge, g
T 96 -- A	12	**5000 ±25**
T 96 -- B	11	**4584 ±25**
T 96 -- C	8	**3330 ±20**

T 96 – D	6	**2500 ±15**
	12	**5000 ±25**

The table 3.5 shows the mass of charge and no of steel balls to be selected as specified by the T 96 (Table 3.5)

Los Angeles Abrasion Value (L.A.A.V): Is obtained from this test and it measures the wear of the material due to abrasion and attrition.

L.A.A.V. = Original mass - retained mass (at sieve # 12) \ Original mass x 100% **(1)**

This value differs one grading to another, so there was specifications that specifies the samples grading with their masses and the charge of balls needed. We used grading A, our choice was based on that this grading is the most common. Grading A consists of four different sizes of aggregate, the first one passes through sieve 37.5 mm and retained atsieve 25 mm, the second size passes through the 25 mm sieve and is retained at 19 mm sieve, third size passing through 19 mm and retained on 12.5 mm and fourth size passing through 12.5 mm and retained on 9.5 mm. According to the specification the total weight of the aggregate that should be used in the test is 5000 ± 25 gm. For grading A it was specified that 12 steel balls shall be placed in the machine with the aggregates. According to the specifications if L.A.A.V. is less than 30% then this aggregate is suitable for all mixture, and if it is more than 50% this aggregate is unusable in any mixture.

The aggregate we used is suitable as Los Angeles Abrasion Value (L.A.A.V) specified by AASHTO T 96 is percentage maximum is 50 and its abrasion value comes out to be 26%. The L.A.A.V is direct proportional to the wear of aggregate.

3.4.2 Impact Value of Aggregate:

The impact value tests give us the strength of aggregates against impact loading. This test is done to determine the aggregate impact value of coarse aggregates as per IS: 2386 (Part IV) – 1963.Toughness is the property of material to resist impact due to traffic loads. The road stones are subjected to the pounding action or impact and there is possibility of aggregate stone breaking into smaller pieces. The road aggregate should therefore be tough enough to resist fracture under impact.

- Aggregate impact tester

The instrument consists of a circular base with two vertical guides. The hammer of weight 13.75 ±0.25 kg can be raised to fall freely down the vertical guides. The height of fall can be adjusted through 380 ± 5mm. The hammer is provided with a locking arrangement. The hammer falls freely to the base and is removable for emptying. Supplied complete with metal measures 75mm dia x 50mm high (for specimen preparation) and tamping rod 230mm long x 10mm dia.

Figure 3.4 Aggregate Impact Testers

2. Specification

- <10 % exceptionally strong
- 10 % to 20 % Strong
- 20 % to 30 % Satisfactory for road construction

Impact value of the aggregates used is ***16%*** as it falls in the range of **strong-**category of aggregates that is 10-20%.

3.4.3 Specific Gravity Test:

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water**.** Water, at a temperature of 73.4°F (23°C) has a specific gravity of 1. Specific Gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity can be used during production to separate the bad particles from the good using a heavy media liquid.

Specific gravity is critical information for the Hot Mix Asphalt Design Engineer. It is used in calculating air voids, voids in mineral aggregate (VMA), and voids filled by asphalt (VFA). All are critical to a well performing and durable asphalt mix. Water absorption can also be an indicator of asphalt absorption. A highly absorptive aggregate could lead to a low durability asphalt mix. The different terms used are explained as follows:

- **Absorption:** The penetration of a liquid into aggregate particles with resulting increase in particle weight

- Bulk Specific Gravity (also known as Bulk Dry Specific Gravity):

The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

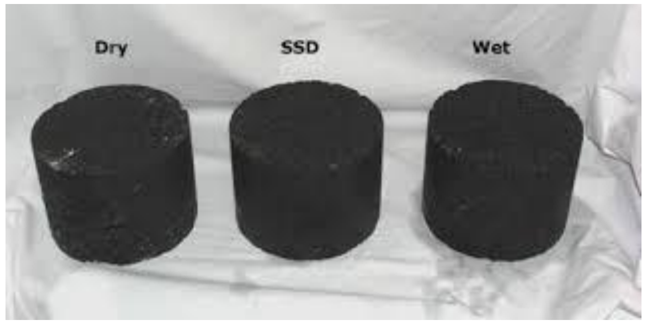


Figure 3.6 showing different samples

- Bulk SSD Specific Gravity:

  The ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours, to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

- Apparent Specific Gravity:

The ratio of the weight in air of a unit volume of the impermeable portion of Aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

- SSD:

Saturated, Surface Dry. The condition in which the aggregate has been soaked in water and has absorbed water into its pore spaces. The excess, free surface moisture has been removed so that the particles are still saturated, but the surface of the particle is essentially dry. This test method determines the specific gravity of coarse aggregates that have been soaked for a period of 15 hours. There are four determinations that may be made from this procedure. They are as follows:

- Bulk Specific Gravity (Gsb) (also known as Bulk Dry Specific Gravity)

The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature (Figure 3.14). This unit volume of aggregates is composed of the solid particle, permeable voids, and impermeable voids.

Gsb = A / (B-C) (2)

Where: A = Oven dry weight.

B = SSD weight.

C = Weight in water.

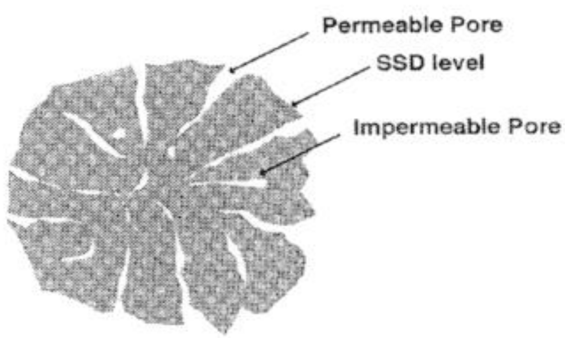


Figure 3.7 Diagram of bulk specific gravity

2. Bulk SSD Specific Gravity (Gsb SSD):

Gsb SSD = B / (B - C) (3)

Where: B = SSD weight.

C = Weight in water.

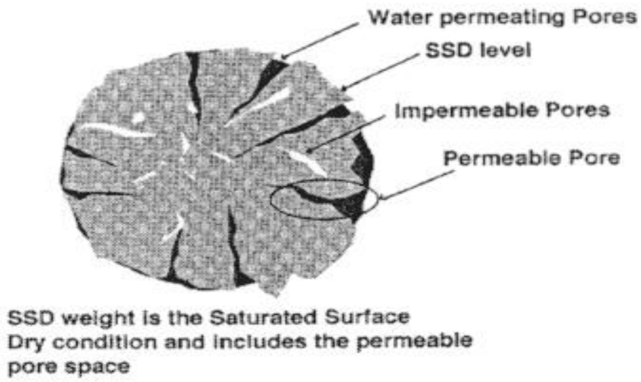


Figure 3.8 Diagram of Bulk SSD Specific Gravity

3. Apparent Specific Gravity (Gsa)

This ratio of the weight in air of a unit volume of the IMPERMEABLE portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

Gsa = A / (A - C) (4)

Where: A = Oven dry weight.

C = Weight in water

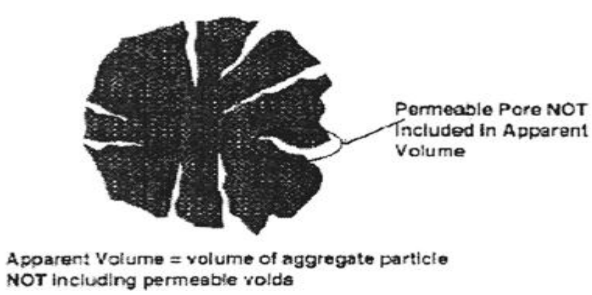


Figure 3.9 Diagram of Apparent Specific Gravity

4. Absorption (% Abs.)

The increase in weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles .

% Abs. = [(B - A) / A] x 100 (5)

Where: A = Oven dry weight.

B = SSD weight

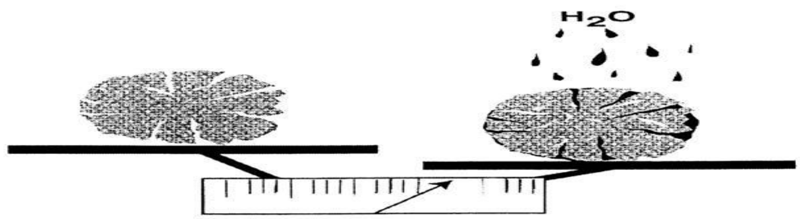


Figure 3.10 Diagram of Increase in mass due to absorption of water

- **Calculations:**
- Coarse aggregates:

Bulk specific gravity=2.67

Apparent specific gravity=2.72

Effective specific gravity=2.70

- Fine aggregate:

Bulk specific gravity=2.67

Apparent specific gravity=2.74

Effective specific gravity=2.71

- Filler:

Bulk specific gravity=2.67

Apparent specific gravity=2. 67

Effective specific gravity=2. 67

3.5 Sieve Analysis:

The sieve analysis, commonly known as the "gradation test" is a basic essential test for all aggregate technicians. The sieve analysis determines the gradation (the distribution of aggregate particles, by size, within a given sample) in order to determine compliance with design, production control requirements, and verification specifications. The gradation data can be used to calculate relationships between various aggregate or aggregate blends, to check compliance with such blends, and to predict trends during production by plotting gradation curves graphically, to name just a few uses.

