# Performance evaluation of WMA with Glass and Plastic as a replacement of Aggregate

**FINAL YEAR PROJECT UG 2018**


By

| | |
|---|---|
| MUHAMMAD BILAL | NUST2018SCEE261370 |
| MUHAMMAD ALI KHAN | NUST2018SCEE268388 |
| HAMZA GULZAR | NUST2018SCEE251203 |
| JUNAID REHMAN | NUST2018SCEE241704 |

**NUST Institute of Civil Engineering (NICE)**

**School of Civil and Environmental Engineering (SCEE)**

**National University of Sciences and Technology (NUST)**

**Islamabad, Pakistan**


**2022**

This is to certify that

The Final Year Project Titled

# Performance evaluation of WMA with Glass and Plastic as replacement of Aggregate

**Submitted by**


| | |
|---|---|
| MUHAMMAD BILAL | NUST2018SCEE261370 |
| MUHAMMAD ALI KHAN | NUST2018SCEE268388 |
| HAMZA GULZAR | NUST2018SCEE251203 |
| JUNAID REHMAN | NUST2018SCEE241704 |


Has been accepted towards the requirements

for the undergraduate degree

In

**CIVIL ENGINEERING**


______________________________

MANSOOR AHMAD MALIK

Assistant Professor

National Institute of Transportation (NIT)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad

Pakistan

# DEDICATION

**CREDIT GOES TO OUR FAMILY AND TEACHERS, WHO HELPED AND INSPIRED US THROUGHOUT OUR LIFE.**

# ACKNOWLEDGEMENTS

All praise be to ALMIGHTY ALLAH, who made everything possible and simple for us to accomplish during our incredible NUST journey. We owe a debt of gratitude to our parents, who sacrificed and prayed for us to succeed in our studies and research.

A very Special thanks to A/P Mansoor Ahmad Malik, the team's respected advisor and mentor, for his constant guidance, motivation, and assistance in completing the team's final year requirements, without whom this would not have been possible. Special thanks to the cooperative staff of NIT lab who diligently assisted us in our experimental work no matter how tough things got.

We would like to owe a special thanks to Late Mr.Fazal Haq and Late Mr.Saad who were our source of motivation for conducting research on Warm Mix Asphalt.

# Table of Contents

## LIST OF FIGURES

# LIST OF TABLES

## LIST OF ACRONYMS

| AASHTO | American Association of State Highway and Transportation Officials |
| --- | --- |
| AC | Asphalt Concrete |
| ASTM | American Society for Testing and Materials |
| HMA | Hot Mix Asphalt |
| WMA | Warm Mix Asphalt |
| ITS | Indirect Tensile Strength |
| NHA | National Highway Authority |
| OBC | Optimum Bitumen Content |
| UTM | Universal Testing Machine |
| VA | Air Voids |
| VFA | Voids Filled with Asphalt |
| VMA | Voids in Mineral Aggregate |
| HWT | HAMBURG WHEEL TRACKER |
| PET | Polyethylene terephthalate |

# ABSTRACT

In the daily lives of social beings, transportation infrastructure is crucial. Because it necessitates large quantities of construction materials, any small reduction in material percentages and replacement with alternate material has a greater impact. Many countries have begun research in this area, with the goal of replacing aggregate with glass and plastic in small percentages. Plastic is inculcated in bitumen for road construction in India (Jamshedpur), which is noteworthy. Similar incidents have been reported in Indonesia (Bali, Bekasi, Makassar, Solo, and Tangerang), indicating that the plastic-asphalt mixture is more prevalent there. Furthermore, Pakistan is also starting to realize the potential of using waste material as a replacement of aggregate. Recently, two roads were constructed in Islamabad which utilized plastic as a replacement of aggregate. One of the roads is in Ataturk Avenue and the other in F9 park. The use of plastic not only saves resources, but it also reduces the massive amount of ocean pollution that Pakistan currently faces.

The same is true for glass, which takes up a lot of space in landfills and causes soil contamination as well as polluting the environment for decades. The largest project in this regard was in New York, where 225,000 metric tonnes of glass was used in the surface course [1]. Their primary application is to combat the growing amount of plastic and glass waste that is polluting the environment and the ocean. Plastic and glass are produced at a much faster rate than they are used or curtailed to save the environment, so their use in roads is a viable option for reducing their massive amounts.

Furthermore, a research concluded that usage of plastic and glass reduces the overall OBC hence decreasing the cost. So, the usage of plastic and glass in road construction is a viable option to lessen the environmental hazards as well as being an economical method for road construction.

Another aspect of this research study is to use a more sustainable, cost and environmental friendly asphalt technology which also improves the overall performance of the asphalt concrete. This is why Warm Mix Technology was adapted in this research. The WMA technology lowers the mixing and compacting temperature by 30-40% [2]. Reducing the harmful emission of PAH compounds by 50% and reducing the fuel costs by 30% [3]. Thereby improving the environmental conditions and providing an

effective way to cut off the cost.

- NHA gradation B for aggregate and Parco 60/70 asphalt was used.
- Sasobit acquired from Sasol Wax based in South Africa.
- Aggregate of PatharGarh was used.
- Plastic and glass were acquired from Multan, Lime which is an anti-stripping agent was bought from I9 Market Islamabad.
- Quality tests were performed on aggregate and virgin asphalt.
- Plastic and Glass percentages of 0.5%, 1.0% and 2%, 4% respectively were used.
- Performance testing was done after finding out the OBC, volumetric, stability and flow of Plastic and Glass containing mixtures, and controlled samples. Using those OBCs, different samples were tested against rutting and moisture susceptibility for evaluation and compared with the performance testing results of mixtures made with HMA.
- It was noted that by using WMA technology the TSR improved by 8-10% and the rut depth decreased by 22-35%.
- Estimation was also done for cost and the overall cost reduced by 10% which can be further reduced if sasobit is manufactured locally.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Due to the economic crisis that Pakistan is facing, and the uncertain conditions prevailing in the country since the last two decades, the overall situation has escalated drastically. Ultimately these conditions have taken a toll at the construction industry. This has resulted in a decrease of allotment of funds by the government, which ultimately results in adaptation of poorer construction practices, using cheap material etc, which results in poor construction. To offer a safe, efficient transportation system that is cost effective the industry has to steer away from the conventional, costly, unsafe, and less efficient methods to new methods which are the need of the hour.

Due to innovative procedures and materials available new technologies have been developed that have the proficiency of lowering the mixing and compacting temperature. These technologies are known as WMA (Warm Mix Asphalt). Warm mix asphalt (also generally known as WMA) is an asphalt technology which reduces the viscosity of the asphalt binder. Due to the reduction of viscosity the asphalt concrete can be produced at reduced temperature [4]. The overall mixing and compaction temperature is reduced as a result the energy consumption and environmental hazards are minimized. The mixing and production temperature of the asphalt concrete is reduced by 20-40C as compared to the conventional HMA technology [2]. There are technologies which are being used to make WMA, that consist of organic and inorganic techniques. The organic additives can be directly added, whereas the inorganic additives require the process of foaming to make WMA. Apart from lowering the temperature these technologies improve the properties of Asphalt concrete. Reduced mixing temperatures results in energy cost savings to the producer and verdicts have revealed that reduced temperatures in plant can lead to a 30 % drop in fuel energy consumption mentioned by Hurley & Prowell (2006). Also Zhang et al (2012) stated that the reduction of temperatures will eventually reduce the emission of harmful compounds and will help reduce health problems. WMA will also permit lengthier haul distances and a lengthier period for construction for the blends which are produced at more normal functioning temperatures. With the lower operating temperatures another prospective added benefit in that it reduces the oxidative hardening of asphalt which may upshot performance of pavement such as decreased block cracking, thermal cracking, and averting the mixes from being tender when placed.

There are fifteen WMA technologies available. Some of them are listed below:

- Double Barrel Green
- Synthetic Zeolite
- WAM Foam
- Low Energy Asphalt
- Evotherm
- REVIXTM
- RedisetTMWMX
- Sasobit.

The first four are foaming based and the rest are chemical additives. In this research study, Sasobit was used to produce the WMA, it is an organic additive, the chemical formula of sasobit is $C_nH_{2n+2}$. It is the product of Sasol Wax in South Africa. It is a long chain of about 40-115 carbon atoms of aliphatic hydrocarbons and produced by the process of coal gasification. It can be used directly on the mix of aggregate as a melted liquid with the help of dosing meter or solid prills.

For production of HMA, Sasol endorses to add Sasobit at a rate of 0.8% to 3% by mass of bitumen, but not to exceed 4 % [5]. Since 1997, Sasobit was used in paving of more than 142 projects, totaling more than 2,271,499 square meters of pavement. Projects were constructed in Belgium, Austria, China, Denmark, Czech Republic, Hungary, France, Italy, Germany, Malaysia, New Zealand, Macau, South Africa, Sweden, Netherlands, Russia, Switzerland, the United States, and the United Kingdom by using WMA technology.

The asphalt paving industry has continuously encouraged recycling of waste materials. The use of glass and plastic is increasing rapidly and when not recycled and left untreated can cause adverse problems to the environment. Plastic is non-biodegradable, and when left untreated **it would take many years to for them to decompose**. Apart from that, toxic substances are released into the soil when plastic bottles are exposed to the sunlight and, if plastic is burned, toxic substances are released causing air pollution. Pakistan alone produced an estimated 3.9 million tons of plastic waste in 2020; out of which only 10% was recycled [6].

Similarly for glass which is left untreated and dumped at dump yards or in some other places for several years, will create hazards for the environment and the overall ecosystem. Glass industry reported recycling around 27 million metric tons worldwide. This is around 21% of the total glass production rest of the glass is left on dump sites which eventually damages the environment. So the waste materials which are dumped do not deteriorate and remain in the Earth causing several harms to the environment.

## 1.2 Problem Statement

Due to the financial constraints and the need of a better pavement performance because of the ever-increasing traffic volume has made it necessary to find an alternative of producing an Asphalt Concrete that has better performance, more workable, has better compaction properties and economical than the conventional asphalt concrete. Moreover, the adverse effects of plastic and glass are already known. Many of the countries have already started to make green pavements (which utilize the waste materials), Pakistan is still lagging behind in this regard. Currently, two plastic roads have been constructed, the government is starting to realize the impacts of waste materials and utilizing them in the pavement is an effective way of recycling. Plastic being a non-biodegradable matter damages the environment when disposed on dump sites and if it is burnt it produces dioxin, a highly toxic chemical. Dioxins are carcinogenic chemicals, which can affect the endocrine gland system causing hormonal, Immunol and reproduction difficulties. Plastic burning causes production of benzo(a)pyrene (BAP) and other polyaromatic Hydrocarbons (PAHs), mostly which leads to carcinogen. Unburnt plastic ends up as garbage on ground or in water streams. It does not only degrade the living conditions of marine life but also a major factor of failure of drainage system in Pakistan.

Glass which is another waste material used in this research study has drastic environmental impacts of its own. It has a decaying span of more than one million years. When dumped on the landfills the nearby areas and soil will get contaminated. Utilizing glass in pavement will definitely reduce waste and save resources. Therefore, this research study is so focused on using waste materials in pavement.

The problems discussed above endorses the requirement of a study to promote the utilization of waste materials in pavement construction in Pakistan with lower temperature by WMA technology for an increased performance.

Therefore, in this study Warm Mix Technology was utilized to study different parameters. The two parameters against which the performance of the asphalt was checked were:

- Resistance against rutting
- Moisture Susceptibility

### 1.3 Purpose of Research

There is an ever increase of Glass and Plastic in Pakistan due to an excessive demand. With an aim to address the consumer consumption demand, there is no way to slow down the production of these materials. Due to the excessive production the environmental hazards related with these waste materials are inevitable.

Currently, India the neighboring country of Pakistan has already started to utilize the waste materials in road construction, but attention towards the new replacement materials is next to none here. Pakistan is currently a developing country, several construction projects are ongoing, and the potential of the construction industry is immense here, but due to the financial position of the country and ever-increasing amount of waste materials being dumped or burned which is damaging the environment. Some steps must be taken right now before things get out of hands. This is the perfect opportunity to shift towards WMA technology and utilize glass and plastic in roads and unlock the true potential of the combination of WMA and waste materials. We have aimed to use Plastic and Glass as an aggregate replacement in Asphalt pavements to reduce the indirect cost of construction and help protect the environment, combined with the using WMA technology replacing the conventional HMA technology.

## 1.4 Research Objective

The main objectives of this research study are to utilize glass and plastic in WMA, further breakdown is listed below:

- To evaluate the resistance against rutting of WMA with glass and plastic.
- Evaluating the moisture susceptibility of WMA with glass and plastic.
- Comparing the performance of WMA (with glass and plastic) against rutting and moisture with the conventional HMA (with glass and plastic).
- Reducing the overall construction of pavement.

## 1.5 Organization of Report

This thesis has five chapters. The detail of each chapter is as under

Chapter 1 gives a shortly explains to problems related with the generation of Plastic and glass and their collective use in pavement construction. Also, the use of WMA and the benefits it can bring in the road construction industry.

Chapter 2 includes literature review on needs of transportation, previous research related to using Plastic and Glass in pavement and problems associated with it, and the findings of the previous researches utilizing WMA technology.

