Analysis of Modified HMA Using Crushed Glass

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DEDICATIONS

We dedicate our Project work to our beloved parents, honorable teachers, mainly our Project Advisor, Lt Col Dr Jawed Iqbal, and our ALMA MATER, MCE.

Contents

Abstract

Utilization of resources at balanced scale is the key to sustainability. Their use at a rate greater than their replacement causes the resources to deplete and will be a challenge to meet the demand for industry. Therefore, one of the viable options is Recycling. It is essential in order to meet demand and help to decrease land pollution and waste management. Pakistan, a developing country is facing negative impacts due to poor waste management.

Amongst other material/resources, Glass is also potential material which can be recycled and utilized in the construction industry of Pakistan. Glass cannot be decomposed or incinerated. Thus, to achieve sustainability in this sector glass can be used as potential alternate to aggregate in asphalt in road construction. A project has been carried out at Military College of Engineering (NUST) to analyze the effect of crushed waste glass in HMA. The maximum size of glass was 4.75mm, in replacement of aggregate, sizing pan material to 4.75mm. Marshall Method was applied. 30 samples were prepared at laboratory out of which 12 were tested to obtain OBC which averaged to be 4.35%. Remaining 18 samples were tested after imparting varying percentage of crushed glass in the mix and resulted to 7.5% of the weight of aggregates. All the results were conforming to the international standards. This research positively recommends to use material such as plastic & iron filings in the mix for future studies.

Chapter-1

Introduction

1.1 Background

Due to an increasingly nurturing economy and an even more rapid intake of resources, vast amount of garbage is produced consequently every year (Wu, S. *et al*., 2003).

The enormous amount of garbage generated includes glass, furnace and steel slag, tire scrap, plastics and construction and industrial waste. All of these are now posing as a nuisance for disposal authorities and need to be handled in landfills or stockpiles. These alternatives are costly and prove to be hazardous for the environment. This issue of waste disposal has become a global issue in the past few years.

The only way that this issue can be dealt with progressively involves the representative authorities and concerned parties to make an organized and assured system that can counter this. An intelligent way in which the problems may be suppressed include the recycling of these waste materials to be used for the construction of highways and roads (Arnold G. *et al*., 2008).

Deployment of waste for the purpose of pavement construction will reap benefits in many aspects. Obviously, the quantity of waste that would have led to safe disposal problems would have been resolved but also this will reduce the costs of obtaining newer materials for pavements. In fact, previously cost was incurred in the disposing off of the material which will now be efficiently utilized in the courses of the pavement (Jony H. *et al*., 2011).

The top contender in the materials is crushed glass with its beneficial characteristics heavily outweighing the few cons. Crushed glass proves to be environment friendly and has excellent engineering properties that are similar to those of the natural aggregates. Plus, it can be easily acquired at a cheap cost (Wartman J. *et al*., 2004).

Apart from the points mentioned above, the importance of crushed glass as an aggregate in highway construction can be seen from the fact that it is an inorganic material with non –metallic properties. Due to these properties the fear of decomposition is finished. It has been recently used a lot in the paving of hot mix asphalt. It has also made its way into the road specifications in many places around the world. Experimentation is in the works for the usage of glass waste as fillers in hot mix asphalt but it is yet to be implemented (Jony H. *et al*., 2011).

Research and investigative studies have shown that glass makes up around **6%** of urban waste in **Pakistan** with Karachi contributing the most followed by Lahore and Faisalabad. Majority of the waste does not reach proper disposal sites such as landfills, recycling centers and incinerators. (Saadat, 2018).

Glasphalt is the term that is used to refer to the finely crushed glass waste that is mixed with hot mix asphalt. This use of glasphalt is increasing day by day as more people are becoming aware regarding it (Kandhal, P., 1992).

The popularity of the usage of glass will lead to many favorable significances which will include but not be limited to reduction in both the waste materials and land required to be used as landfills and the raw material perk also.

1.2 Problem Statement

Even though the properties of glass remain favorable to be used as a material in highway structures, no proper usage is being carried out in Pakistan at a noticeable level. The country’s waste of solid materials is approximately 77,000 tonnes per day. Amongst this a good 6% (which makes about 4620 tonnes) is contributed by glass waste.

Much thought has been put on this matter and conclusions have been reached regarding implementing the plans of incorporating glass waste in construction of pavements. Glass can be used as an aggregate in base and sub-base for roads as well as an aggregate in asphalt, tiles and architectural decorative concrete. All these will lead to the preservation of the natural resources as less demand for raw materials will arise when another will be used instead.