A known amount weight of material, the amount being determined by the largest size of aggregate, is placed upon the top of a group of nested sieves (the top sieve has the largest screen openings and the screen opening sizes decrease with each sieve down to the bottom sieve which has the smallest opening size screen for the type of material specified) and shaken by mechanical means for a period of time. After shaking the material through the nested sieves, the material retained on each of the sieves is weighed using one of two methods.

The cumulative method requires that each sieve beginning at the top be placed in a previously weighed pan (known as the tare weight), weighed, the next sieve's contents added to the pan, and the total weighed. This is repeated until all sieves and the bottom pan have been added and weighed. The second method requires the contents of each sieve and the bottom pan to be weighed individually. Either method is satisfactory to use and should result in the same answer. The amount passing the sieve is then calculated. Two types of sieves shakers are used

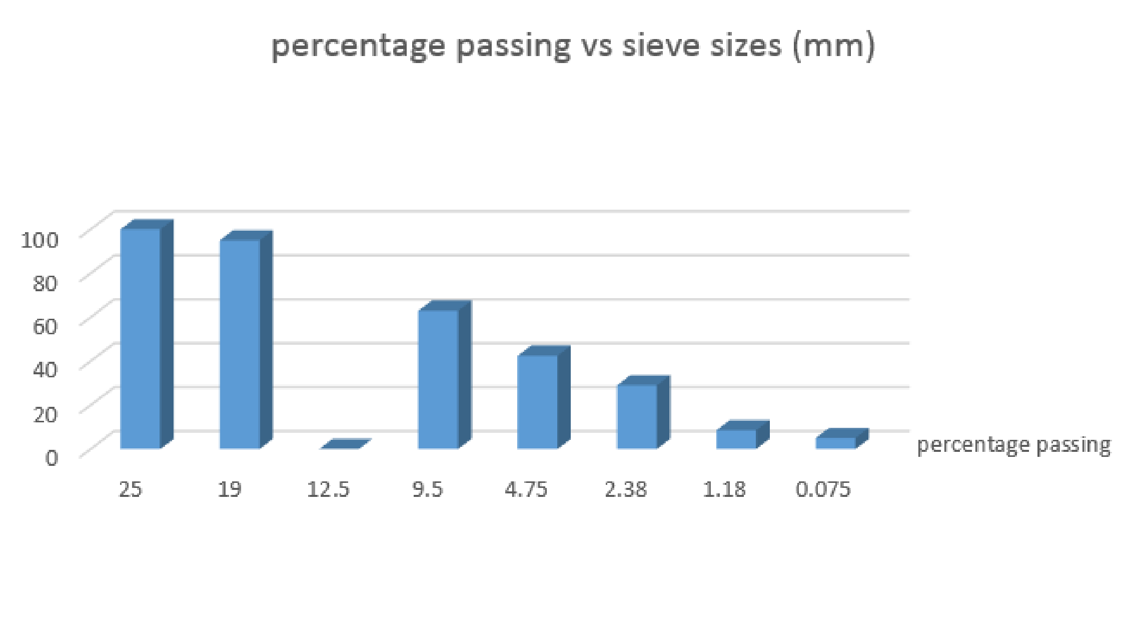
Figure 3.11 Small Sieve Shaker for fine aggregate

Figure 3.13 Sieve Analysis Samples

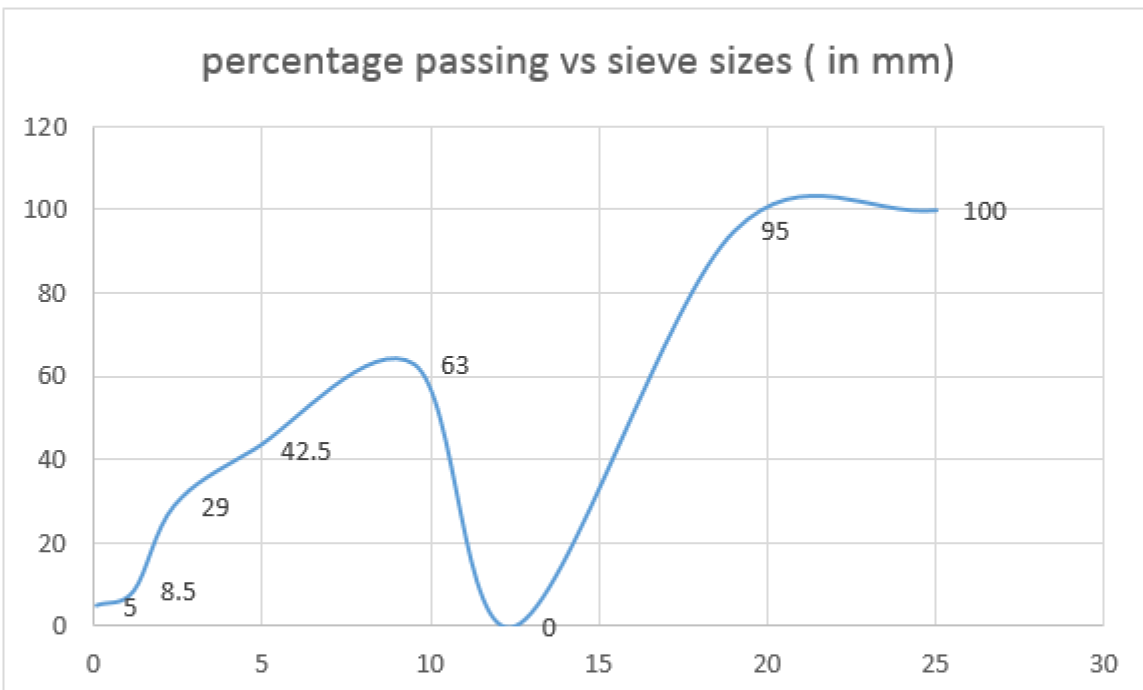
Table 3.6 showing results of sieve analysis

Sieve size mm	inch	Class A	Class B	Percentage passing	Percentage retained
25	1	100	-	100	0
19	3/4	90-100	100	95	5
12.5	1/2	-	75-90	-	-
9.5	3/8	56-70	60-80	63	32
4.75	#4	35-50	40-60	42.5	20.5
2.38	#8	23-35	20-40	29	13.5
1.18	#16	5-12	5-15	8.5	20.5
.075	#200	2-8	3-8	5	3.5

NHA specifications were used for aggregate gradation so the aggregate that we have used in this project is of CLASS A as specified by NHA (Table 3.11)



Graph 3.1: NHA Specifications for Aggregate Gradation and Percentage Used



Graph 3.2 Percentage passing as per NHA Specifications

3.6 Marshall Mix Design Method

The mix design determines the optimum bitumen content. The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's crumb rubber flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

The Marshall Mix design method consists of 6 basic steps:

- Selection of aggregate
- Asphalt binder selection.
- Sample preparation (including compaction).
- Stability determination using the Marshall Stability and flow test.
- Density and voids calculations.
- Optimum asphalt binder content selection

3.6.1 Aggregate Size

The size of an aggregate is not quite what it seems. The size of a particular aggregate will depend on what sieve sizes determine the grading of an individual material, or in the case of a quarry what screen sizes are used to separate out crushed aggregate.

If you have a material where the normal sieve/screen sizes are, 37.5mm, 28mm, 14mm, 10mm, 6.3mm, etc., a 28mm. aggregate will be that aggregate which passes the 28mm. sieve and is retained on the 20mm. sieve. So, in the case of a 28mm. aggregate the size could be 27.9mm or 20.1mm, and still be regarded as a "28mm. aggregate". This variance in true size can be a particular problem with surface dressing chippings, which are single size.

It leads to such expressions as a "bold" 10mm. chipping, or a "small" 10mm. chipping, meaning the bulk of the chippings are quite near the 10mm size or the 6.3mm size. Chippings being "bold" or "small" can necessitate a change in binder spread rates to ensure retention of the chipping, or to prevent "fatting up" of binder.

3.6.2 Aggregate Grading

Aggregate grading is the term given to the percentages of the different size fractions, after sieving, that go to make up the whole material.To obtain the different size fractions for weighing, the sample of aggregate is sieved on the appropriate sieve sizes for the particular material, and the retained aggregate amounts weighed.This process is known as "grading", or, more scientifically put you are determining the particle size distribution of the material.

The test for particle distribution of a "dry stone" aggregate is fully described in, BS 812 : Testing Aggregates : Part 103 - Method for determination of particle size distribution. The reverse process to performing a grading on a material is a supplier blending appropriate amounts of single size aggregates to create the correct blend of aggregate to satisfy the "mix" specified. The Client/Engineer will in due course perform a grading on supplied material to ensure it meets the specification.

Dry the samples of aggregate in the oven for approximately 18 hours at 105°C to 110°C. Separate aggregate into individual sieve sizes by dry sieving. Select the sieve sizes corresponding to the specifications for the "type" of recombine individual aggregate fractions in correct proportions to obtain the average stockpile gradation which is submitted from the field along with the sample. Use a trial and error method as described in the following paragraph.