Chapter 3 explains the methodology used in this research which consists of the collection and laboratory characterization of materials, the Marshal Mix design and performance testing.

Chapter 4 shows the compilation of results and the analysis based on results.

Chapter 5 Summarizes the research, included the conclusions and recommendation for future research work in the same domain.

CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter contains a brief review of the literature and theory related to the response of asphalt mixes containing glass, plastic and sasobit to the Hamburg Wheel Tracker test (for determining permanent deformation) and Indirect Tensile Strength test (for determining moisture damage). This chapter deals with glass, plastic and sasobit, and their impacts on various performance properties and some research that were conducted previously to predict permanent deformation and moisture damage of asphalt mixes using Hamburg Wheel Tracker test and Indirect Tensile Strength test.

## 2.2 Transportation-need of the hour

The significance of well-defined, interconnected routes within the country is critical to the country's progress. The number of passengers who use this method are massive. Other mobilizing facilities like railway are not as good as they are in other developed countries such as China and Japan, so the focus is on highways and motorways, which are currently developing at a breakneck pace. A well-developed transportation network is critical to the country's economic growth. In this context, Pakistan has worked hard to build strong road networks throughout the country. The total road density in Pakistan is 0.32Km/sq km [7]. Important cities like Peshawar,Lahore, Multan, and Islamabad all have important motorways that provide fast transportation.

Pakistan is currently constructing a trade route known as the China Pakistan Economic Corridor with the help of China (CPEC). The total cost of developing such a massive undertaking was $54 billion. As part of CPEC, a 1,100-kilometer motorway will connect

Karachi and Lahore.

The Karakoram highway, that connects the Khunjerab China border with Rawalpindi, is also nearing completion and will soon be operational. By December 2019, the main railway line between Karachi and Peshawar will be upgraded to allow trains to travel at up to 160 km per hour. Despite its rapid growth, the country is unable to meet the country's needs because deprived areas still lack adequate road networks.

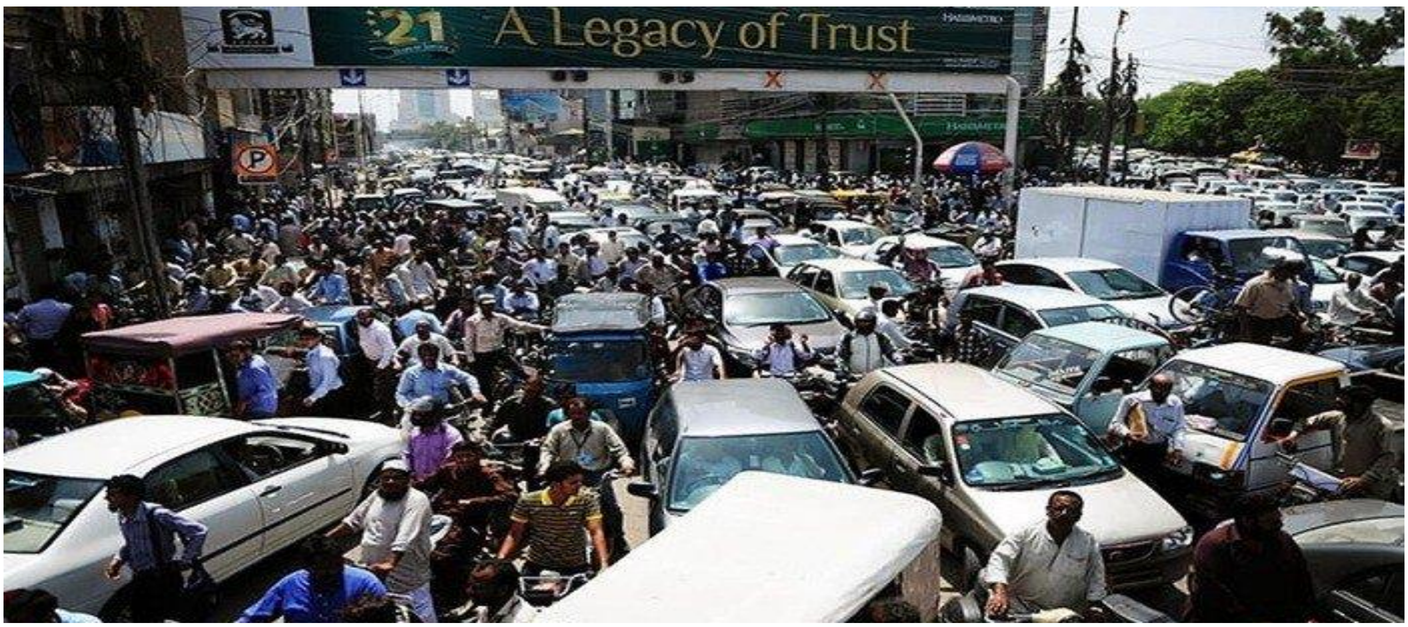



**Fig 2.1 Traffic congestion in Pakistan (Geo-News)**

### 2.3 Glass: An Unreplaceable product

Because of its unique quality of transparency, glass is utilized in a wide range of everyday equipment, gadgets, and building materials. The glass-making process entails combining vast volumes of silica sand with comparatively lesser amounts of lime and soda ash, as well as other minerals, then heating the mixture in a furnace until it transforms into a viscous mass to give the glass unique properties. It comprises roughly 72% silica, 15% sodium oxide, 9% calcium oxide (lime), and 4% of an additional component [8]. The material has a significant market all over the world due to its wide range of applications and qualities. From decorations to optic fibers, colored to tainted glasses, wind shields to window shields, glass can be durable, brittle, and resistant to high heat and cooling.

### 2.3.1 Glass use and impact in Pakistan

The Glass mostly produced in Pakistan is inexpensive (Lime containing) glass which is due to high reserves availability in the country. The industry focuses mainly focuses on creating building windows, decoration pieces, bottles (medicine and fizzy drinks), car windscreens etc. However, high quality of glass is mainly exported to meet the needs within the country. The huge amount produced does not all go to the recycling. One estimate suggests that Australia utilizes only 350,000 out 850,000tons for recycling which is only 40% of total [9]. The rest is disposed. The Australian example is indicative of the glass waste disposal throughout the world and especially in Pakistan attention is given mainly on paper or small amount of glass recycling. Hence, large amount of glass is dumped on the landsite which takes hundreds of years to decompose.

**Fig 2.2 Waste Glass dump yard**

### 2.3.2 Previous work

Numerous researches have been carried out to check performance of pavement containing different percentages of waste recycled glass and plastic. Some important studies that discussed the use of waste recycled plastic and glass in HMA include: Nur Izzi and Md Yosaff 2018; Ghasemi and Marandi 2003; Sahar Mohsenian and Hadad Amlashi 2015; Y.Issa 2016; Modarres and Hamedi 2014; Taher Baghaee Moghaddam 2012. The stiffness modulus of an asphalt mixture including glass and an anti-stripping agent increases when compared to control samples, according to Airey et al. The bond between glass and binder is poor without the addition of an anti-stripping agent.

To compensate for this issue, Su and Chen suggested adding 2% lime [10]. Glass particles with larger angularity, according to Arabani et al., can prolong the fatigue life of an asphalt pavement by creating a higher internal friction angle, which improves the interlocking between different constituent particles [11]. When larger glass particles or a higher fraction of glass particles are utilised, however, various issues can arise, such as insufficient friction and bonding strength.

Navarro et al. recently shown that by using waste glass as a sand fraction substitute in moderate doses (8%) produced asphalt mixtures with mechanical qualities suitable for road surface courses [12].

Study shows that incorporation of 4% waste recycled glass and 1% plastic produces best optimum results [13]. However, glass up to 10% can be used without compromising strength and other mechanical properties. Recommended usage of waste plastic is within range of 2-3%.

## 2.4 Plastic: A Replacement for many products

Plastic is made up of two main products. Polyethylene and Polythene. The second of which is produced from distillation of raw oil, natural gas, coal and salt. Plastic has basically taken over thousands of products from its invention. From food plates to aluminum cans, packaging and toys, every material in such fields have plastic as their priority use. The main reason for its high usage is its ability to be molded in desired shaped easily. Furthermore, unlike wood and steel which are mostly get attacked by termite or resting, plastic is free from all such attacks. The ease of creation, cost effectiveness and a long-term usage are some reasons why Plastic is a major replacement to many products.

### 2.4.1 Impacts of plastic bags on Environment

The rapid increase in plastic is greatly linked with tremendous land and ocean pollution. Plastic adds up about 10% waste in the environment. Some estimates suggest that amount of plastic will overrun fish in the sea by 2050. Some other facts and figures regarding the plastic pollution in sea are [14]:

i. More than 8 million metric tons of plastic is finds way into oceans from industries per annum.

ii. More than 100,000 marine animals die annually by digesting or entangling in plastic bags each year.

iii. Approximately 4,600 turtles are being killed each year due to plastic pollution.

The rapid increasing industries and of plastic means that it's waste products also increasing at a faster pace. Most of which takes hundreds of years to decompose and remained in the environment to cause pollution and harm the environment and affect aquatic life. The damages have inculcated such a vast concern in some that they have committed to erase it from their use.

### 2.4.2 Use in Pakistan

In Pakistan the generation plastic is high. Where steel and timber are expensive material, plastic provides a cheaper alternate for production and ease for the masses to purchase. Secondly as there is no check or limit in for the production and sale of plastic. As indicated in surveys conducted in 2007, the polythene bags consumption in Pakistan have increased from 12 million in 1990 to 55 billion in 2007 [15]. Plastic mostly utilized in bottles producing beverages like Pepsi, sprite, mineral water etc.

The use is further broadened to add plastic shopping bags, which is produced and used without any government check. Therefore, the amount has coasted so much pollution that clogged drainage systems, high dumping sites, burning waste and many diseases has become norm in the country. Furthermore, the rise in temperature, abrupt climate changes and sudden irregular flood patterns are at increase in Pakistan. (DAWN news).

**Fig 2.3 (Picture credit: DAWN news)**

### 2.4.3 Previous work

Modarres and Hamedi concluded that adding plastic improves the fatigue behavior. It also decreases Resilient Modulus when amount of plastic used is greater than 2% [16].

According to Mohamed Meftah Ben Zair, plastic enhances the mechanical properties of the asphalt. Almost all studies conducted resulted that if a lower proportion of PET (2–4%) is added, it would result in better resistance against rutting [17].

Moghaddam (2013) concludes that the mixtures with a PET particle content of up to 1%, resulted in the highest fatigue life, reaching double of conventional mixtures at lower stress levels [18].

Nur Mustakiza Zakaria found that the asphalt mixture sample containing 1% recycled plastic and 4% recycled glass shows almost similar and satisfactory results compared to the control sample in all tests [13].

## 2.5 Warm Mix Asphalt

Warm Mix Asphalt technology, initiated in Europe but now getting popular all over the world for its advantages. The additives which are added to prepare WMA increase the workability of asphalt mix and decrease the viscosity of asphalt binder at lesser mixing temperature. WMA technology allows to mix, transport, and pave at considerably reduced temperature. Using WMA technology, asphalt mix can be prepared at as much as 100ºF lower than Hot Mix Asphalt.

Almeida-Costa, A., & Benta, A., (2016) conducted research in which a warm asphalt concrete of high modulus by adding a chemical additive and a warm rough asphalt concrete by the inclusion of organic additive was produced.  The maximum theoretical cost of additive was calculated for both cases [19]. According to the results obtained from their study, the maximum cost obtained for warm mixture for the production of the respective warm mix is economically better. $CO_2$ emission is also decreased.

Reduced carbon dioxide emissions and significant reduction of energy consumption was observed for both mixtures under study. So it can be observed that environmental and economic benefits can be achieved along an assuring enhancement of the pavements.

According to McCormack et al (2014), Information obtained from manufacturers and materials suppliers show that reduction of around 30% CO2 emission and energy consumption are possible using Warm Mix Asphalt as compared to typical Hot Mix Asphalt [20].

According to Braziunas et al (2013), improved compaction is one of the key performance related parameters. In case of HMA, most of the asphalt binder aged when exposed to raised temperatures in the plant. While for WMA, reduced mixing temperature helps in reduced oxidative hardening which enhances pavement longevity and flexibility while reducing its vulnerability to cracking [21].

According to Rossi et al (2013), positive impacts will be demonstrated on pavement performance by technologies with production temperatures lesser than HMA. These technologies should decrease (or at least not increase) compaction energy required which will ultimately improve workability and enhance in-place density [22].

Jamshidi et al. (2013) concludes that Sasobit saves energy by reducing fume emissions, and it also drops the production cycle times [23].

Burak Sengoz's (2016) research indicates that For best performance, Sasobit should be added at a rate of 3.0% by weight of bitumen. In terms of rut depth, all WMA combinations perform better than HMA mixtures [24].

According to Raveesh J (2018), the most extreme strength for 60/70 review bitumen is accomplished at 135°c temperature by adding the 3% of sasobit by the weight of the binder [25].