Keeping in mind the local conditions of the country, investigations have been carried out to analyze the effect of using crushed glass as a filler in the asphalt binder or as a course sand also. Experimentation and iterations will pave the path for calculation of the optimum percentage of crushed glass needed to produce glasphalt according to the local country.

1.3 Aims and Objectives

a. Aim

This study has been carried out for the sole aim of investigating the methods of using crushed glass sand as an aggregate and filler in the local environment of Pakistan.

b. Objectives

- Checking and testing the effect that varying crushed glass percentages have on the overall mechanical and chemical characteristics of the asphalt mix.
- Calculating and determining the right amount glass waste required to be used in the hot mix asphalt.
- Providing practical and purposeful solutions for waste glass usage in this field so it lessens the burden on disposal and the environment on the whole.

1.4 Importance of the Study

- Usage of crushed glass waste as filler and as coarse sand so that the overall strength and properties of the asphalt pavement are made better.
- Working towards the minimization of waste and the land that will be used landfills.
- Using recycled waste will ease the increasing burden on the depleting natural resources for raw materials.

1.5 Limitations of the Study

This study was carried out while keeping in mind some limitations and parameters to which we were bound to. Adherence to these was the only way to work extensively on this project. The limitations are as follows:

- Special care was taken that the crushed glass to be used was from bottles only. No glass from sources including glass tubes, mirrors, medical equipment or ordinary sheet glass was included in this study.
- Attention was paid to the fact that the gradation of the waste glass used matches the gradation of the aggregate which was 0 to 4.75 mm.

1.6 Methodology of the Study

In order to successfully reach towards the desired objectives and study aims, the methodology listed below was taken into consideration:

a. A literature review and a comprehensive revision of available materials that include scientific papers, books, studies, and science blogs related to the field of recycling for researching in this area of study.
b. Deep study on the criterion for asphalt mix design, its production keeping in mind the local as well as international standards as most importantly the type of technology involved in the process.
c. Proper execution of all laboratory tests to find out the optimum bitumen content (OBC) using Marshal Mix design tests for the binder courses.
d. Care needs to be taken that the collected glass waste is clean and crushed suitably according to the required gradation.
e. Making of different specimens consisting of varying percentages of the crushed glass.
f. Carrying out tests on the above-mentioned specimens to figure out the consequence of varying proportions of the crumpled glass on the characteristics of the mix by making a comparison with the traditionally used asphalt mix. Mechanical properties such as air voids, Marshall Stability and bulk density need to be accounted for.
g. Thorough analysis and talks on the results.
h. Obtaining conclusions and recommendations from the data.

1.7 Structure of Project Thesis

This thesis comprises of five chapters. An overview is given below briefly:

Chapter 1: Introduction

The first chapter as the name says contains an introduction that precedes the problem statement followed by the aims and objectives. Next come the limitations of the study, methodology of the research and the chapter is concluded with the thesis structure.

Chapter 2: Literature Review

In this section, a detailed literature review is written linked to the topic of HMA, waste glass and the new glasphalt.

Chapter 3: Methodology of Experimental Work

In this chapter, light is thrown on two topics, the first one is the assessment of the materials which are bitumen, aggregates and glass to be used after experimentation. The second is the conclusions and description of the experimentation done for this study.

Chapter 4: Results and Analysis

The results and conclusions of the successful results of the experiments are mentioned in this chapter. Tests were performed to find the asphalt binder course gradation curve, OBC, bitumen characteristics. On the whole, the best glass percentage needed to be determined.

Chapter 5: Conclusions and Recommendations

This chapter contains all the conclusions and recommendations of the study.

Chapter-2

Literature Review

2.1 Introduction

Basically, Asphalt is a mixture of following naturally occurring materials:

- coarse and fine (sand) aggregates
- filler
- bitumen.

To change the performance of the mixture other additives can also be utilized. Usage of waste or recycled materials as additives is preferred because it can help in waste management as well. (Huang, Y. *et al*, 2011).

Recycled or waste glass has been tried in HMA paving. Its usage as a filler in HMA has not been thoroughly experimented (Jony, H. *et al*, 2011). Such a mixture having waste glass in crushed form is also named 'glasphalt'. (Kandhal, P., 1992).