Combine trial percentages of each size, then run a wet sieve and compare the result to the stockpile average. Adjust the proportions of each size and repeat the procedure until the desired gradation is achieved. Use the final percentages of each size to produce specimens as required later in the procedure

3.6.3Application of Test

The objective to be achieved using the Marshall Method for hot-mix asphalt mix design is to determine an economical blend and gradation of aggregates (within the limits of project specifications) and asphalt that yields a mix having;

1. Sufficient asphalt to ensure a durable asphalt surface course.
2. Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
3. Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding and loss of stability, yet low enough to keep out harmful air and moisture.
4. Sufficient workability to permit efficient placement of the mix without segregation.
5. Characteristics which allow normal construction operating variations without falling outside of the specified requirements.

3.6.4 Specimen Preparation

The Marshall method, like other mix design methods, uses several trial aggregate-asphalt binder blends, each with different asphalt binder content. Then, by evaluating each trial blend's performance, optimum asphalt binder content can be selected. In order for this concept to work, the trial blends must contain a range of asphalt contents both above and below the optimum asphalt content. Therefore, the first step in sample preparation is to estimate optimum asphalt content. Trial blend asphalt contents are then determined from this estimate.

Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190°C (Figure 3.22). Bitumen is heated to a temperature of 121-125°C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154-160°C. The mix is placed in a preheated mould and compacted by a Marshall compactor with 75 blows on either side at temperature of 138°C to 149°C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by + 0.5% and repeat the above procedure. Numbers of trials are predetermined.

Figure3.13 Heating of Aggregates and Filler

3.6.5 Compaction with Marshall Hammer

Each sample is then heated to the anticipated compaction temperature and compacted with a Marshall hammer (Figure 3.23), a device that applies pressure to a sample through a tamper foot. Some hammers are automatic and some are hand operated. Key parameters of the compactor are:

- Sample size = 102 mm (4-inch) diameter cylinder 64 mm (2.5 inches) in height (corrections can be made for different sample heights)

- Tamper foot = Flat and circular with a diameter of 98.4 mm (3.875 inches) corresponding to an area of 76 cm^2 (11.8 in^2).
- Compaction pressure = Specified as a 457.2 mm (18 inches) free fall drop distance of a hammer assembly with a 4536 g (10 lb.) sliding weight.
- Number of blows = Typically 35, 50 or 75 on each side depending upon anticipated traffic loading.
- Simulation method = the tamper foot strikes the sample on the top and covers almost the entire sample top area. After a specified number of blows, the sample is turned over and the procedure repeated.
- AASHTO T 245: Resistance to Crumb rubber Flow of Bituminous Mixtures Using the Marshall Apparatus load, 0.25 mm units. In this test and attempt is made to determine optimum binder content for the type of aggregate mix.

Figure3.14 Marshall Stability and Flow Test Apparatus

3.6.6 Selection of Asphalt Binder Content

The optimum asphalt binder content is finally selected based on the combined results of Marshall Stability and flow, density analysis and void analysis. Optimum asphalt binder content can be arrived at in the following procedure:
Plot the following graphs:

- Asphalt binder content vs. density. Density will generally increase with increasing asphalt content, reach a maximum, and then decrease. Peak density usually occurs at higher asphalt binder content than peak stability.
- Asphalt binder content vs. Marshall Stability. This should follow one of two trends:
- Stability increases with increasing asphalt binder content, reaches a peak, then decreases.
- Stability decreases with increasing asphalt binder content and does not show a peak. This curve is common for some recycled HMA mixtures.
- Asphalt binder content vs. flow.
- Asphalt binder content vs. air voids. Percent air voids should decrease with increasing asphalt binder content.
- Asphalt binder content vs. VMA. Percent VMA should decrease with increasing asphalt binder content, reach a minimum, and then increase.
- Asphalt binder content vs. VFA. Percent VFA increases with increasing asphalt binder content.

Determine the asphalt binder content that corresponds to the specifications median air void content (typically this is 4 percent). This is the optimum asphalt binder content. Determine properties at this optimum asphalt binder content by referring to the plots. Compare each of these values against specification values and if all are within specification, then the preceding optimum asphalt binder content is satisfactory. Otherwise, if any of these properties is outside the specification range the mixture should be redesigned.

3.6.7Weight Volume Terms and Relationships

Basic weight-volume relationships are important to understand for both mix design and construction purposes. Fundamentally, mix design is meant to determine the volume of asphalt binder and aggregates necessary to produce a mixture with the desired properties. However, since weight measurements are typically much easier, they are typically taken then converted to volume by using specific gravities.

V_T	=	Total volume of the compacted specimen	W_T	=	Total weight of the compacted specimen
V_a	=	Volume of air voids	W_D	=	Dry weight
V_b	=	Volume of asphalt binder	W_{SSD}	=	Saturated surface dry (SSD) weight
V_{be}	=	Volume of effective asphalt binder	W_{sub}	=	Weight submerged in water
V_{ba}	=	Volume of absorbed asphalt binder	W_b	=	Weight of the asphalt binder
V_{agg}	=	Volume of aggregate	W_{be}	=	Weight of effective asphalt binder
V_{eff}	=	Effective volume of aggregate = $(V_T - V_{AC})$	W_{ba}	=	Weight of absorbed asphalt binder
G_b	=	Asphalt binder specific gravity	P_b	=	Asphalt content by weight of

mix (percent)

G_{sb} = Bulk specific gravity of the aggregate

P_s = Aggregate content by weight of mix (percent)

G_{se} = Effective specific gravity of the aggregate

P_a = Percent air voids

3.6.8 Properties of the Mix

The properties that are of interest include the theoretical specific gravity G_t, the bulk specific gravity of the mix Gm, percent air voids Vv, percent volume of bitumen V_b, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. These calculations are discussed next. To understand these calculations a phase diagram is given in Figure below:

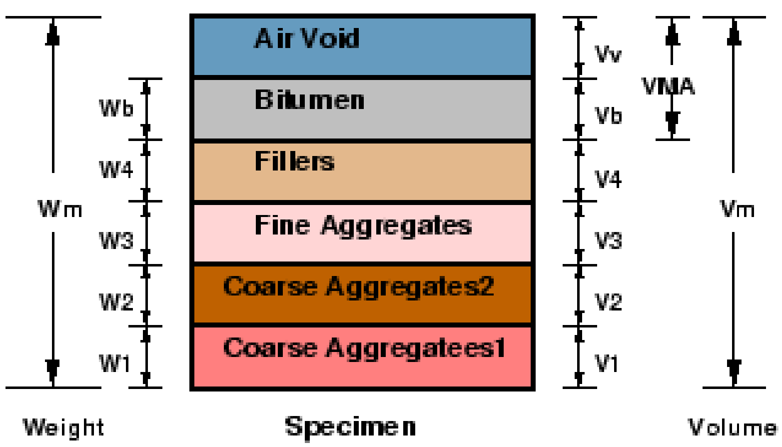


Figure 3.15 Phase diagram of a bituminous mix

- Theoretical Specific Gravity of The Mix G_t

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

$$G_t = \frac{W_1+W_2+W_3+W_B}{\frac{W_1}{G_1}+\frac{W_2}{G_2}+\frac{W_3}{G_3}+\frac{W_B}{G_B}} \quad (6)$$

Where, W_1 is the weight of coarse aggregate in the total mix, $W_2$is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of fine aggregate, G3 is the apparent specific gravity of filler and $G_b$is the apparent specific gravity of bitumen

- Bulk Specific Gravity of Mix G_m.

The bulk specific gravity or the actual specific gravity of the mix G_m is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w} \quad (7)$$

Where, W_m is the weight of mix in air, W_w is the weight of mix in water, Note that W_m -W_w gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This however requires considering the weight and volume of wax in the calculations.

- Air Voids Percent V_v

Air voids V_v is the percent of air voids by volume in the specimen and is given by:

$$V_v = \frac{(G_t - G_m) * 100}{G_t} \tag{8}$$

Where G_t is the theoretical specific gravity of the mix, and Gm is the bulk or actual specific gravity of the mix.

- Percent Volume of Bitumen V_b

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

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}} \tag{9}$$

Where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix .

- Voids in Mineral Aggregate VMA

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

$$VMA = V_v + V_b \tag{10}$$

Where, V_v is the percent air voids in the mix and V_b is percent bitumen content in the mix.

- Voids Filled with Bitumen VFB

Voids filled with bitumen V FB is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

$$VFB = \frac{V_b * 100}{VMA} \tag{11}$$

Where, V_b is percent bitumen content in the mix and VMA is the percent voids in the mineral aggregate.

- **Bulk Specific Gravity of the Compacted Asphalt Mixture (G_{mb})**

The ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature. This value is used to determine weight per unit volume of the compacted mixture. It is very important to measure G_{mb} as accurately as possible. Since it is used to convert weight measurements to volumes, any small errors in G_{mb} will be reflected in significant volume errors, which may go undetected.

The standard bulk specific gravity test is:

AASHTO T 166: Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens

The bulk specific gravity of the specimen was determined in accordance with ASTM D 2726. The specimen was cooled to room temperature and weighed. The specimen was hung from a scale and immersed in a water bath at 25±1°C for three to five minutes. The weight of the specimen in water was then recorded. The sample was removed from the water bath, surface dried with a towel and weighed again. The bulk specific gravity, Gmb, was determined as:

$$\mathbf{Gmb} = A/(B-C) \tag{12}$$

Where:

A = Dry weight of specimen, grams

B = Surface Dried weight of specimen, grams

C = Weight of specimen in water, grams

The unit weight of the specimen was calculated by multiplying the bulk specific gravity by the unit weight of water. The averages of the three specimens were the values recorded for unit weight and bulk specific gravity.