# CHAPTER 3

# RESEARCH METHEDOLOGY AND TESTING

## 3.1 Introduction

This chapter mainly explains the methodology utilized to get the desired objectives of our research which consists of testing material acquisition, experiments on the acquired material, specimen preparation and experiments on the prepared samples. The study was performed on the control as well as the specimens containing 1% to 4% Plastic and Glass in HMA and as well as in WMA. Evaluation of the OBC on different percentage additives, HWT test and ITS test were the main works done. The chapter further delineates equipment used, procedure to produce specimens and input parameters during various tests will be discussed in this chapter.

## 3.2 Research Methodology

For this research coarse and fine aggregates were collected from Pathar Garh quarry. The asphalt of penetration grade 60/70 was used and sourced from PARCO. The purpose of selecting grade 60/70 is due to its vast usage in Pakistan moreover due to its appropriateness for the climate of Pakistan. The Sasobit was imported from a South African company Sasol Wax. The aggregate structure in the mix provides the maximum resistance to permanent deformation which is almost 95% and left over 5% is provided by the asphalt binder. HMA properties are greatly affected by gradation, surface texture and shape of the aggregates. These strength related properties of aggregate are greatly influenced by the texture and shape. A more angular and rougher textured aggregate exhibits more resistance against stresses due to temperature changes and stresses induced due to moving traffic loads. Several tests are performed per ASTM and BS to check properties of aggregate affecting pavement.

Sasobit is a WMA additive used in this study. The product was in the form of prills and was imported from a company based in South Africa named Sasol Wax. Sasobit is generally added at the rates of 0.8 to 3 percent by the weight of Asphalt. In this study Sasobit was added at 3% of OBC [5]. For addition of Sasobit, there are two possible ways, either it can be pre-blended with the asphalt binder or it can be introduced directly in the mix with the aggregates after the required amount of bitumen is added.

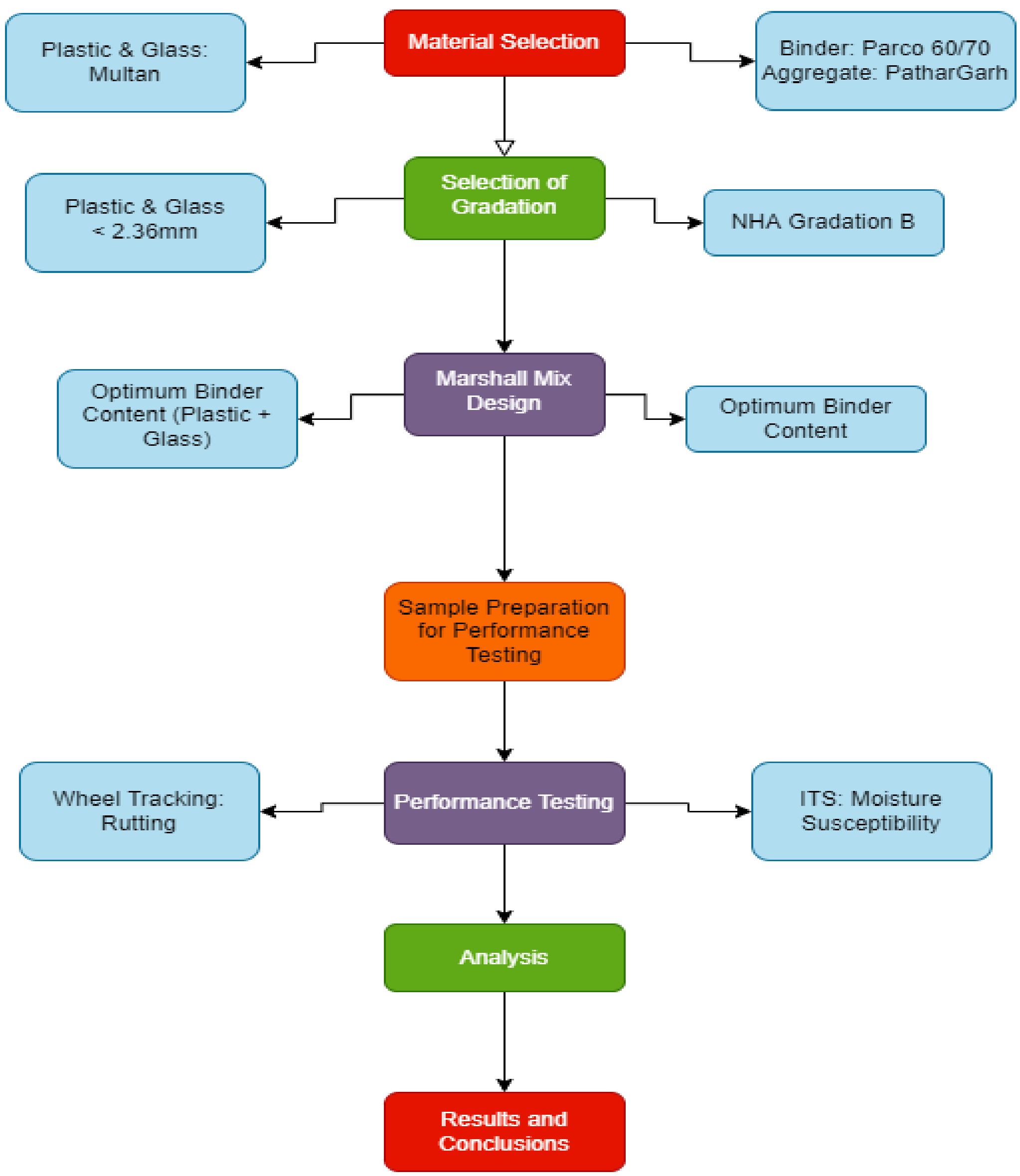



**Fig 3.1 (Research Methodology)**

### 3.2.1 Material Characterization

#### 3.2.1.1 Aggregate Tests

The aggregate skeleton of the mix is the central portion which offers the maximum resistance to permanent deformation against various stresses induced in the asphalt concrete matrix. An aggregate should have the appropriate texture, toughness, strength, durability, absorption indexes and shape to fulfill all the required criteria essential to be utilized in the asphalt concrete mix. Therefore, to investigate the selected aggregates against the required properties several aggregate quality control tests were performed. These include:

- Impact Value Test of Aggregates
- Aggregate Shape Test
- Specific Gravity and Water Absorption Test of aggregates
- Los Angeles Abrasion Test on aggregate

For each experiment three samples were taken and to minimize the errors average value of the three was used.

#### 3.2.1.2 Shape test of Aggregate (ASTM D 4791-99)

Strength and workability of asphalt mixture mostly depends on the shape of particles. It also effects the effort required for compaction vital to achieve the necessary density. According to ASTM D4791, aggregate particles are categorized as flaky aggregate having smaller dimension less than 0.6 of their mean sieve size, while the aggregate particle will be called elongated with a length of more than 1.8 of their mean sieve size. Flaky and elongated aggregates tend to break quickly/easier under cycles of traffic loads. Preferred shape of aggregates is angular so that it can have better interlocking property and offer more resistance under different loading conditions.

Both flakiness index as well as elongation index should be **less than 15% [26].**

**Fig 3.2 (Flakiness Index, Elongation Index)**

#### 3.2.1.3 Specific Gravity Test (ASTM C 127 & ASTM C 128)

Specific gravity represents the weight volume characteristics of aggregate material. Weight of given volume of aggregate divided by weight of equal volume of water at 23 °C gives value of specific gravity. This test was performed only on coarse aggregate per ASTM C 127-88. To calculate specific gravity three weights were determined i.e., oven dried aggregate weight, weight of completely submerged aggregate in water, and Saturated surface dry weight of aggregate. Specific Gravity of Fine aggregate and water absorption was determined using ASTM C 128.

**Absorption of Aggregates:**

The increase in mass caused by water in the pores of an aggregate is known as aggregate absorption. It holds immense importance due to:

1. High values can imply non-durable aggregate.

2. Absorption relates to the quantity of asphalt binder absorbed by the aggregate.

Aggregate must not have an absorption **greater than 3%.**

The experiment was performed under the standards of **ASTM C 127-88 [27]**.

A sample of aggregate is taken and weighed. After that it is immersed in water for approximately 24 hours. The pores of aggregates get filled with water, aggregate sample is then removed, and water is dried from the surface. The surface dried aggregates are weighed again, and absorption is calculated as a percentage.

**Fig 3.3 (Equipment for Specific Gravity and Absorption)**

#### 3.2.1.4 Impact Value of Aggregate (BS 812)

The aggregate impact value is a measure of resistance to an impulsive impact or shock, which may differ from resistance to a progressive compressive force. Toughness refers to a material's ability to withstand impact. Aggregates are subjected to impact as a result of vehicle movement on the road, which causes them to break down into smaller pieces. As a result, the aggregates must be strong enough to withstand disintegration due to impact.

The aggregate impact value measures an aggregation's resistance to a sudden shock.

The apparatus required for measuring impact value includes

- Impact testing machine
- Tamping rod
- Sieves of sizes 1/2”, 3/8” and #8 (2.36mm.)

Around 350g of aggregate passing through 1/2” sieve and retaining on 3/8” sieve was taken and filled in the mould of Impact Testing Machine in three layers, tamping each layer 25 times. The sample was transferred into the larger mould of the machine and 15 blows from a height of 38 cm were given with the hammer weighing 13.5 to 14 kg. The resulting aggregate was removed and passed through sieve #8. The impact value was measured by the percentage of aggregate passing through 2.36mm sieve [28].

**Fig 3.4 (Apparatus for Impact value)**

#### 3.2.1.5 Los Angeles Abrasion Test (ASTM C 535)

This test determines hardness and toughness of road aggregate. Aggregate must be hard enough to resist wear and tear due to heavy traffic loads. The apparatuses used for this test are listed as under:

- Los Angeles Abrasion machine
- Balance, set of sieves and steel balls.

Aggregate gradation of **NHA Class B** was selected. 2500 g of aggregate retained on ½" and 3/8" sieves, which is a total of 5000g (W1) of aggregate along with 11 steel balls or charges were placed in the Los Angeles abrasion machine. The LA machine rotated at an RPM of 30-33 for 500 revolutions. After the set revolutions were completed the material in the machine was sieved through 1.7mm sieve. Weight of sample passing through it (W2) was noted down [29].

**The abrasion value was found out by = W2/W1×100**

**Fig 3.5 (Apparatus for Los Angles )**

**Table 3.1 (Aggregate Tests Results)**

| Test Description | Specification Refrence | | Result | Limits |
|---|---|---|---|---|
| Elongation Index (EI) | ASTM D 4791 | | 2.56 % | ≤ 15 % |
| Flakiness Index (FI) | ASTM D4791 | | 10.5% | ≤ 15 % |
| Aggregate Absorption | Fine | ASTM C 127 | 1.47% | ≤ 3 % |
| s | Coarse | | 1 % | ≤ 3 % |
| Impact Value | BS 812 | | 17.32 % | ≤ 30 % |
| Los Angles Abrasion | ASTM C131 | | 22.89% | ≤ 45 % |
| Specific Gravity | Fine Agg | ASTM C 128 | 2.61 | b/w 2.5-3.0 |
| | Coarse Agg | ASTM C127 | 2.63 | b/w 2.5-3.0 |

### 3.2.2 Asphalt Testing

According to Asphalt Institute MS-4 manual, consistency, safety and purity are some properties of binder which should be considered for construction and engineering purposes. Because the consistency of asphalt binder varies with temperature, a standard temperature is required for comparing the consistency of asphalt binder. Binder ductility tests and softening point tests provide information and assurance on consistency. The following tests were performed in order to describe the asphalt binder in the laboratory:

- Penetration Test of Bitumen
- Softening Point Test of Bitumen

- Ductility Test of Bitumen
- Flash and Fire Point Test of Bitumen

#### 3.2.2.1 Penetration Test (AASHTO T49-03)

The penetration test of bitumen is used to measure the hardness or softness of bitumen by measuring the depth of penetration by a standard needle in five seconds while maintaining the bitumen sample temperature at 25 °C. Using three PARCO 60/70 specimens, values from each specimen were taken after performing penetration tests. The required criteria of penetration test as per specifications was fulfilled by all values obtained. Penetration test result is presented in Table [30].

**Fig 3.6.1(Penetration Test Equipment)**

#### 3.2.2.2 Softening Point (AASHTO-T-53)

Bitumen is a visco-elastic material, as the temperature increases it becomes softer and its viscosity reduces. The softening point of a bitumen is the temperature at which sample of a standard size of bitumen cannot uphold the weight of 3.5 gm steel ball and they fall a distance of 25mm by passing through the bitumen. AASHTO-T-53 specifications ring and ball apparatus was used for softening point determination of asphalt. Table shows the results of softening point test [31].

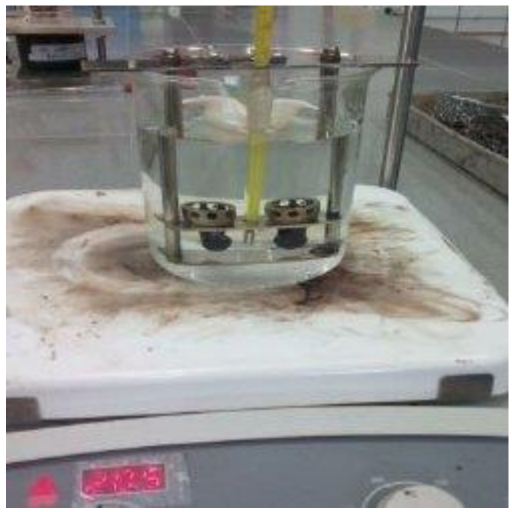


**Fig 3.6.2 Softening Point Test Equipment)**

#### 3.2.2.3 Ductility (AASHTO T 51-00)

Ductility is a significant property of bitumen and an important factor to depict the performance of asphalt mixture. It shows the behavior of asphalt with the changes in temperature. Ductility by definition is the distance to which a standard specimen of binder lengthens without breaking when its two ends are pulled away from each other at the speed of 5 cm/min and at a specific temperature of 25 ± 0.5 °C (AASHTO T 51-00). Table shows the results obtained for ductility tests for bitumen. All specimens satisfied the minimum 100cm ductility criteria [32].