According to some research work glass makes up almost 6 percent of the solid waste produced in Pakistan. It is anticipated that incorporating that glass will reduce

- waste,
- land area used for landfill
- consumption of new raw materials.

Ensuring optimum mix design and optimum amount of waste glass the characteristics of the asphalt can be rendered better.

2.2 Asphalt Concrete Pavements

Following layers in roads make up the pavements

- Sub-grade
- Sub-base
- Base
- Surface

Asphalt concrete pavement made up of aggregate and asphalt binder is flexible as compared to cement pavement hence the name flexible pavement. Generally, by weight, aggregate is about 95 percent while binder makes up the remaining in HMA. By volume, it is about 10% asphalt binder, 85% aggregate and 5% air voids. The binder is the source of cementing without which the aggregate will have no cohesion. The purpose of incorporation of additives is to increase performance and workability.

(Transportation research board committee, 2011).

2.2.1 Flexible Pavement Layers

In them asphalt concrete is not laid on the soil directly but it is a properly designed structure, in which each layer has thickness according to the design.

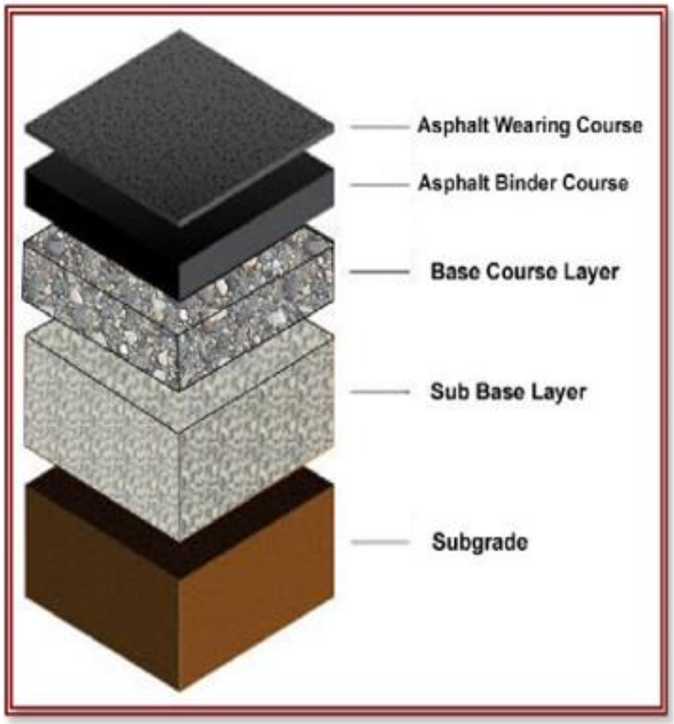


Figure 2.1: *Flexible Pavement Layers*

Subgrade:

Natural soil surface on which further layers are laid. Some soils are naturally in good condition only the organic materials are to be removed. Other materials which can transform the properties and make it more feasible and it can bear load easily (Blades, C. *et al*, 2004).

Sub-base layer:

It is under subgrade and base course. It supports structurally, makes drainage better and stops fine particles from intruding in. Also, in case of an open graded base a finer sub base can act as a filler between subgrade and base. (Blades, C. *et al*, 2004).

A thick base course can also be an alternative to sub base. (Transportation research board committee, 2011).

Base course layer:

A layer of designed thickness having crushed stone or slag, or other processed or untreated materials laid directly under the binder course. It also helps in effective load distribution. (Mathew, T., & Rao, K., 2007).

Asphalt binder course:

It is an HMA layer in-between the wearing course and either

- a granular base course
- stabilized base course
- an existing pavement
- or another HMA binder course (Ontario Provincial Standard Specification, 2002)

It also helps in distribution of load because distributed load is less effective than concentrated loads. It also helps in making of the surface layer (Garcia, J., & Hansen, k., 2001).

- **Binder course gradation:**

Table and Figure represent gradation limits for the dense graded asphalt binder course.