- **Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures (G_{mm})**

The ratio of the mass of a given volume of void less (Va = 0) HMA at a stated temperature (usually 25 °C) to a mass of an equal volume of gas-free distilled water at the same temperature. It is also called Rice Specific Gravity (after James Rice who developed the test procedure). Multiplying G_{mm} by the unit weight of water gives Theoretical Maximum Density (TMD).

The standard TMD test is:

AASHTO T 209 and ASTM D 2041: Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

The maximum theoretical specific gravity of each mixture was determined in accordance with ASTM D 2041. After the sample was properly mixed, it was spread on a table and allowed to cool. The clumps of fine aggregate materials were then broken into particles ¼ inch in diameter or smaller. Following separation of the coated fine and coarse aggregate particles, the sample was weighed and then placed into a pycnometer and submerged in water at a temperature of 25±1°C. The sample was subjected to a vacuum of 30 mmHg for 15 minutes while the pycnometer was agitated on a vibrating table. The pycnometer was then filled completely with water and the pycnometer and contents were weighed. The maximum theoretical specific gravity, G_{mm}, was calculated as:

$$G_{mm} = A/ (A+B-C) \tag{13}$$

Where:

A = Weight of Dry Sample, grams

B = Weight of pycnometer completely filled with water, grams

C = Weight of pycnometer filled with water and sample, grams

- **Air Voids (V_a)**

The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. The amount of air voids in a mixture is extremely important and closely related to stability and durability. For typical dense-graded mixes with 12.5 mm (0.5 inch) nominal maximum aggregate sizes air voids below about 3 percent result in an unstable mixture while air voids above about 8 percent result in a water-permeable mixture

3.7 Marshall Stability and Flow Calculations:

3.7.1Optimum Asphalt Binder Content

Total of 5 samples are made to find the optimum asphalt binder content with varying percentages of bitumen (3.0, 3.5, 4, 4.5, and 5) (Figure 3.26). The optimum asphalt binder content comes out to be 4.0%. The calculation is shown in ANNEX A.

Figure 3.16 showing conventional samples

Graphs:

1. Asphalt Content v/s Unit Weight (gm/cc)

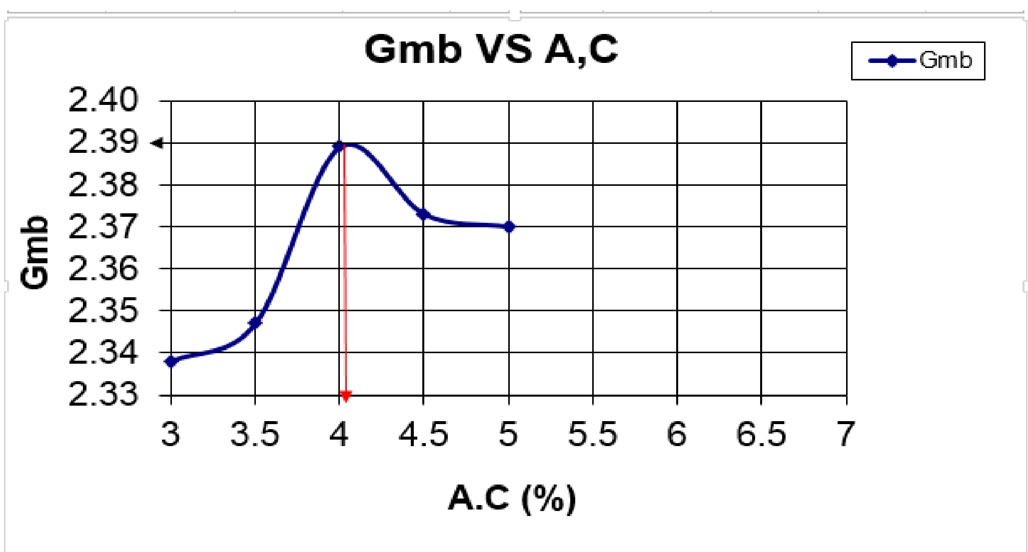


Figure 3.17 7 Asphalt content v/s Unit Weight (gm/cc)