**Fig 3.6.3 Ductility Test Equipment**

#### 3.2.2.4 Flash and Fire point ()

Flash and Fire point test is conducted to determine the safe temperature up to which the bitumen can be exposed. It was conducted as per D3143/D3143M-13 standards.

The tests mentioned above were carried out in laboratory to characterize the asphalt binder (PARCO 60/70). Table shows the tests performed on bitumen [33].

**Table 3.2 (Bitumen Test results)**

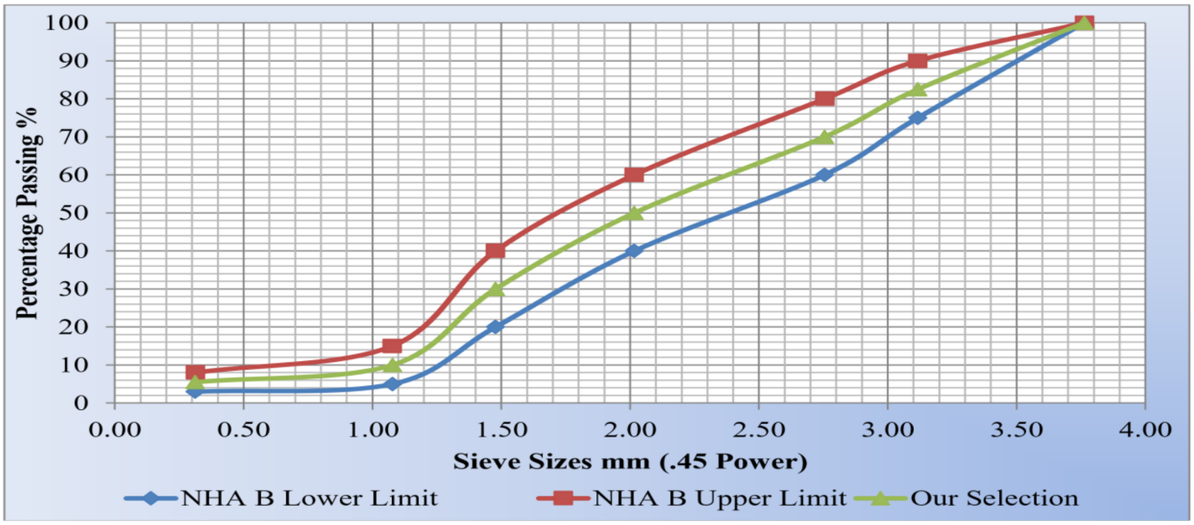
| S No. | Test Description | Specification | Result |
|---|---|---|---|
| 1 | Penetration Test @ 25 (°C) | ASTM 5 | 66.67 |
| 2 | Flash Point (°C) | ASTM D 92 | 361 |
| 3 | Fire Point (°C) | ASTM D 92 | 390 |
| 4 | Softening Point (°C) | ASTM D36-06 | 52 |
| 5 | Ductility Test (cm) | ASTM D113-99 | 107.66 |

### 3.2.3 Gradation Selection

For aggregate gradation NHA Class B gradation of wearing course was used. The nominal maximum aggregate size selected for NHA Class B gradation was 19mm which is a standard according to Marshall Mix Design. The selected gradation is shown in Table 3.3.

**Table 3.3 (NHA Gradation B)**

| S.NO | Sieve Size mm | NHA Specification Range (% Passing) | Our Selection | Retained (%) |
|---|---|---|---|---|
| 1 | 19 | 100 | 100 | 0.00 |
| 2 | 12.5 | 75-90 | 82.5 | 17.50 |
| 3 | 9.5 | 60-80 | 70 | 12.50 |
| 4 | 4.75 | 40-60 | 50 | 20.00 |
| 5 | 2.38 | 20-40 | 30 | 20.00 |
| 6 | 1.18 | 5-15 | 10.00 | 20.00 |
| 7 | 0.075 | 3-8 | 5.5 | 4.50 |
| 8 | Pan | … | … | 5.50 |




### 3.2.4 Asphalt Mixture Preparation

Two types of asphalt mixtures are prepared, one is the controlled mix having only virgin having only virgin aggregate, the other having varying percentage of glass and plastic i.e. 0.5%, and 2,1% and 4% of both. These specimens are prepared to determine OBC at each glass and plastic percentage and of controlled mix. These specimens are prepared per Marshal Mix Design Procedure. After determination of OBC, samples were prepared for Performance Testing.

#### 3.2.4.1 Preparation of Aggregate and Bitumen

After sieving the Aggregate into different sizes required for the project, these aggregates were then oven dried at 110 °C. The total sample weight of Marshall Mix is 1200gm. The weight of bitumen varied according to its percentage which is from 3.5% to 5.0% of mix. The aggregate then used is composed of different sizes according to gradation used. While for preparation of sample having glass and plastic, first get the retain of sieve #4, then the amount of glass and plastic in mix is determined per its percentage used while the remaining portion of specimen is composed of virgin bitumen and virgin aggregate based on the percentage of Bitumen being used. The weight of bitumen and aggregate can be obtained by following formula:

$W_T$ =
$W_B$ +
$W_A$
$W_B$ =
X/10
0* $W_T$

Where:

$W_T$ = Mass of the Total mix

$W_A$=Mass of Aggregate

$W_B$= Mass of bitumen

X= Percentage of Bitumen

#### 3.2.4.2 Mixing of Aggregate, Glass and Plastic and Asphalt

For Controlled Samples, bitumen is first heated to about 150 °C then oven dried aggregate is mixed with it. Keep mixing until homogenous mix is formed. For the samples having glass and plastic, first heat it up to 140 °C then mix it as the same procedure followed for controlled sample.

#### 3.2.4.3 Compaction of Specimen

According to Marshall Mix design, there are three criteria for compaction depending on either the surface is prepared for light, medium or heavy traffic. We have designed pavement for heavy traffic so 75 blows on each side of specimen are applied to achieve compaction. The loose mix obtained from heating aggregate with bitumen is transferred to mold having base plate. A filter paper was placed both above and below the specimen. After achieving 75 blows on one side, specimen was inverted, and 75 blows were applied in other side of specimen. Marshall Compactor was used to achieve compaction .

**Fig 3.7 (Marshall Compactor)**

**Fig 3.8 (Marshall Samples)**

### 3.2.5 Determination of OBC

The volumetric properties of specimen are calculated by determining Gmb and Gmm and values after placing the specimen at room temperature. The tests for Gmb and Gmm are performed in accordance with ASTM D2726 [34] AND ASTM D2041 [35] respectively. For determination of Gmb firstly weight in air of specimen is determined, after which its weight in water and SSD weight are determined.

**Fig 3.9 (Determining Gmb)**

After the determination of Gmb, the specimen is transferred for 30-40 minutes at 60 °C then tested for Marshall Stability and flow using Marshall Equipment. After placing the sample in Marshall Apparatus, it is loaded at constant deformation rate of 5mm/minute until the specimen fails. The maximum load that the specimen takes is its **Stability** value and the strain that occurs at maximum load is recorded as **Flow number** in mm. According to Marshal Mix design Criteria MS-2, for a surface designed for heavy traffic load should have a Stability value not less than 8.006 ,KN and Flow should be between 2 to 3.5 mm.

**Fig 3.10 (Marshall Stability and Flow Apparatus)**

For Gmm calculation weight the loose mix, first determine the calibration weight of apparatus, after that transfer the mix to apparatus and apply vacuum. After the removal of air entrapped in mix, weigh again the apparatus containing mix.

**Fig 3.11 (Gmm Determination)**

### 3.2.6 Asphalt Mix Preparation

There are four types of mixtures one is controlled asphalt mixture, the second one containing Sasobit, the third one with some percentage of glass and plastic without Sasobit and the last one with different percentage of glass and plastic with 3% Sasobit. The mixtures were prepared after the determination of OBC using Marshal Mix design procedure.

The procedure of preparing the asphalt mixes is described in the following headin

### 3.2.6.1 Preparation of Bituminous mixes for Marshall Mix Design

The bituminous mixes were prepared to determine OBC according to ASTM D 6926 [35], which is the standard method for the manufacture of bituminous mixes utilising Marshall Apparatus. The OBC for each sort of gradation had to be calculated by updating the Marshall Mix design technique because there were three different gradations in terms of % of glass and plastic. The Marshall Mix design criterion was met in terms of stability and flow, and the OBCs were calculated using the criteria proposed by Marshall Mix Design. The Marshall Mix Design process is as follows:

### 3.2.6.2 Preparation of Bitumen and Aggregates for Mix Design

The aggregates were dried after sieve analysis. For the preparation of compacted 4 inch' diameter sample by Marshall Mix Design method, the total mass of the sample should be 1200 gm. The total mass is sum of aggregate and bitumen.

$$M_T=M_A + M_B \qquad (3.1)$$

$$M_B=(X/100)(M_T) \qquad (3.2)$$

Where,

$M_T$ = Mass of the Total mix

$M_A$ = Mass of the Aggregate

$M_B$ = Mass of the Bitumen

X = Percentage of Bitumen

### 3.2.6.3 Mixing of Aggregates and Asphalt Cement

It is recommended by ASTM D6926 to use a mechanical mixer for proper mixing of bitumen and aggregates. The dried aggregates and heated bitumen were added in mechanical mixing machine right after removing from the oven. The range of mixing temperature was between 160℃ to 165℃ which is according to NHA Specifications.

### 3.2.6.4 Compaction of Specimens

Marshall Compactor was used to compact each mix after it had been mixed. A spatula was used to add the mix to a mould assembly that included a mould cylinder, extension collar, and base plate. The cylinder has a 3-inch height and a 4-inch internal diameter. However, before adding, the mould was cleaned and a piece of filter paper equal to the diameter of the mould was placed at the bottom. Another filter paper sheet was placed over the entire mix once it had been introduced to the mould and spread evenly.

The heavily trafficked pavement or design criteria of ESALs 30 million for dense graded wearing courses were chosen as the adopted designed criterion. As a result, 75 blows were applied on each side.

### 3.2.6.5 Extraction of Specimens from Mold

The mould assembly was removed from the Marshal Compactor and the samples were removed from the mould after few minutes through a hydraulic jack. The removed samples were kept at room temperature.

### 3.2.6.6 Number of Specimens for Each Job Mix Formula

Three samples were prepared for each combination of asphalt and aggregates. For each percentage of glass, plastic and bitumen, three samples were prepared so the total number of samples prepared were 45. It can be seen in the following test matrix:

| Plastic (%) | Glass (%) | Bitumen | No. Of Samples |
| --- | --- | --- | --- |
| **0** | 0 | 3 | 3 |
| | | 3.5 | 3 |
| | | 4 | 3 |
| | | 4.5 | 3 |
| | | 5 | 3 |
| **0.5** | 2 | 3 | 3 |
| | | 3.5 | 3 |
| | | 4 | 3 |
| | | 4.5 | 3 |
| | | 5 | 3 |
| **1** | 4 | 3 | 3 |
| | | 3.5 | 3 |
| | | 4 | 3 |
| | | 4.5 | 3 |
| | | 5 | 3 |
| **Total Number of Tests** | | 45 | |

**Table 3.4 (Test Matrix for Marshal Mix Design)**

### 3.2.7 DETERMINATION OF VOLUMETRIC STABILITY AND FLOW

After determining their theoretical maximum specific gravity (Gmm) and bulk specific gravity (Gmb), the volumetric parameters of the mix, such as Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Air Voids (Va), and unit weight of the mix, were estimated using their equations. After the determination of Bulk Specific Gravity, the samples were put in water bath for 1 hour at 60℃ before testing for stability and flow using Marshall Test machine.