Table 2.1: *Gradation limits*

Sieve No	Sieve size mm	NHA Specifications Class A Passing Percentage by weight	
		Lower limit	Upper limit
3/4"	**19.00**	**90**	**100**
3/8	**9.00**	**56**	**70**
# 4	**4.75**	**35**	**50**
# 16	**1.18**	**5**	**12**
# 200	**0.075**	**2**	**8**
Pan	0.0	0	0.0

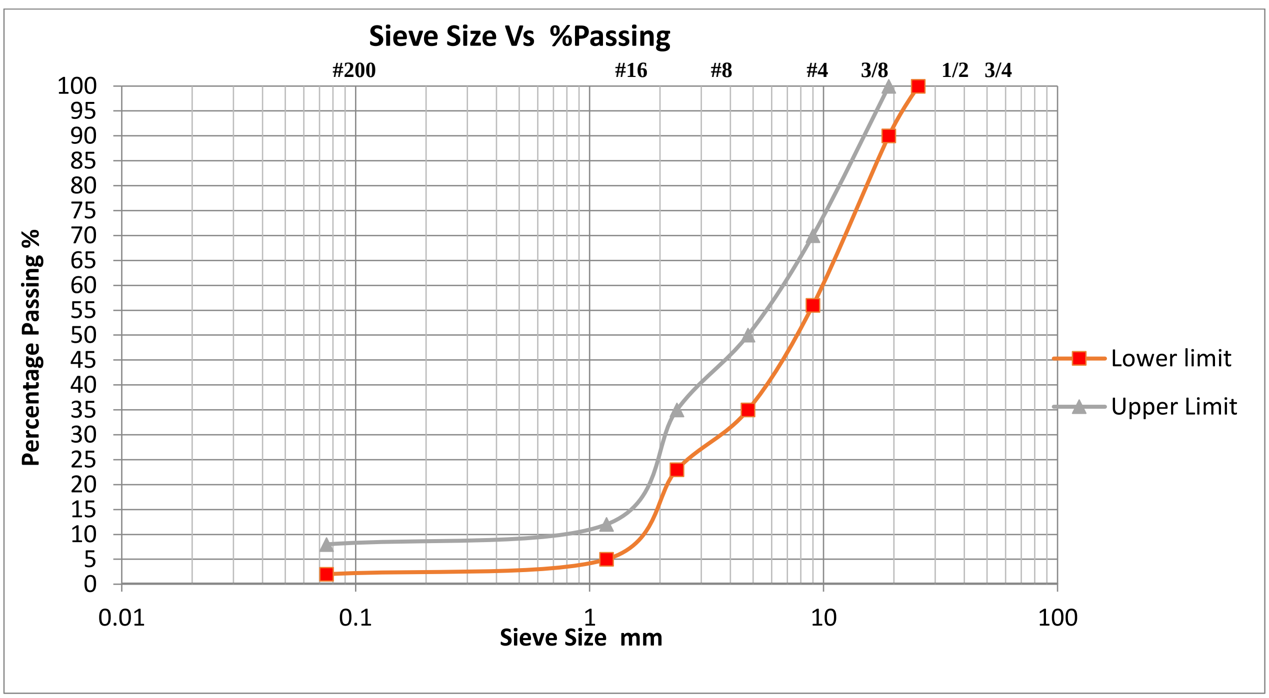


Figure 2.2: *Gradation limits*

Asphalt wearing course:

The top most layer of the pavement which faces the environmental and traffic exposure directly. (Transportation research board committee, 2011).

Besides stopping the intrusion of water in underlying layers it provides following characteristics

- Friction
- Evenness
- Noise regulation
- Pothole
- Shoving resistance
- Drainage. (Garcia, J., & Hansen, k., 2001).

2.3 Waste glass in asphalt concrete pavements

2.3.1 Waste Glass

With ratcheted up consumerism and economic activities waste generated has skyrocketed. Glass is an important component of municipal waste and makes up a large proportion of it. (Wu, S. *et al.,* 2003). Some important products are:

- Vehicles windscreens glass
- Bottles
- Glassware
- Vacuum tubes

It is a transparent material made by fusing a mixture of materials like

- Silica
- Soda ash

- $CaCO_3$

These materials are melted at high temperature and then cooled to solidify without crystallization (Gautam, S. *et al.*, 2012).

Some properties

- It is an inorganic and non-metallic material which cannot be effectively decomposed or incinerated (Wu, S. *et al.*, 2003).
- It is free of clay and other contaminants and has qualities of silica sand.
- It is inert and durable
- Because of low absorption it is a good binder in asphalt mix (Neilson, A., 2009).
- Usage of waste glass has become expedient because of increased awareness. (Gautam, S. *et al.*, 2012).
- It is energy efficient and eco-friendly (Wu, S. *et al.*, 2003).
- Mixed colour glass is generally not used as a raw material for glass and has to be disposed of. (Maupin, G., 1998).