2. Asphalt Content v/s Stability (KN)

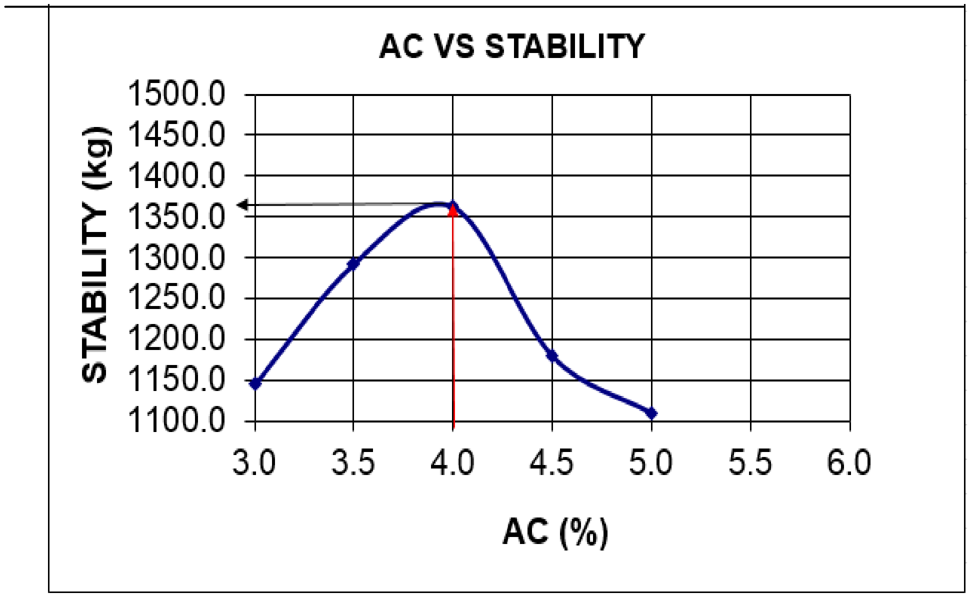


Figure 3.18 Stability (Kg) v/s Asphalt Content

3. PAV v/s Asphalt Content

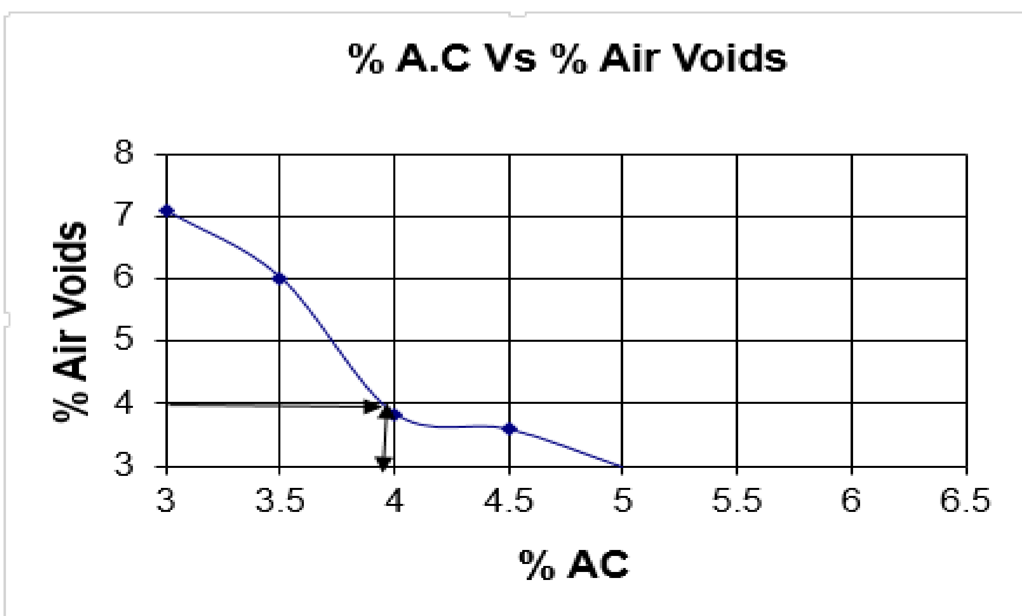


Figure 3.19 PAV v/s Asphalt Content

4. Asphalt Content v/s VFB (%)

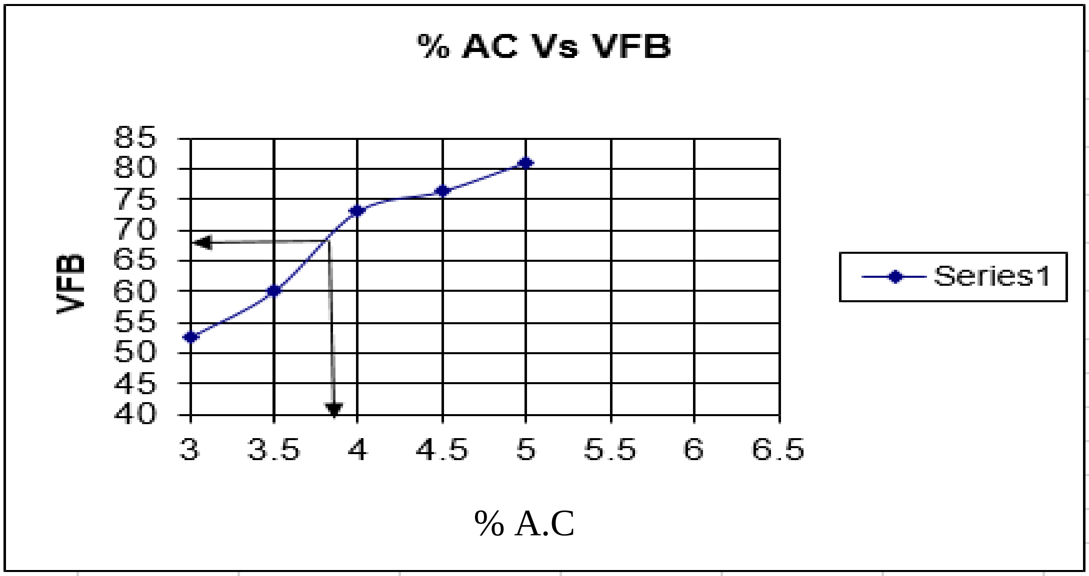


Figure 3.20 VFB v/s Asphalt Content

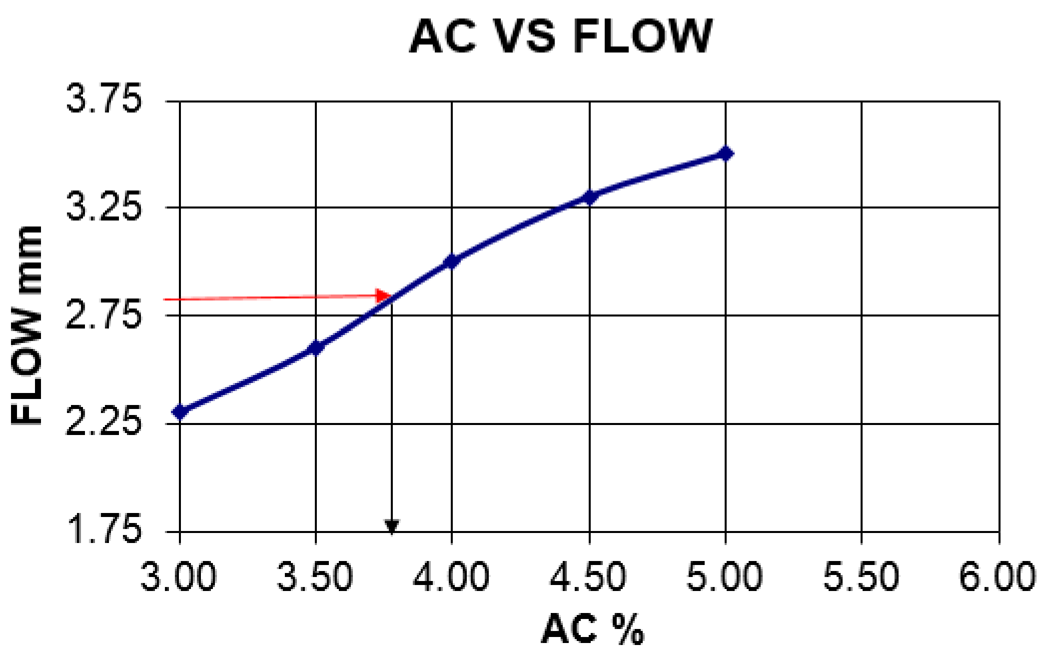


Figure 3.21 Flow v/s Asphalt Content

3.7.2 Dry and Wet Processes for Preparation of Modified HMA:

1. Preparation of Modified HMA Samples

Now Marshall Stability test is done by using both wet and dry process. Proportions of 1.5% and 2% of zycosoil, and 2% of lime by weight of the optimum binder content (4.0%) were selected for both dry and wet process. Total numbers of zycosoil samples were 12 (6 samples with 1.5% zycosoil and 6 samples with 2% zycosoil). Number of lime mixed asphalt samples were 6 having 2% lime content. And 6 controlled, unmodified samples of asphalt were lastly prepared.

Figure 3.22 Showing prepared samples (all types)

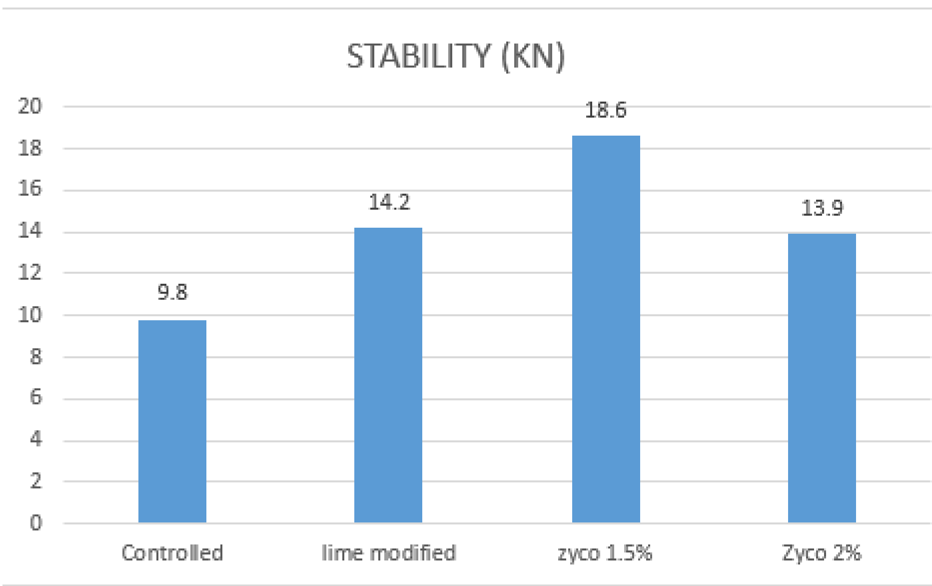
2. **Dry Process**

Samples are prepared by adding aggregate and heated up to 170’C and adding asphalt and filler. For dry process three controlled samples were taken and tested for Marshall Stability. This gives us a value of 9.8KN (taken lowest of three values).The Marshall Stability values for zycosoil samples having 1.5% zycosoil comes out to be 18.6KN. Three samples of 2% zycosoil added mix were tested and the result came out to be 13.9KN. And finally 3 samples lime added mixes were tested and the results came out to be 14.2KN. The Marshall Stability value increases from 9.8KN to 18.6KNat 1.5% zycosoil. In general, it may also be concluded that this method is the best suited process for the use of lower percentage of zycosoil. The stability increases approximately 89%. The results are shown in table below:

Table 3.7 showing Marshall Stability values of wet process

Samples	Type	Stability (valuex2.119) Lbs.	Flow (valuex.01) Mm	
C1	Controlled Samples	630x2.119=1350	330x.01	3.3
C2		525x2.119=1110	390x.01	3.9
C3		460x2.119=980	220x.01	2.2
L1	Lime 2% Added	680x2.119=1440	250x.01	2.5
L2		670x2.119=1421	210x.01	2.1
L3		690x2.119=1460	280x.01	2.8
Z1		880x2.119=1860	200x.01	2.0

Z2	Zycosoil 1.5% Added	880x2.119=1860	270x.01	2.7
Z3		900x2.119=1900	290x.01	2.9
Z1	Zycosoil 2% Added	700x2.119=1480	200x.01	2
Z2		670x2.119=1420	310x.01	3.1
Z3		655x2.119=1390	290x.01	2.9

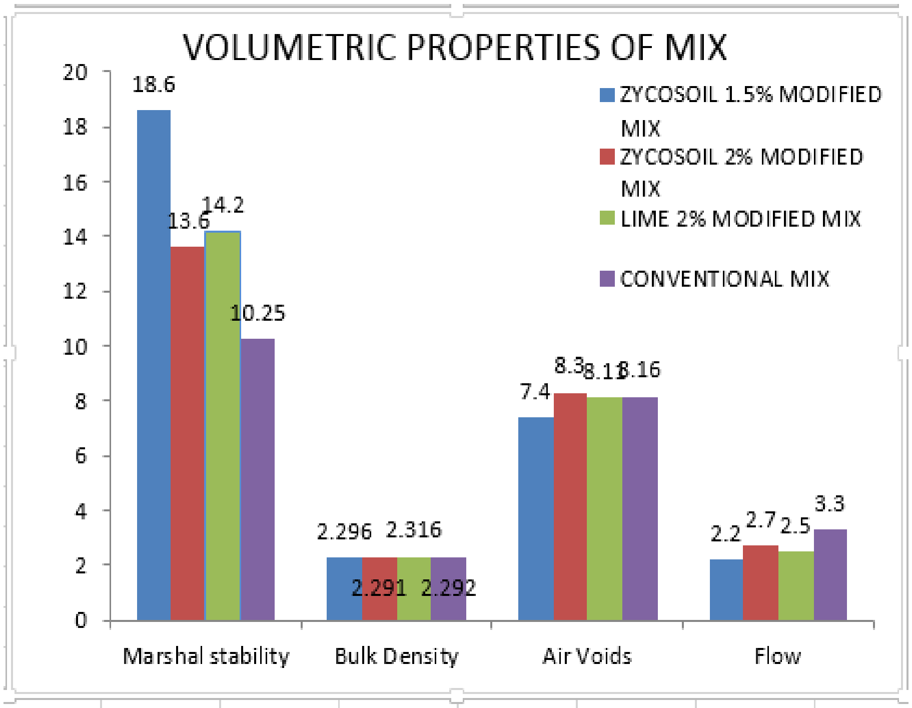


Graph 3.3 Comparison of Marshall Stability Value

3. Volumetric Properties of Mixes

Table 3.8 Comparison of Volumetric Properties of Mixes

PROPERTIES	MODIFIED MIX(**1.5 % ZYCOSOIL)**	MODIFIED MIX **(2% ZYCOSOIL**)	MODIFIED MIX (**2% LIME**)	CONVENTIONAL MIX
Marshall Stability	**18.6KN**	**13.6KN**	**14.2KN**	**10.25**
Bulk Density	**2.296**	**2.291**	**2.316**	**2.292**
Air Voids	**7.4**	**8.30**	**8.11**	**8.16**
Flow (mm)	**2.2**	**2.7**	**2.5**	**3.3**