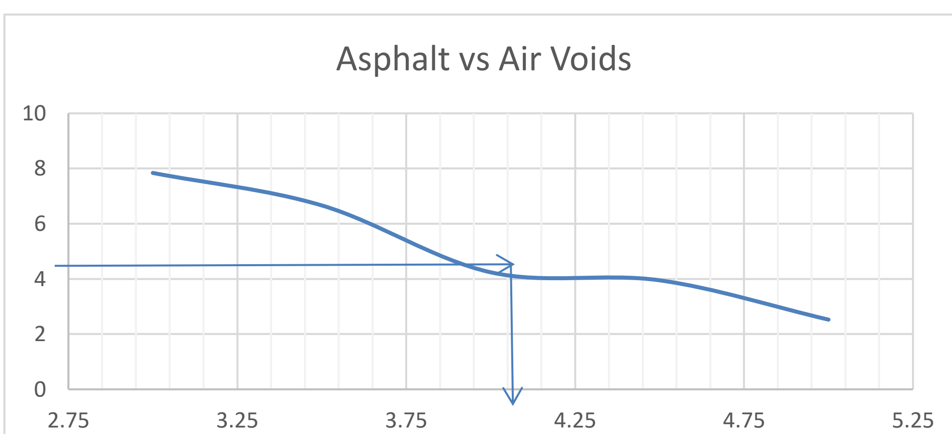
While testing on Marshal Test equipment, the load was applied at deformation rate of 5 mm/minute on the samples. The value of Marshal stability and flow was noted. The Marshal stability value was taken as the total maximum load in KN, and the deformation that occurred at maximum load was taken as the flow number value in mm. For a heavily trafficked wearing course, the specimen stability should not be less than 8.006 KN, and the flow number should be between 2 and 3.5, according to Marshall Mix Design Guidelines.

### 3.2.7.1 Volumetric Properties of Mix Having 0% Glass and Plastic

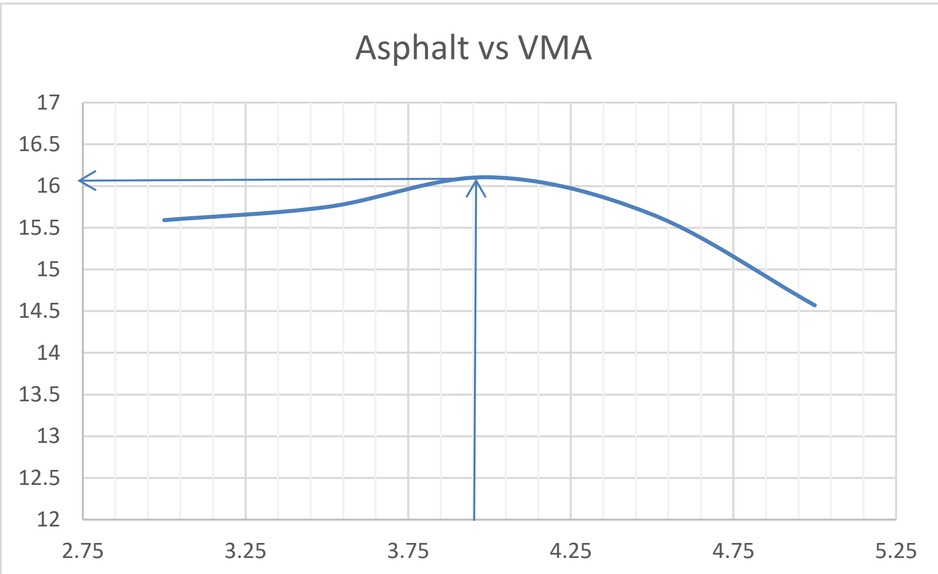
The volumetric properties, stability and flow correspond to the mix having 0% of Glass and Plastic are as shown below:

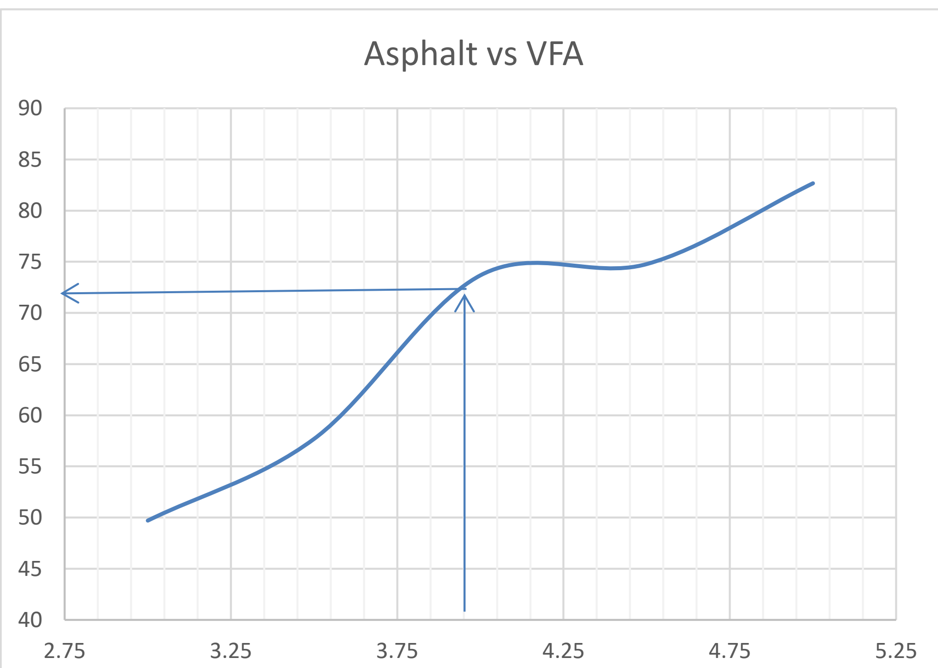
**Table 3.5 (Volumetric Properties of Mix Having 0% Glass and Plastic)**

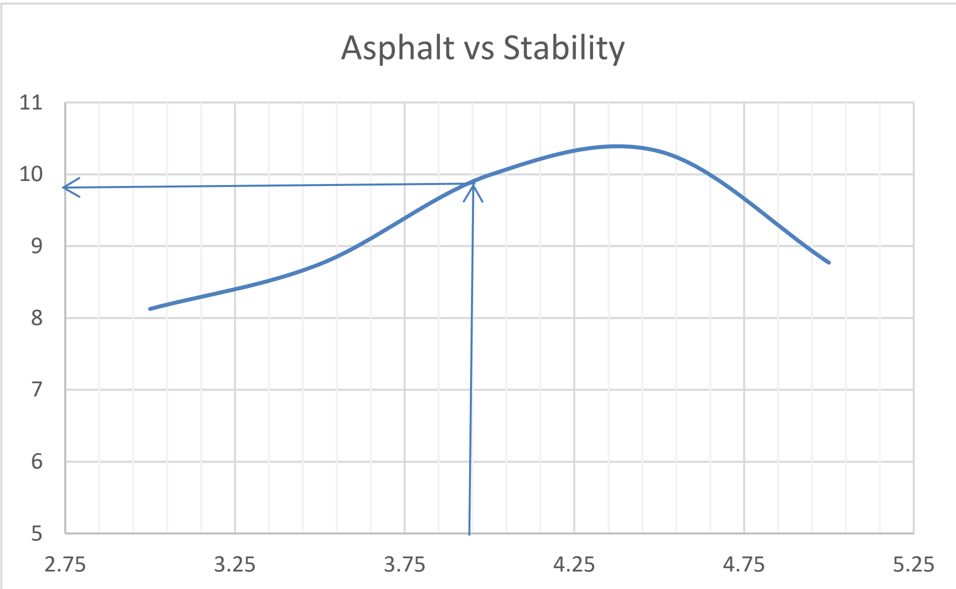
| Bitumen | Air Voids | Flow | Stability | VMA% | VFA% |
|---|---|---|---|---|---|
| **3** | 7.841412374 | 3.08 | 8.126 | 15.59065 | 49.70438 |
| **3.5** | 6.66305828 | 3.16 | 8.75 | 15.74858 | 57.69105 |
| **4** | 4.239831239 | 3.29 | 9.99 | 16.10482 | 73.67352 |
| **4.5** | 3.950162305 | 3.418 | 10.32 | 15.65866 | 74.77331 |
| **5** | 2.525198255 | 3.513 | 8.77 | 14.56918 | 82.66753 |



For the determination of OBC of mix having 0% Glass and Plastic, the graphs between asphalt contents and volumetric properties, stability and flow were plotted.





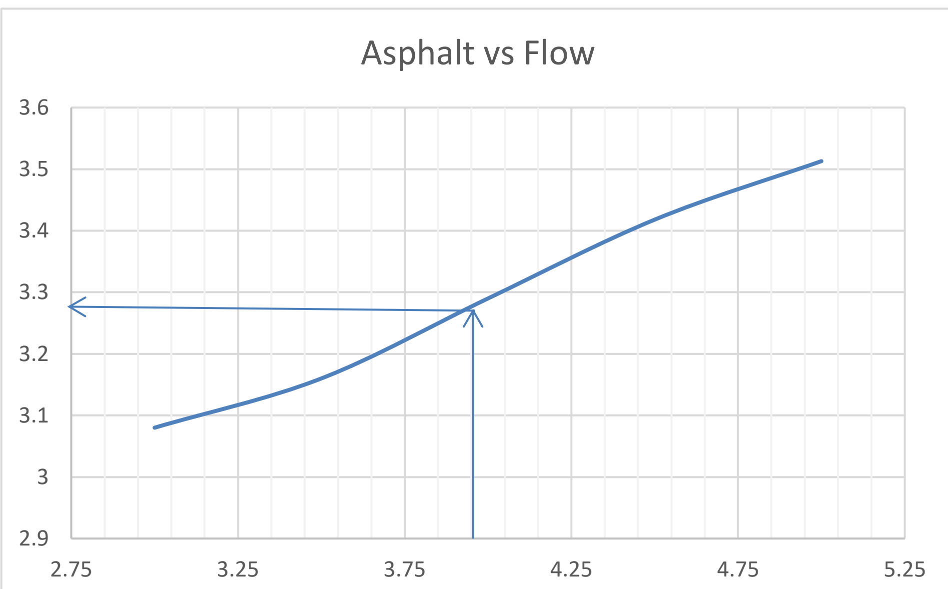




Figure 3.12: Graphs of Volumetric properties of mix having 0% Glass and Plastic

**Table 3.6 Summary of Properties of Mix Having 0% Glass and Plastic)**

| Asphalt Content (%) | AIR VOIDS | Flow(mm) | Stability (KN) | VMA% | VFA% | Gmb | Gmm |
|---|---|---|---|---|---|---|---|
| **3** | 8.04243295 | 3.07 | 8.13 | 15.90731 | 49.44189 | 2.245361 | 2.441736 |
| **3.5** | 5.775168961 | 3.18 | 8.69 | 15.35567 | 62.39065 | 2.271801 | 2.411042 |
| **4** | 4.167451102 | 3.27 | 9.47 | 16.10482 | 74.12295 | 2.246653 | 2.344353 |
| **4.5** | 2.387423437 | 3.46 | 10.3 | 15.65866 | 84.75334 | 2.324588 | 2.381443 |
| **5** | 1.979030479 | 3.55 | 8.8 | 14.15122 | 86.01513 | 2.340508 | 2.387763 |

The asphalt contents at 4% air voids i.e. OBC of mix with 0% Glass and Plastic came out to be 4.1%. It is clear from the table below that all of the volumetric properties, stability and flow are meeting the criteria.

| PROPERTY | RANGE | OBTAINED | REMARKS |
|---|---|---|---|
| **VMA** | MIN 16 | 16.2 | OK |
| **VFA** | 68-75 | 73 | OK |
| **STABILITY** | MIN 8KN | 9.8KN | OK |
| **FLOW** | 2-3.5mm | 3.38mm | OK |

### 3.2.7.2 Volumetric properties of mix having 0.5% Plastic and 2% Glass

The flow, stability, and volumetric properties of controlled mix are shown in the table below.

The graphs between Asphalt content and different volumetric properties were plotted to find out OBC

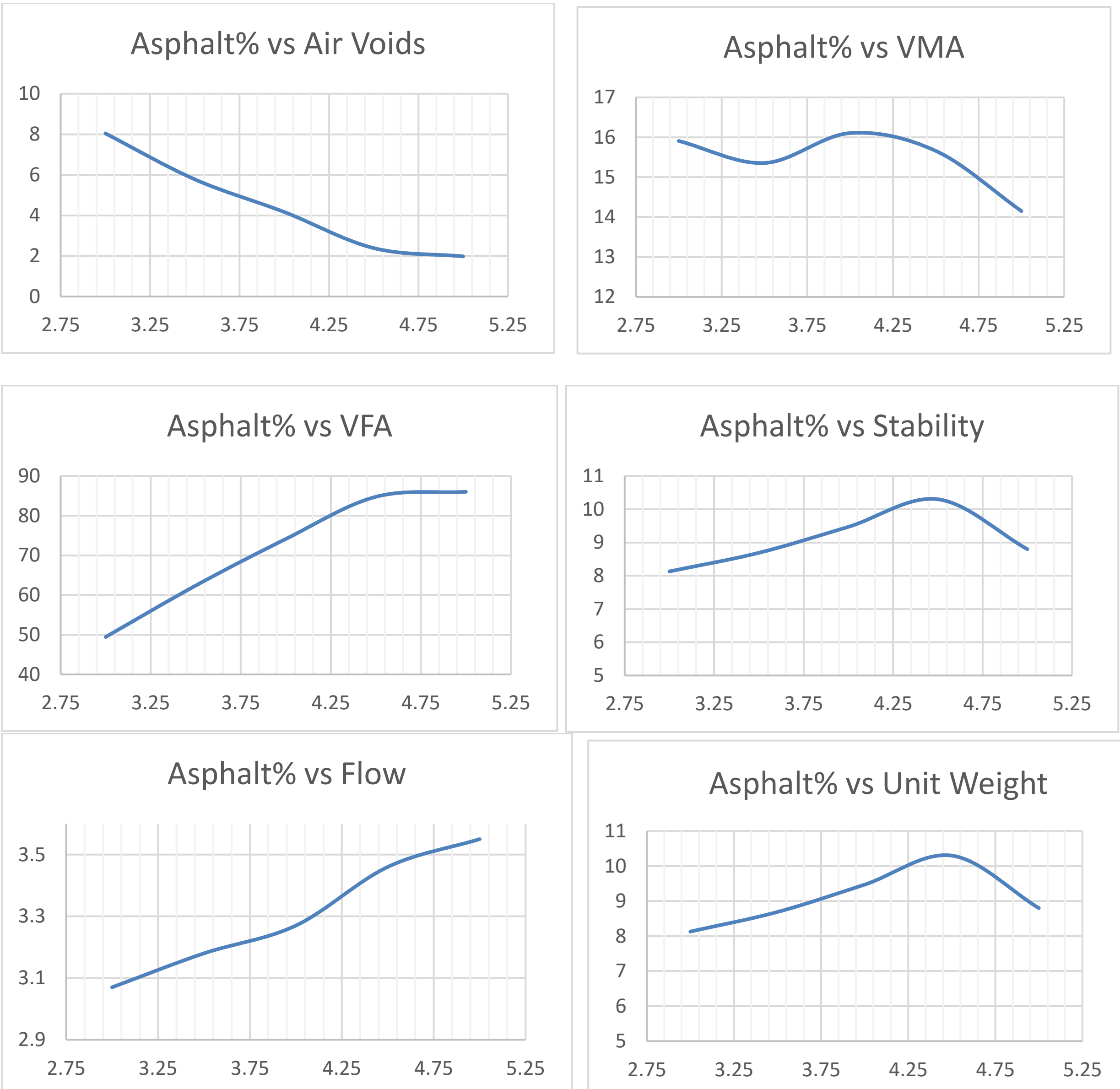



Figure 3.13: Graphs of Volumetric properties of mix having 2% Glass and 0.5%Plastic