Graph 3.4Volumetric properties of mixes

3.7.3 Wet Process:

Samples are prepared by adding aggregate and heated up to 170’C and adding asphalt and filler. WET process means placing the samples for 18 hours in water at 60’C and then tests are conducted. For Wet process three samples were taken and tested for Marshall Stability. This gives us a value of 6.2KN (taken lowest of three values).The Marshall Stability values for zycosoil samples having 1.5% zycosoil comes out to be 13.8KN. Three samples of 2% zycosoil added mix were tested and the result came out to be 10.6KN. And finally 3 samples lime added mixes were tested and the results came out to be 11.8KN. The Marshall Stability value increases from 6.2KN to 13.8KN at 1.5% zycosoil. In general, it may also be concluded that this method is the best suited process for the use of lower percentage of zycosoil.

Table 3.9 showing Marshall Stability values of wet process

Samples	Type	Stability (valuex2.119) N	Flow (valuex.01) mm	
C4	Controlled Samples	480x2.119=1020	320x.01	3.2
C5		400x2.119=840	340x.01	3.4
C6		290x2.119=620	320x.01	3.2
L4	Lime 2% Added	560x2.119=1200	260x.01	2.6
L5		550x2.119=1180	220x.01	2.2
L6		550x2.119=1180	230x.01	2.3
Z4	Zycosoil 1.5% Added	720x2.119=1530	220x.01	2.2
Z5		650x2.119=1380	250x.01	2.5

Z6		700x2.119=1490	230x.01	2.3
Z4	Zycosoil 2% Added	530x2.119=1120	310x.01	3.1
Z5		500x2.119=1060	260x.01	2.6
Z6		540x2.119=1140	270x.01	2.7

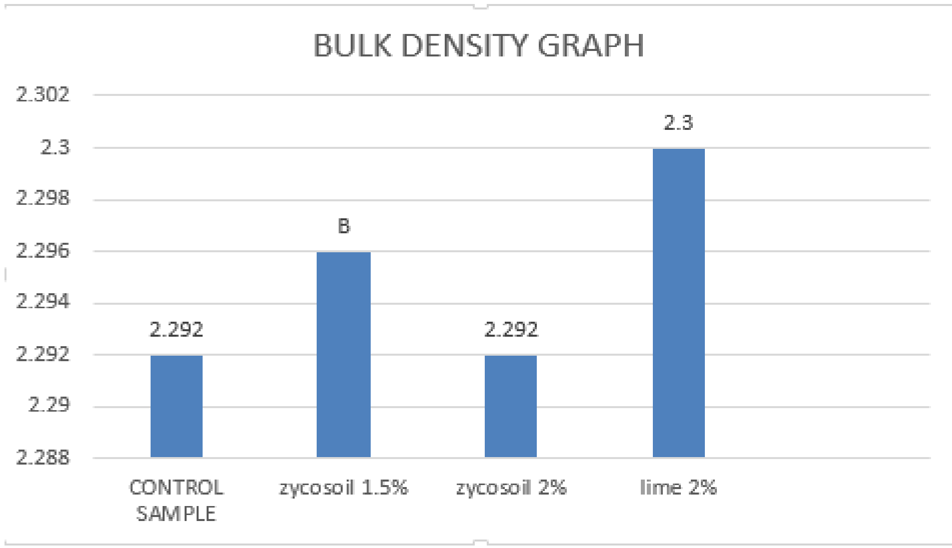
Note: The percentage of modifier added is always with respect to the weight of bitumen used.

3.8 Comparison Of Properties Of Zycosoil, Lime And Conventional Mixes:

A comparison betweenZycosoil, Lime and Conventional Mixesisperformed on the basis of bulk specific density, stability, flow and PAV.

3.8.1 Comparison of Bulk Density Values:

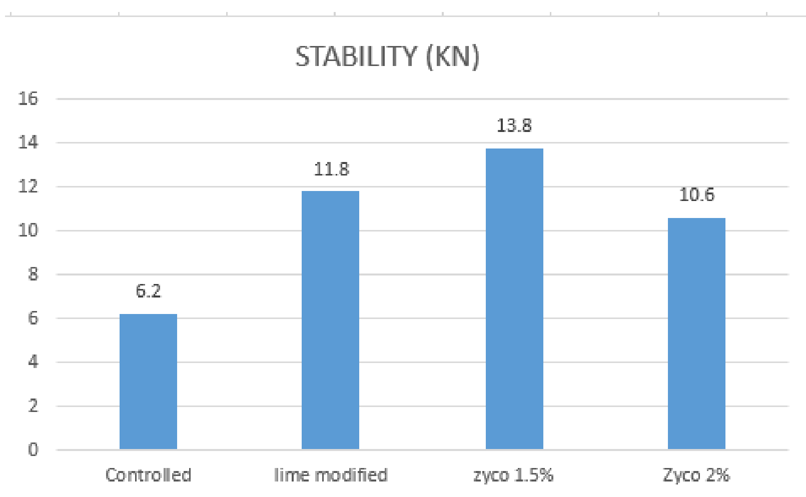
The bulk density of the modified asphalt concrete mixture sand the conventional asphalt concrete mixture is shown by following graph. The maximum bulk density is found when the lime content is around 2% (Figure 3.34).



Graph 3.5 Comparison of Bulk Density (g/cc)

3.8.2 Marshall Stability Values of Different Samples:

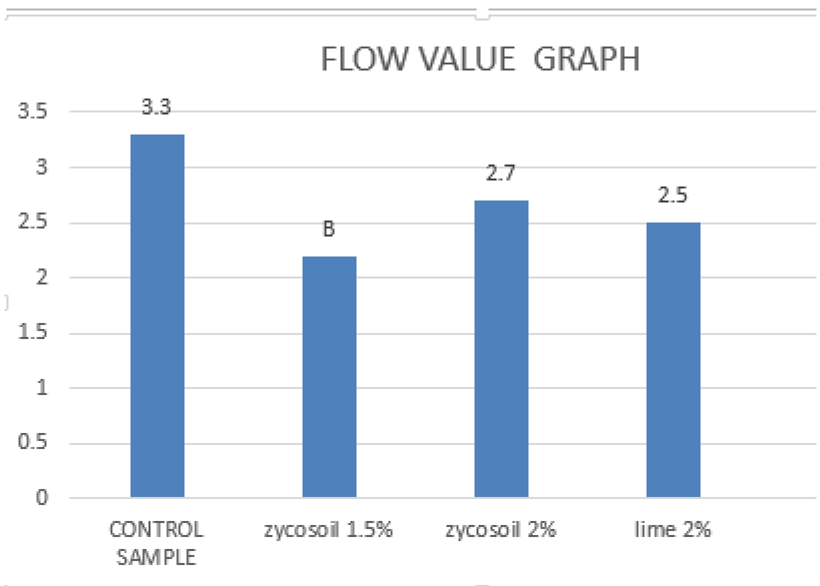
The stability of the modified asphalt concrete mixtures is higher than the conventional asphalt concrete mixture. The highest stability was reported for asphalt mixture that is modified with 1.5% zycosoil (13.82 KN).This shows that the asphalt layer will bear more load as compared to conventional mix.



Graph 3.6 Comparison of Marshall Stability (KN)

3.8.3 Flow Value Comparison:

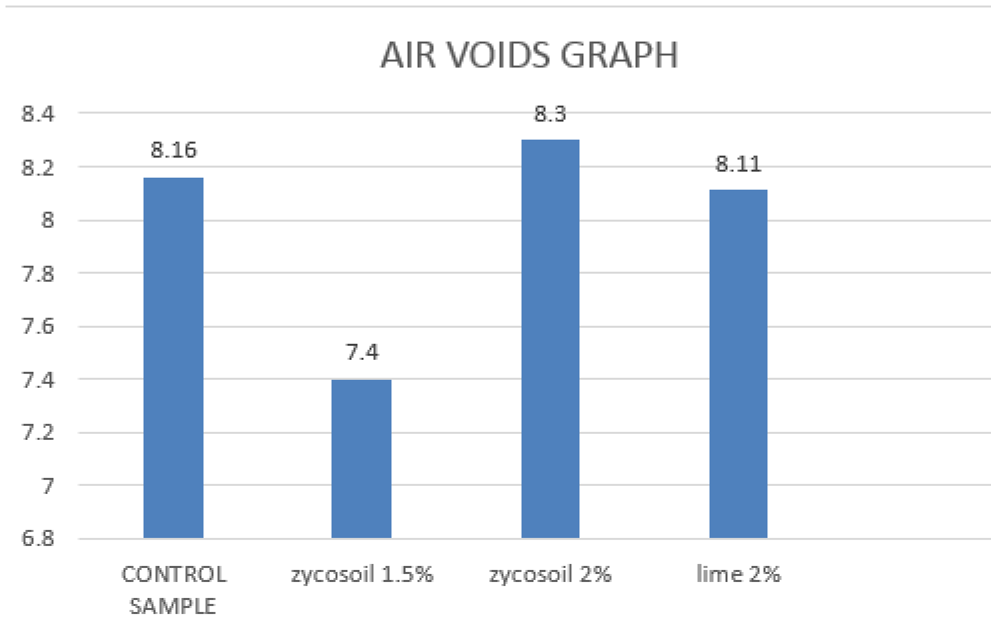
The flow of the modified asphalt concrete mixtures is lower than the conventional asphalt concrete mixture - no modifier. The highest flow value is accounted for controlled sample.



Graph 3.7 Comparison of Flow value (mm)

3.8.4 Air Void (AV) content Relationships:

Generally, the AV proportion of the modified asphalt concrete mixtures is higher than the conventional asphalt concrete mixture - no modifier. The minimum value of air voids is achieved at zycosoil 1.5%. This shows that lower the value of air voids, greater will be compaction achieved. So modifier has helped in attaining the better compaction.



Graph 3.8 Comparison of PAV

3.9 Hamburg Wheel Tracking Test:

Measures the rutting and moisture susceptibility of an asphalt paving mixture by rolling a steel wheel across the surface of an asphalt concrete slab that is immersed in hot water (generally held at 50°C.) Susceptibilities to rutting and moisture are based on pass/fail criteria. The basic purpose of this test is to calculate the rut potential of mix design prior to the field performance. Use this test method to determine the premature failure susceptibility of bituminous mixtures due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage and other factors including inadequate adhesion between the asphalt binder and aggregate. This test method measures the rut depth and number of passes to failure. [ASTM, 1998]

The rut resistance can be quantified as the rate of rutting during the test or the rut depth at the conclusion of the test. The Wheel-Tracking Device measures the combined effects of rutting and moisture damage by rolling a steel wheel across the surface of asphalt that had a rubber tire developed the device in the 1970's (Figure 3.41). The device was originally used to measure rutting susceptibility. The test was performed for 5,000 wheel passes at either 45 or 60 degrees. Greater than 10,000 wheel passes was generally needed to show the effects of moisture damage.

Figure 3.23 Hamburg Wheel Tracking Machine

The machine tests slabs that typically have a length of 1 foot, a width of 1 foot, and a thickness of 2 inch. Thickness up to 2.5 inch can be tested. Each specimen is placed into a container so that its surface is level with the top edge of the container. This allows the full range of the rut depth measurement system to be utilized. Containers are manufactured in heights of 40, 80 and 120 mm. Steel spacers can be placed under cores and pavement slabs if needed. The container with the specimen is then placed into the wheel-tracking device. The container rests on steel; this provides a rigid, load-bearing base for the specimen.

The sample was compacted up to 2mm thickness with the help of roller compactor (Figure 3.42). The compactor used for compaction was automatic. The most commonly used test temperature is 45 degrees, although 40 degrees has been used when testing certain base mixtures. A temperature of 45 degrees is reached within 45 min. Specimens are conditioned at the test temperature for a minimum of 30 min. Heat is provided by heated coils.

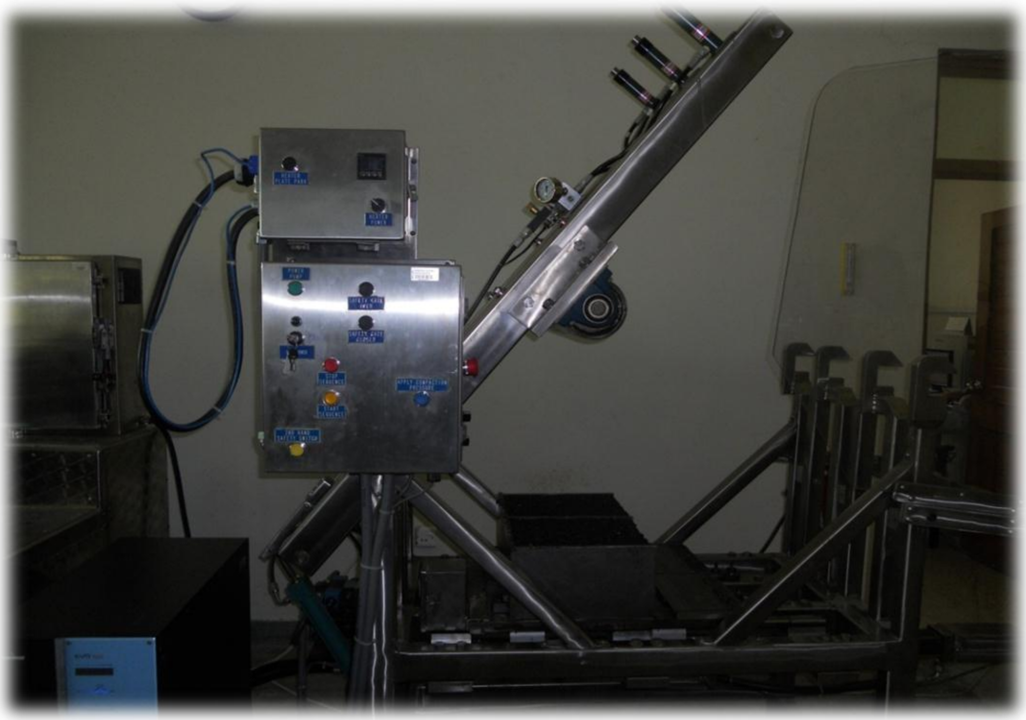


Figure3.24 Roller Compactor

The device tests one slab simultaneously using one reciprocating solid steel wheel. The wheels have a diameter of 203.5mm and a width of 47.0 mm. The load is fixed at 685N and the average contact stress given by the manufacturer is 0.73MPa. This assumes an average contact is of 970m^2, which is based on the 47mm wheel width and an average contact length of 20.6mm in the direction of travel.

However the contact area increases with rut depth, and thus the contact stress is variable. The manufacturer states that a contact stress of 0.73 MPa approximates the stress produced by one rear tire of a double-axle truck. The number of wheel passes being used in the USA is 5,000, although up to 10,000 wheel passes can be applied. The rut depth in each slab is measured automatically and continuously by a linear variable differential transformer that has an accuracy of 0.01mm. Deformation is calculated at every 20, 50, 100 or 200 wheel passes with the help of gauge. Approximately, 3 h and 8 minutes are needed to apply 10,000 wheel passes; however, the device will automatically stop if the rut depth in one of the slabs exceeds 15mm. The post-compaction consolidation is the deformation at 1,000 wheels passes. It is called post-compaction consolidation because it is assumed that the wheel is densifying the mixture within the first 1,000 wheel passes.

3.9.1Preparation Of Sample

Total two samples are made one with zycosoil having 1.5% content and one without modifier (Figure 3.40).Zycosoil was mixed with asphalt (dry process). Rutting potential is determined at 10,000 passes/load repetitions (ANNEX B & ANNEX C). The results are shown in table 3.11

Figure 3.26 Preparation of sample (1)

Figure 3.26 Preparation of Sample (2)

Figure 3.26 Compaction Using Roller Compactor

Table 3.10 showing Hamburg Wheel Test results

No of passes	Deformation (mm), without modifier	Deformation (m), with zycosoil
0	**0.0**	**0.0**
2000	**4.41**	**0.95**
4000	**5.25**	**1.23**
6000	**5.75**	**1.44**
8000	**6.20**	**1.55**
10000	**6.60**	**1.67**