The bitumen value against 4% air voids is considered for OBC. The OBC for this particular blend of glass and plastic is 4.05%. All other properties are verified against the standard for the particular bitumen content initially selected. If all the properties follow the standard specified by MS-2 the selected bitumen content value is assumed to be correct else OBC value needs to be adjusted. All the properties were within their specified range.

**Table 3.7 (Summary of Properties of Mix Having 2% Glass and 0.5% Plastic)**

| Parameters | Value Measured | Limits | Remarks |
|---|---|---|---|
| OBC (%) | 4.05 | - | - |
| VMA (%) | 16.4 | ≥ 13 | Pass |
| VFA (%) | 74 | 65-75 | Pass |
| Stability (KN) | 9.7 | ≥ 8.006 | Pass |
| Flow (mm) | 3.34 | 2-3.5 | Pass |

### 3.2.7.3 Volumetric properties of mix having 1% Plastic and 4% Glass

The flow, stability, and volumetric properties of controlled mix are shown in the table below.

**Table 3.8 (Volumetric Properties of Mix Having 4% Glass and 1% Plastic)**

| percentage | AIR VOIDS | Flow | Stability | VMA% | VFA% | Gmb | Gmm |
|---|---|---|---|---|---|---|---|
| **3** | 8.861693862 | 3.05 | 8.102 | 16.6565 | 46.79738 | 2.225357 | 2.441737 |
| **3.5** | 5.219928953 | 3.23 | 8.73 | 14.85689 | 64.86526 | 2.285188 | 2.411043 |
| **4** | 4.050543848 | 3.32 | 9.37 | 16.10482 | 74.84886 | 2.258189 | 2.353519 |
| **4.5** | 2.387423437 | 3.44 | 10.3 | 15.65866 | 84.75334 | 2.324588 | 2.381443 |
| **5** | 1.979030479 | 3.53 | 8.8 | 14.15122 | 86.01513 | 2.340509 | 2.387763 |

The graphs between Asphalt content and different volumetric properties were plotted to find out OBC

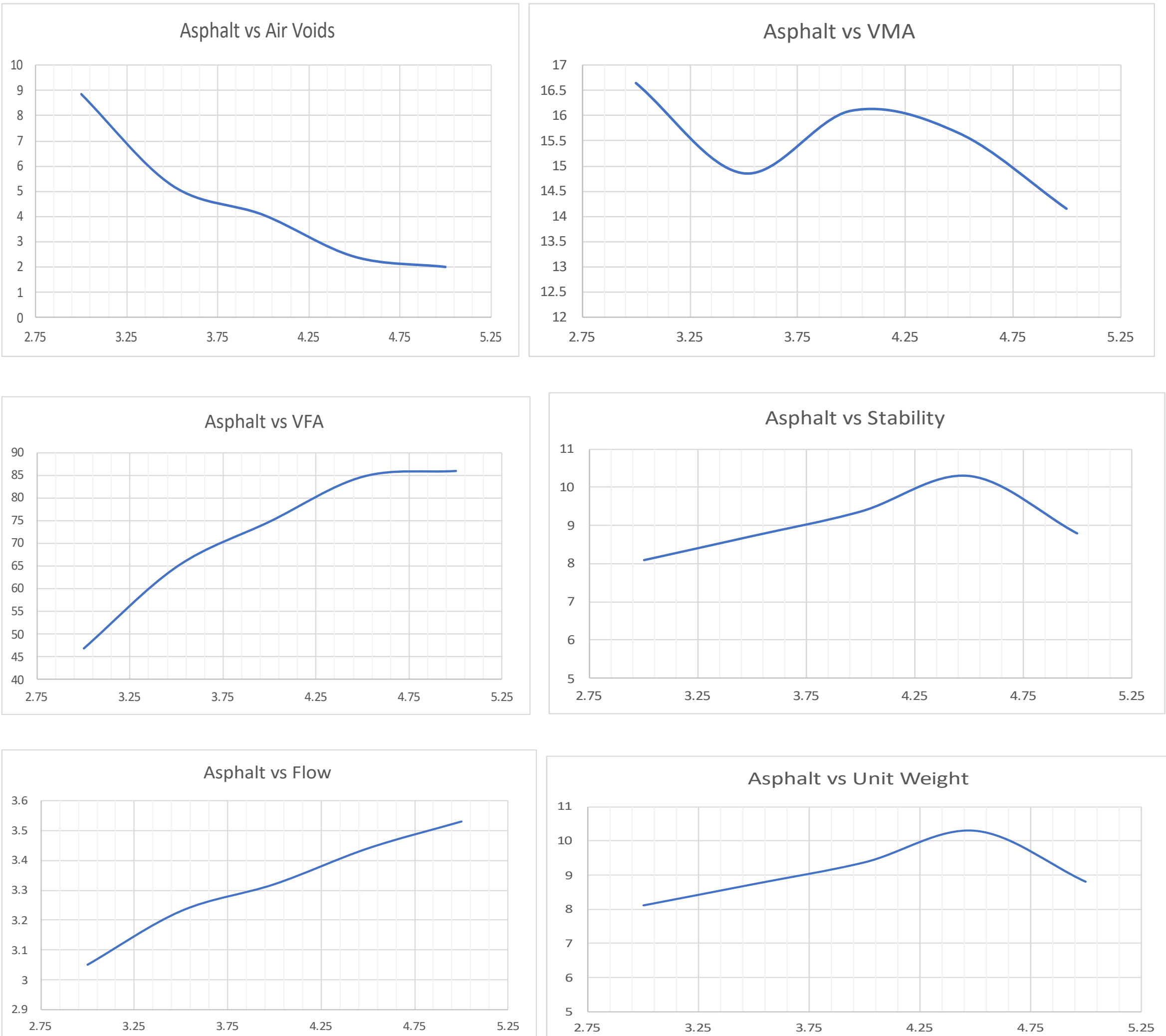



Figure 3.14: Graphs of Volumetric properties of mix having 4% Glass and 1% Plastic

The bitumen value against 4% air voids is considered for OBC. The OBC for this particular blend of glass and plastic is 4.02%. All other properties are verified against the standard for the particular bitumen content initially selected. If all the properties follow the standard specified by MS-2 the selected bitumen content value is assumed to be correct else OBC value needs to be adjusted. All the properties were within their specified range.

**Table 3.9 (Summary of Properties of Mix Having 4% Glass and 1% Plastic)**

| Parameters | Value Measured | Limits | Remarks |
|---|---|---|---|
| OBC (%) | 4.02 | - | - |
| VMA (%) | 15.8 | ≥ 13 | Pass |
| VFA (%) | 70 | 65-75 | Pass |
| Stability (KN) | 9.72 | ≥ 8.006 | Pass |
| Flow (mm) | 3.36 | 2-3.5 | Pass |

#### 3.2.7.3 Preparation of Sample for Performance Tests

After the OBCs of virgin asphalt concrete and asphalt concrete containing varying percentages of waste materials was obtained. Performance evaluation was done. In this research study two parameters of asphalt concrete were tested which are:

- Resistance against rutting.
- Moisture susceptibility

For those two tests were incorporated: were

- Hamburg Wheel Tracker Test (ASTM 324) [36]
- Indirect Tensile Strength Test (ASTM D 6931-07) [37]

For Indirect Tensile Strength test, 36 samples were prepared which included the controlled samples (no waste material) and samples containing varying percentages of waste material, following the same procedure of Marshall sample preparation. For ITS both the conditioned and unconditioned testing was carried out. The acceptable value of TSR employed was 80%.


Figure 3.15 Performing ITS Test

For wheel tracker test 18 samples of 6kg were prepared which included the controlled and the samples containing waste material, these were compacted using the gyratory compactor. Diamond Saw Cutter was used to cut the samples according to the dimensions for wheel tracking device. A fixed number of passes 10,000 were selected as per standard and the mode of testing was dry at room temperature i.e 25 C. According to the TEXAS DEPARTMENT OF TRANSPORTATION, the rut depth of any AC sample should not exceed 12mm.

Figure 3.16 Cutting samples with Diamond Cutter

**Figure 3.10 TEST MATRIX FOR PERFORMANCE EVALUATION TESTS:**

| Sr. no | Plastic (%) | Glass (%) | Sasobit (%) | Indirect Tensile Strength | | Hamburg Wheel Tracker |
|---|---|---|---|---|---|---|
| | | | | Conditioned | Unconditioned | |
| 1 | 0 | 0 | 0 | 3 | 3 | 3 |
| | | | 3 | 3 | 3 | 3 |
| 2 | 0.5 | 4 | 0 | 3 | 3 | 3 |
| | | | 3 | 3 | 3 | 3 |
| 3 | 1 | 4 | 0 | 3 | 3 | 3 |
| | | | 3 | 3 | 3 | 3 |

# CHAPTER 4

# RESULTS AND ANALYSIS

## 4.1 Introduction

This study is based on incorporating glass and plastic as aggregate replacement in HMA (Hot Mix Asphalt) mixture and finds their effect on fatigue life and rutting. Glass and Plastic utilized were acquired from Multan,Pakistan. Samples for Performance testing are prepared after determining OBC at different Percentages of Glass and Plastic. The gradation used was NHA class B.

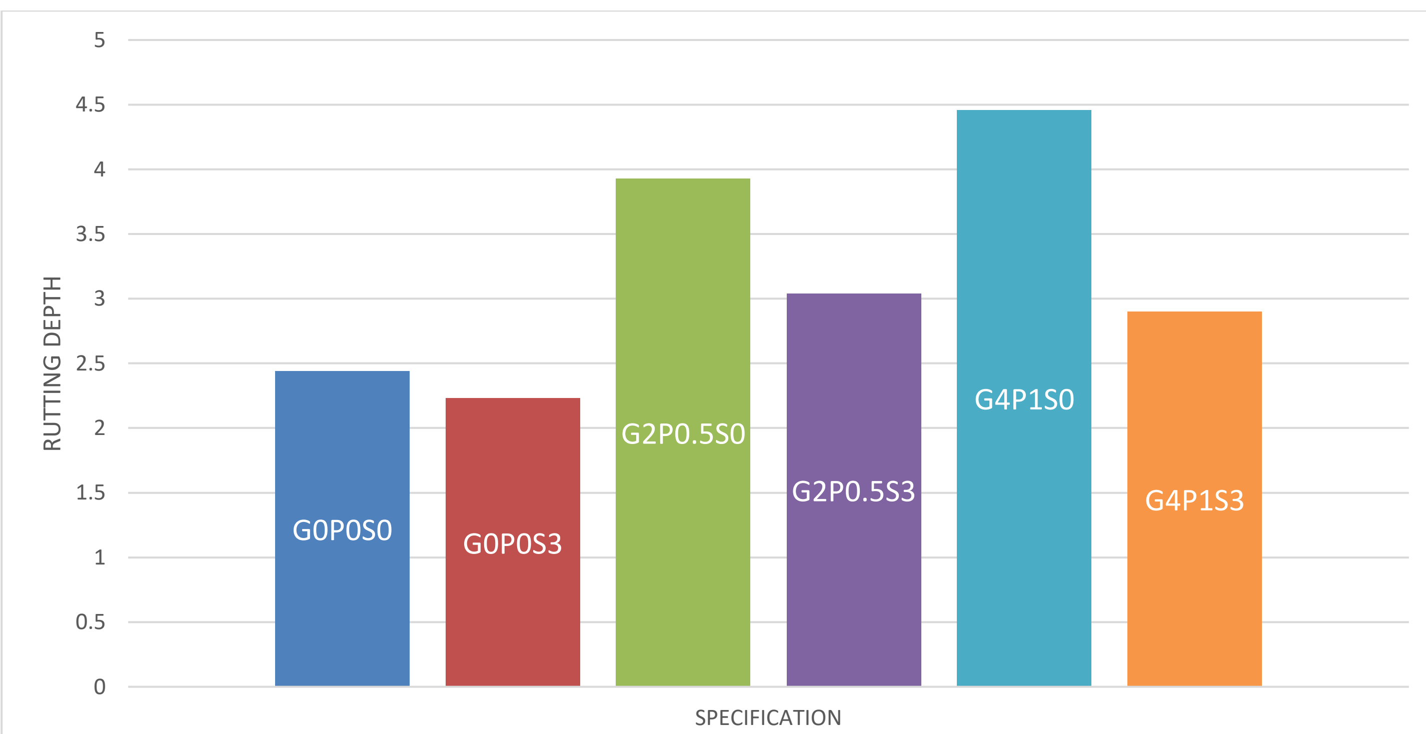
In this chapter, results are shown and analyzed for tests i.e. Wheel Tracking (Rutting) and ITS test. The details of these tests are already discussed in chapter 3. Glass and Plastic contents were taken to be 2%, 4% and 0.5% and 1% respectively. The results of these tests were compared with those of control samples.