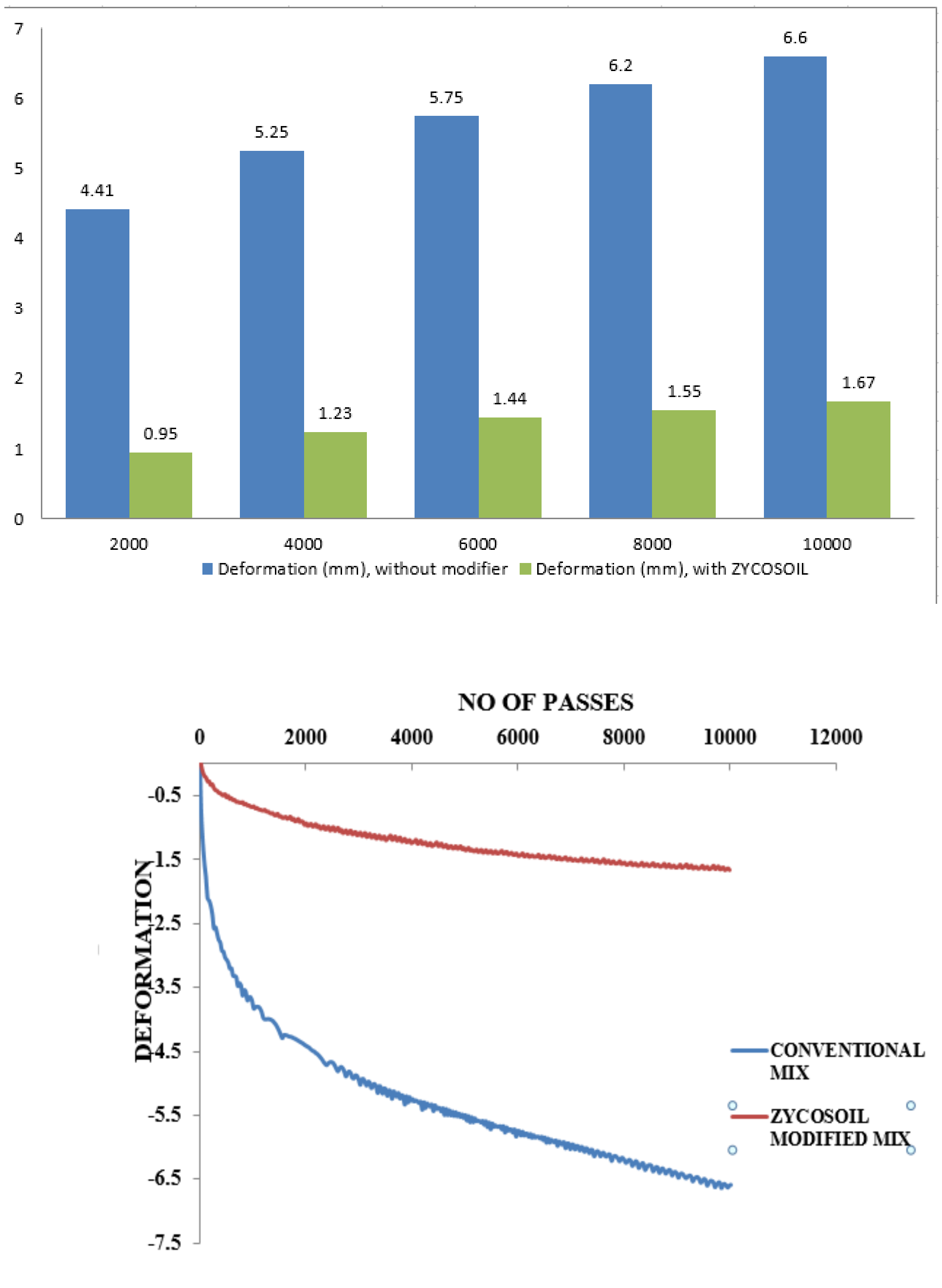


Figure 3.27 Comparison of Rutting Resistance

3.10 Economic Analysis of The Project:

3.10.1. Buying of Zycosoil:

Since the product is new to the market so it's not locally prepared. It is manufactured in countries like America & India. However there are local retailers and dealers available for procurement of Zycosoil. Cost per Kg of zycosoil is 12000 Rs. In addition, delivery charges required are 4000 Rs. per Kg. This makes a total of 16000 Rs. per KG. Though this cost looks big, but this cost is balanced by proportion of Zycosoil that is used, which is only 1 Kg per 1000kgs (1MT).Hence overall the product cost is balanced due to proportionality of use.

3.10.2 Cost Calculations

In control Asphalt mix:

- Asphalt wearing course:

Quantity of asphalt wearing course (approx. 2 inches) =438 tons per km

Rate of asphalt wearing course mix = Rs 6500 per ton

Total cost of asphalt wearing course per lane km = 438*6500 = **Rs28, 47,000.**

- Bitumen used (bitumen content=4.0%)

Quantity of bitumen in asphalt wearing course

= bitumen content * asphalt wearing course

=.04 * 438=17.52 tons

Cost of bitumen =90,000 per ton

Total cost of bitumen used in asphalt wearing course

= 17.52 * 90,000 =Rs. 15, 76,800.

In Zycosoil Modified Asphalt mix:

- Bitumen saved:

Bitumen saved in modified mix = 1.5% of total bitumen in control mix

= .015 * 17.52 = .2628 tons per km lane

Processing cost of zycosoil = buying cost + cleaning and shredding cost

= RS 12000+Rs. 4000 = **Rs. 16000 per kg**

Amount of Zycosoil used = .2628Tons per km lane=262.8 kg approx. per km lane.

1Kg of zycosoil is used for 1000 kilograms of bitumen

So for 262.8 kg approx. per km lane we shall require .2628 kg of zycosoil

Cost of zycosoil = .2628*16000= Rs.4204 per km of lane

- Cost saved:

Amount of bitumen saved in modified mix =.2628 tons

Cost of bitumen = Rs 90000 per ton

Cost saved = .2628 * 90000 = Rs23652

Processing cost of zycosoil = Rs4204

Cost saved excluding processing cost of Zycosoil

=23652-4204 = 19,448Rs

Table 3.11 Economy Analysis

Size of the road	**Bitumen needed**	**Zycosoil needed**	**Bitumen saved**	**Cost reduced**
1kmX 3.75 m	17.52 tons	.2628tones	.2628 tons	Rs 19,448

3.11 Comparison Of Conventional Bituminous Mix Modified Bituminous Mixes:

PROPERTIES	MODIFIED MIX	CONTROL MIX	% INCREASE / DECREASE
Marshall Stability Value	More (18.6KN)	Less (9.8KN)	APPROX 89 %
Binding Property	EXCELLENT (enhanced by 95%)	Good	--
Rutting	Less (1.67 mm)	More (6.60 mm)	310% DEC
Stripping (Pot Holes)	No	Much trouble	--
Seepage of Water	No	Yes	--
Durability	Better	Good	--
Cost	Less	Normal	--

CHAPTER 4

RECOMMENDATION & CONCLUSIONS

4.1 Additives and Modifiers In HMA:

Although asphalt modifiers have been used over 50 years there is a renewed interest over the past ten years. This resurgence in interest can primarily be attributed to the following factors: The increased demand on HMA pavements. Traffic volume, traffic loads, and tire pressure have increased significantly in recent years causing premature rutting of HMA pavements. The environmental aspects desire that additives and modifiers be added to decrease the total consumption of main materials and hence preserve the natural environment

4.2 Conclusions

- Optimum percentage of Zycosoil, by weight of binder content was found out to be 1.5 % in this study.

- Marshall Stability value was observed to be more for zycosoil having 1.5%, asphalt binder content. Therefore HMA is expected to yield better road performance and load carrying capacity.

- Zycosoil modified mix exhibited better stability value profile as compared to lime modified mix and conventional asphalt mix. Zycosoil samples show 89% increase in stability as compared to stability of control mix.

- According to the specifications if L.A.A.V. is less than 30% then this aggregate is suitable for all mixture, and if it is more than 50% this aggregate is unusable in any mixture. Its abrasion value comes out to be 26%. The L.A.A.V is direct proportional to the wear of aggregate. According to the value our aggregate can be satisfactorily used for mix.

- Impact value of the aggregates used is 16%as it falls in the range of strong category of aggregates that is 10-20%, hence we get satisfactory results.

- Analysis of results reveals that Zycosoil modified mixes exhibit better binding properties.

- Basing on the Marshall Flow results values, Zycosoil added mixes has been found to reduce the flow values thereby making the mix stiffer compared to conventional mix.

- Careful observations and results show that using 1.5% (of binder content) asphalt in mix yielded better results as compared to adding 2% of zycosoil. This provides us the idea of preserving the material, and hence economizing the project.

- Basing on rutting test results, rutting was much lower in case of mixes containingZycosoilwhich is attributed primarily to stiffness of mix due to addition of modifier. Rutting results indicated that modified mixes containing Zycosoilshowed 4 times decrease in deformation/rutting compared to control mixes. This, in turn, shows that Zycosoil modified mixes are less susceptible to rutting (i.e. they have greater rutting resistance) compared to conventional bituminous mixes.

- Use of zycosoi lwould lead to introduction of nano-technologically prepared materials, and hence will open future prospects of exponential growth in this area of expertise.

- Overall, polymer modified HMA, in general, and zycosoil modified HMA, in particular, yielded better results in terms of HMA performance properties compared to conventional (un-modified) HMA.

- Basing on the results of this study it is revealed that zycosoil modified HMA is expected to exhibit better load carrying capacity, improved serviceability/pavement performance, greater resistance to rutting, longer service life, and indeed reduced life cycle cost.

- Economic analysis revealed that using the zycosoil in HMA, 1.5 % bitumen can be saved leading to overall saving of *Rs.19, 448*per-lane-km as compared to using conventional HMA in road construction.

4.3 Recommendations

- Since zycosoil is cost effective it can be used in mega projects in Pakistan.
- Zycosoil yields better values of stability and flow compared to conventional HMA so, it can be used efficiently in roads especially those designed for heavy loads.
- Further investigations on the use of zycosoil modified HMA basing on field testing on test road sections are recommended.
- Workout life cycle cost analysis basing on field test road sections.
- 60/70 grade bitumen is used in this study, further study is recommended to analyze effect of using different grades of bitumen.
- Exploration of nano-products like zycosoil to be used in road for enhancement of properties and service life.
- After requisite testing and further exploration modified specifications and standards are recommended to be prepared for road construction industry.

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