### 4.1.1 Wheel Tracking (Rutting) Test

Wheel tracker test was conducted on specimens for checking their resistance against rutting. The mode of testing was chosen to be dry. 18 samples were tested, which contained the controlled samples and samples containing various proportions of waste material. Each sample was cut with the diamond cutter so that it matched the dimensions of assembly placed in the machine. The sample was cut in two equal parts, and these were placed inside the assembly, after the test was completed an average of both the specimens' reading was taken to ensure the omission of any error. The number of passes were fixed at 10,000 under dry conditions at 25C. The failure criteria was rut depth values increasing a cutoff of 12mm. It is evident from the results that the WMA samples exhibited a greater resistance against deformation against rutting.

**Table 4.1 (HWT Results)**

| Sr. no. | Plastic (%) | Glass (%) | Sasobit (%) | AVG. Rutting Depth (mm) | Remarks |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 2.44 | Ok |
| | | | 3 | 2.23 | Ok |
| 2 | 0.5 | 2 | 0 | 3.93 | Ok |
| | | | 3 | 3.04 | Ok |
| 3 | 1 | 4 | 0 | 4.46 | Ok |
| | | | 3 | 2.90 | Ok |



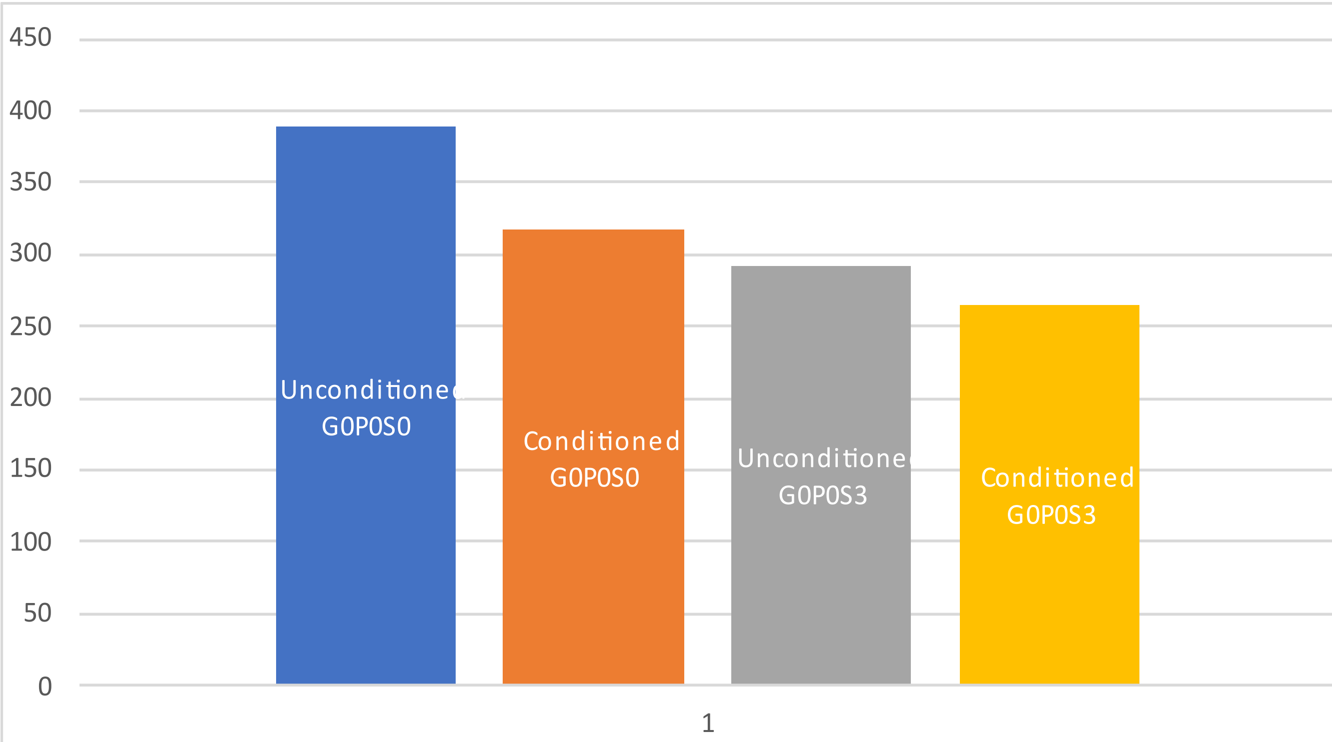
### 4.1.2 MOISTURE DAMAGE (ITS TEST RESULTS)

After completing the mix design, moisture susceptibility test was performed on the asphalt concrete samples according to ASTM D 6931-07. The conditioning of the samples was done by ALDOT 361. A total of 36 samples at 4% air voids were prepared and tested for Moisture Susceptibility Test. 18 samples were tested unconditioned and 18 samples were tested after conditioning. The conditioned and unconditioned strength values are shown in Table 4.2. The results show that the samples with sasobit performs better than virgin samples.

Tables 4.2 summarize the moisture sensitivity results and Figures 4.9 to 4.18 shows trends of ITS test results along with TSR. According to superpave criteria, TSR should be minimum 80%. The TSRs for all the samples calculated were all above 80 percent.

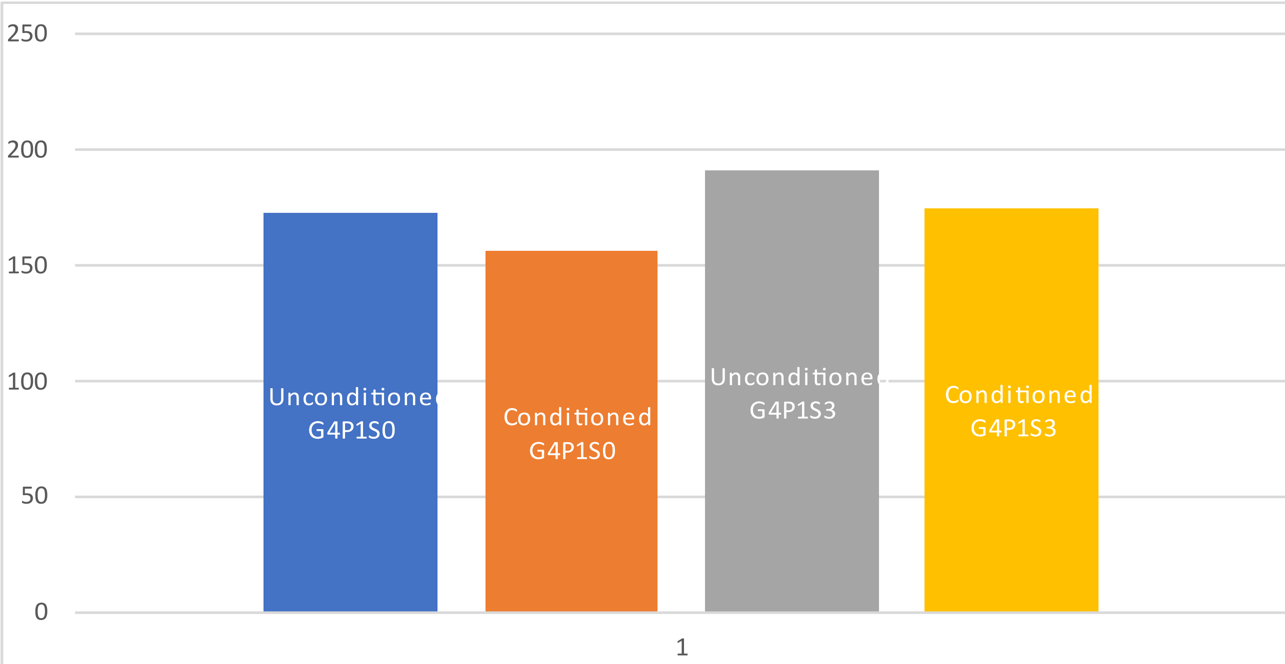
**Table 4.2 ITS Test Results**

| Specification | Codes | UnConditioned Strength, S1 (KN) | Conditioned Strength, S2 (KN) | TSR=S2/S1 (%) |
|---|---|---|---|---|
| 0% Glass, 0% Plastic,0% SASOBIT | **G0P0S0** | 3.731 | 3.448 | 92.709 |
| 0% Glass, 0% Plastic,3% SASOBIT | **G0P0S3** | 3.881 | 3.684 | 93.335 |
| 2% Glass, 0.5% Plastic,0% SASOBIT | **G2P0.5S0** | 2.637 | 2.238 | 85.139 |
| 2% Glass, 0.5% Plastic,3% SASOBIT | **G2P0.5S3** | 2.917 | 2.352 | 89.12 |
| 4% Glass, 1% Plastic,0% SASOBIT | **G4P1S0** | 1.885 | 1.694 | 90.15 |
| 4% Glass, 1% Plastic,3% SASOBIT | **G4P1S3** | 2.077 | 1.901 | 91.81 |




With 0.5% plastic and 2% glass

With 1% plastic and 4% Glass




## 4.2 Summary

In this chapter, we have seen the results obtained from ITS and HWT test With glass and plastic it has been observed that samples of WMA are performing better then that of HMA.

## Chapter 5

# CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Summary

The main aim of this research study was to conduct the performance evaluation of WMA with Glass and Plastic as a replacement of aggregate, so as to develop an environmental friendly asphalt that has superior properties than a conventional asphalt pavement with glass and plastic.

This research work compares the performance of HMA and WMA with glass and plastic as a replacement of aggregate. The parameters which are studied in this research include:

- Resistance against rutting
- Moisture Susceptibility

The percentage of Sasobit was limited to 3% by weight of OBC. Rutting and moisture damage are one of the severe problems witnessed in flexible pavements. In order to study these parameters two performance-based tests were selected which are:

- Hamburg Wheel Tracker Test
- Indirect Tensile Strength Test

Hamburg Wheel Tracker is an equipment used to evaluate the rutting potential of the asphalt concrete samples whereas the Indirect Tensile Strength test evaluates the moisture susceptibility or moisture damage. The aggregate was sourced from PatharGarh, the gradation selected was NHA CLASS-B Mid Gradation. The bitumen was procured from PARCO and was of 60/70 penetration grade. Sasobit was imported from a SouthAfrican based company known as Sasol Wax. Marshal Mix design procedure was used to determine the OBC for virgin samples and then for different percentages of glass and plastic. After that samples were made for Hamburg Wheel Tracker Test and tested under 10,000 cyclic loading repetitions, dry condition and steel wheel was selected for testing purpose. After that Moisture Susceptibility was checked for both conditioned and unconditioned samples. The key findings of the performance-based tests and their conclusion is explained in this section.

## 5.2 Conclusions

The conclusions drawn after analysis of tests conducted, as described in previous chapter are listed as under:

- Using Plastic and Glass and employing the WMA technology will not only reduce the indirect cost, improve performance, pavement life, but also help in conserving the natural resources, moreover, using waste materials like glass and plastic will make environment more sustainable and greener.
- The OBC of the AC samples decreased with an increase of waste material proportion.
- The TSR of samples made using WMA technology showed an increased resistance against moisture damage as compared to HMA samples.
- The TSR of the WMA samples increased by a percentage of 8-10%.
- The samples containing plastic=1% and glass=4% made with WMA technology showed a greater TSR values as compared to other samples containing waste materials.
- The rut depth of the samples made from WMA technology showed a greater resistance against rutting.
- The rut depth of samples made with WMA technology improved by 22-35%.
- The least rut depth of samples containing waste materials, had a composition of plastic=1% and glass=4% which were made using WMA technology.

- The use of sasobit made the mixtures more workable.
- The overall cost reduced by 10% which can be further reduced if a production plant of sasobit is made.

**5.3 Cost Analysis:**

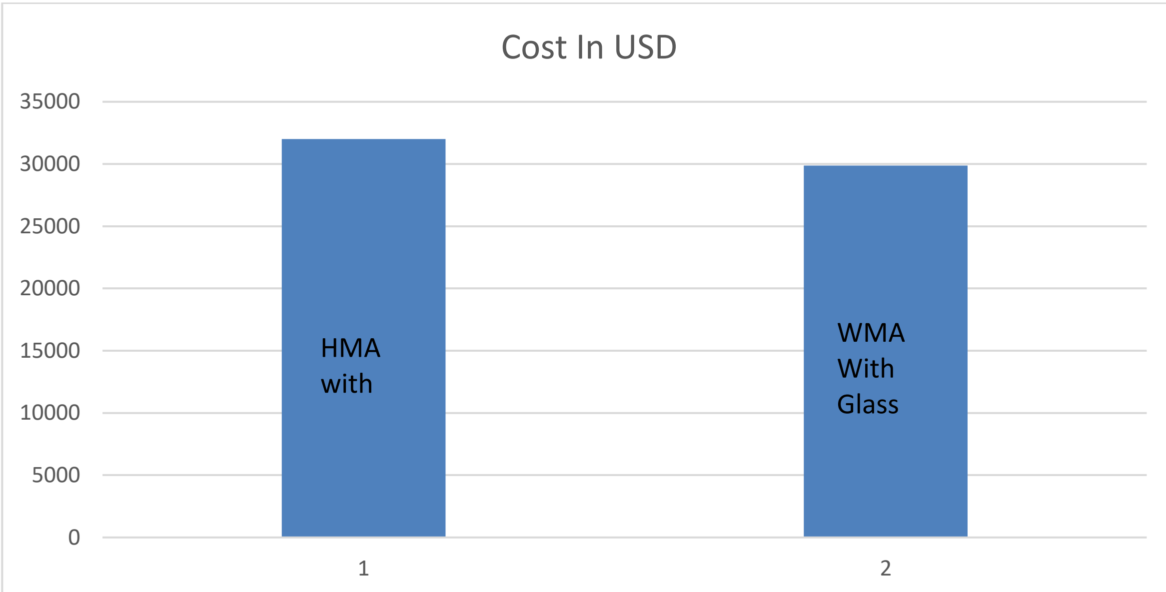
The high cost involved with the production of virgin HMA is attributed to the high material cost and high energy requirement for mix production. An enormous amount of energy is required to maintain the mixing temperature of AC at 160C. This results in the excessive use of fuel, and since the price of oil is on the ascend in the past 10 years. The production of AC is becoming extremely expensive.

Another aspect of this research study was to lower the overall cost of the AC; therefore, a switch was made from HMA to WMA. Vaitkus et al. concluded that Sasobit reduces fuel costs by 40% as compared to HMA. This reduction is associated with lower mixing and compaction temperature of WMA technologies. Cutting of the fuel costs substantially reduces the overall cost of the AC. Apart from that, the addition of plastic and glass reduces the OBC. As, bitumen is the most expensive constituent of the AC reducing the quantity of bitumen reduces the price considerably.

The cost analysis was done on the basis of NHA CSR 2014. The price of plastic and glass was set equal to the price of aggregate. The variables which were included in the calculations were:

- Fuel cost
- The change of OBC
- Cost of Sasobit (Market rate of Germany was used)

The density of AC samples of HMA and WMA with glass and plastic was 2370 kg/m3 and 2368 kg/m3 respectively. A 1km long section, ACWC of 4inches and a lane width of 3m was used in the calculations. It was found that using WMA can reduce the overall cost by 10%. This includes the price of sasobit taken from the German market. If the sasobit was available in Pakistan, the cost could have been further reduced by a staggering 20-25% due to raw material being cheaper in Pakistan. The difference between the construction cost of virgin HMA and WMA with glass and plastic per kilometer per lane of a road section is presented in Figure.




**5.4 Environmental Impacts**

There are several adverse impacts on the environment due to the production of HMA. Moreover, the impacts of pollution caused due to waste materials mainly plastic, and glass are immense. In this research study one of the many goals was to minimize the environmental damages caused by waste material and the production of HMA. Catering the two problems simultaneously while still not degrading the pavement characteristics. This is why WMA technology was adopted in the study.

The detrimental impacts on the environment involved with the production of virgin HMA are attributed to high energy requirement for mix production. To produce a conventional asphalt concrete mix, the temperature needs to be maintained at 160C to have an appropriate mixing of the constituents. The heating of bitumen and natural aggregates at elevated temperatures of around 160C results in the emission of harmful gasses.

Because of the high temperature used in mix production, bitumen emits fumes and these fumes contain carcinogenic Polycyclic Aromatic Hydrocarbon (PAH) components. Since, the use of sasobit reduces the mixing temperature required by 30-35%. This results in the reduction of the PAH compounds emission by up to 50%. Reducing the overall environmental impacts and improving the working conditions of the workers simultaneously. D'Angelo et al. revealed in their research study that the use of WMA reduces CO2, NOx, SOx, and other volatile organic compounds up to 15-70%. Incorporating the waste materials in the research study was solely done to lessen the environmental hazards caused by the waste materials. Plastic causes enormous environmental damage, in Pakistan alone produced an estimated 3.9 million tons of plastic waste in 2020, Out of which, less than 10 percent is being recycled. The remaining proportion which is not recycled degrades the environment. Another waste material glass which is also harmful to the overall environment was utilized in this research study. Glass industry reported recycling around 27 million metric tons worldwide (2018). This is around 21% of the total Glass production. Glass composes 6% of Total Solid Waste being produced in Pakistan. The impacts of unrecycled waste are clear, employing these in road construction would definitely help preserve the environment.

It is clear that the properties of HMA degrade when glass and plastic are added as a replacement of aggregate, therefore WMA technology should be adopted to make up for the loss in AC properties caused by the addition of waste material, since it elevates the properties and performance. Thereby making the pavement somehow comparable to a HMA pavement with no waste materials added and simultaneously improving the environmental conditions.

### 5.5 Recommendations

Based on the results of the study the recommendations are as follow:

- WMA is a new technology and therefore several aspects about it are yet to be evaluated. In order for it to be implemented several parameters need to be studied. In this research study two performance tests were adopted; for further understanding about the properties of WMA other performance tests like creep test, fatigue analysis, dynamic modulus should be carried out.
- The percentages of glass and plastic can be changed to see how the performance is affected.
- Using a higher percentage of sasobit(greater than 3%) to examine the changes in performance or durability.
- Different type of plastic other than PET bottles and glass can be used in the research
- It is recommended to construct a trail section to verify the blend's performance in temperature and traffic conditions of Pakistan
- Research can be done on the self healing properties of WMA with glass and plastic, porous asphalt pavement etc

Based on the results of this study, it is recommended with confidence that WMA along with Plastic and Glass can used in the future. It fulfills all the desired volumetric and performance criteria. Since it performs better than the conventional HMA, it has the potential to save country's resources and bring sustainability in Transportation industry of Pakistan.

## REFERENCES


1- Abendeh, Raed. (2017). Effect of Waste Glass on Properties of Asphalt Concrete Mixtures. Jordan Journal of Civil Engineering.

2- Hurley, G. C., & Prowell, B. D. (2005). Evaluation of Sasobit for use in warm mix asphalt. NCAT report, 5(06).

3- Tutu, K. and Tuffour, Y. (2016) Warm-Mix Asphalt and Pavement Sustainability: A Review. *Open Journal of Civil Engineering*

4- https://www.sciencedirect.com/topics/engineering/warm-mix-asphalt

5- Hurley, Graham & Prowell, Brian. (2005). Evaluation of Sasobit® for use in warm-mix asphalt. National Center for Asphalt Technology (NCAT), Auburn, NCAT Report.

6- https://www.weforum.org/agenda/2021/11/4-ways-pakistan-is-tackling-plastic-waste-and-pollution/

7- https://tradingeconomics.com/pakistan/road-density-km-of-road-per-sq-km-of-land-area-wb-data.html#:~:text=Road%20density%20(km%20of%20road%20per%20100%20sq.,compiled%20from%20officially%20recognized%20sources.

8- https://www.britannica.com/technology/soda-lime-glass

9- Salamatpoor, S., Salamatpoor, S. Evaluation of adding crushed glass to different combinations of cement-stabilized sand. *Geo-Engineering* **8,** 8 (2017)

10- Nan Su J.S Chen "Engineering properties of asphalt concrete made with recycled glass" (2001)

11- Arabani, Mahyar. (2011). Effect of glass cullet on the improvement of the dynamic behavior of asphalt concrete. Construction and Building Materials - CONSTR BUILD MATER. 25. 1181-1185. 10.1016/j.conbuildmat.2010.09.043.

12- Moreno-Navarro, Fernando & Pérez-Martínez, Miguel & Marin, Jesus & Sol-Sánchez, M. & Gámez, Ma. (2015). Mechanical Performance of Asphalt Mixes Incorporating Waste Glass. The Baltic Journal of Road and Bridge Engineering. 10. 8. 10.3846/bjrbe.2015.32.

13- Nur Mustakiza Zakaria "The Use of Mixed Waste Recycled Plastic and Glass as an Aggregate Replacement in Asphalt Mixtures" ResearchGate (January 2018).

14- https://theconversation.com/eight-million-tonnes-of-plastic-are-going-into-the-ocean-each-year-37521#:~:text=You%20might%20have%20heard%20the,of%20coastline%20(excluding%20Antarctica).

15- https://theconversation.com/eight-million-tonnes-of-plastic-are-going-into-the-ocean-each-year-

37521#:~:text=You%20might%20have%20heard%20the,of%20coastline%20(excluding%20Antarctica).

16-Modarres, Amir & Hamedi, Hamidreza. (2014). Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes. Materials & Design. 61. 8–15. 10.1016/j.matdes.2014.04.046.

17-Meftah, Mohamed & Mohd Jakarni, Fauzan & Muniandy, Ratnasamy & Salihudin, Hassim. (2021). A Brief Review: Application of Recycled Polyethylene Terephthalate in Asphalt Pavement Reinforcement. Sustainability. 13. 1303. 10.3390/su13031303.

18-Moghaddam, T. B., & Baaj, H. (2016). The use of rejuvenating agents in production of recycled hot mix asphalt: A systematic review. Construction and Building Materials, 114, 805- 816

19-Almeida-Costa, A., & Benta, A. (2016). Economic and environmental impact study of warm mix asphalt compared to hot mix asphalt. Journal of Cleaner Production, 112, 2308-2317.

20-McCormack, S. M., Sturgill, R. E., Howell, B., Van Dyke, C. W., & Kreis, D. (2014). Green Infrastructure.

21-Bražiūnas, J., Sivilevičius, H., & Virbickas, R. (2013). Dependences of SMA mixture and its bituminous binder properties on bitumen batching system, mixing time and temperature on asphalt mixing plant. Journal of Civil Engineering and Management, 19(6), 862-872.

22-Rossi, D., Filippi, S., Merusi, F., Giuliani, F., & Polacco, G. (2013). Internal structure of bitumen/polymer/wax ternary mixtures for warm mix asphalts. Journal of Applied Polymer Science, 129(6), 3341-3354

23-Jamshidi, A., Hamzah, M. O., & You, Z. (2013). Performance of warm mix asphalt containing Sasobit®: State-of-the-art. Construction and Building Materials, 38, 530-553.

24-Sengoz, Burak & Topal, Ali & Oner, Julide & Yilmaz, Mehmet & Dokandari, Peyman & Kök, Baha. (2016). Performance Evaluation of Warm Mix Asphalt Mixtures with Recycled Asphalt Pavement. Periodica Polytechnica Civil Engineering. 61. 10.3311/PPci.8498.

25-Raveesh J (2018) Experimental Study of WMA by Using Sasobit Additive

26-ASTM D4791-19. Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate. ASTM International, West Conshohocken, PA.

27-ASTM C127. (2007). Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate. ASTM International, West Conshohocken, PA.

28-DETERMINATION OF AGGREGATE IMPACT VALUE (AIV) BS 812-112

29-ASTM C535. (2007). Standard Test Method for Resistance to Degradation of Large-size Coarse

Aggregate by Abrasion and Impact in Los Angeles Machine. ASTM International, West Conshohocken, PA.

30- AASHTO T 49, 2007 Edition, 2007 - Standard Method of Test for Penetration of Bituminous Materials

31- AASHTO T 53, 2009 Edition, 2009 - Standard Method of Test for Softening Point of Bitumen (Ring-and-Ball Apparatus)

32- AASHTO T 51, 2009 Edition, 2009 - Standard Method of Test for Ductility of Asphalt Materials

33- ASTM D3143/D3143M-13 Standard Test Method For Flash Point Of Cutback Asphalt With Tag Open-Cup Apparatus

34- ASTM D2726. (2008). Standard Test Method for Bulk Specific Gravity and density of Non-Absorptive Compacted Bituminous Mixtures. ASTM International, West Conshohocken, PA.

35- ASTM D2041. (2000). Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures. ASTM International, West Conshohocken, PA.

36- AASHTO T 324, 2019 Edition, 2019 - Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures

37- ASTM D6931-07 Standard Test Method For Indirect Tensile (IDT) Strength Of Bituminous Mixtures