Some applications of waste glass are

- tile
- decorative items
- abrasive
- filtration
- bead manufacturing
- brick manufacture
- concrete pavement,

- aggregate and road use (Missouri Recycling Association, 2011).

2.3.1.1 Waste glass in Pakistan

The pie graph shows the composition of waste produced in Pakistan (United Nations Environment Program, 2016).

Figure 2.3: Municipal solid waste composition in Pakistan

2.3.2 Mixture of Asphalt with Glass

Some advantages of the usage of waste in construction are

- reducing the amount of waste materials to be disposed
- provide construction materials with substantial savings over new materials.
- provide value to what was once a costly disposal problem (Jony H. *et al.*, 2011).

Asphalt with glass cullet is commonly referred to as '**Glasphalt**' (Arnold G. *et al.,* 2008). The evaluation of its engineering properties has become expedient after the discovery of many environmental and economic benefits recently.

Usage

- Usage varies based on application. Crushed recycled glass was used independently, and can also be mixed with aggregates (Finkle I., & Ksaibati K., 2007).

It is used in thick structural layers of the pavement under the wearing course to avoid issues like:

- lack of skid resistance
- poor bonding of glass to the bitumen, causing stripping and ravelling problems (Arnold G. *et al.,* 2008).

Su and Chen (2002) studied, according to the ASTM and AASHTO following variables:

- Marshall stability value,
- dry/wet moisture damage,
- skid resistance, light reflection,
- water permeability

and test results proved that glass was a feasible material and the mixture yielded mechanical and economic benefits.

Arabani (2011) observed HMA in varying temperatures, composition and gradation. It was observed that dynamic properties of glasphalt were better.

Increased internal friction increased stiffness. It was also observed that the glasphalt is less reactive to temperature variations.

2.3.3 Waste glass as aggregate in Glasphalt

Fulton (2008) observed that incorporating glasphalt was good practice viz sustainability.

Finkle & Ksaibati (2007) recommended that the proportion of glass should not be more than twenty percent and the maximum size should not be larger than half inch.

Wu *et al*. (2003) recommended maximum size of 4.45 mm and maximum proportion of 10 percent for achieving optimum:

- strength index,
- high temperature stability
- water stability.

Viswanathan (1996) observed glass cullet having qualities like natural aggregates and ensured feasibility in usage as a highway material.

Ouda *et al*. (2010) and Diab *et al*. (2010) At the Islamic university of Gaza, found out that incorporating glass can improve absorption and adsorption vales besides other advantages.

2.3.4 Waste Glass powder as filler in Glasphalt

Pereira *et al*. (2010) observed similar behavior as was observed in the usage of traditional materials as fillers and ensured effective usage in asphalt pavements.

Jony *et al*. (2011) observed better Marshal stability compared to Portland cement and limestone.

2.4 Summary

The literature review depicts usage of glass in asphalt as a filler and as a component of base layer but instead of asphalt mix, it was applied differently, so this project work focuses its usage as coarse sand and filler material in asphalt mix in the binding course.

CHAPTER: 3

Methodology of Experimental Work

3.1 Introduction:

In this chapter, we will study materials (i.e. bitumen, aggregates and waste glass), their properties, and their use in the laboratory tests as well as how the project's objectives have been achieved throughout the experimental work.

3.2 Materials and Their Sources:

The materials (raw) used during this project are bitumen, aggregates and waste glass.

Some of the materials are obtained from local sources while others from main sources. The given table shows materials and their sources.

Table 3.1: *Sources of Materials*

Materials	Source
Bitumen	NHA
Aggregate	Hakeem Abad Plant
Waste Glass	Cadet's Canteen (Jinnah Block)

3.2.1 Bitumen (Asphalt Cement):

For project work, the bitumen used for the preparation of all test specimens was 60/70 penetration grade. Before producing the specimens, different laboratory tests for the physical properties of bitumen were carried out.

Transportation Laboratory of NUST College of Civil Engineering Risalpur was used during the research.

3.2.2 Aggregates:

During this project work, the conventional fine and coarse aggregates are used for the asphalt mixes.

Figure 3.1: *Aggregate Used*

3.2.3 Properties of Aggregates:

For the particle size distribution of aggregates used in the research, Gradation Tests were carried out while for the Physical Properties, Laboratory tests were conducted.

3.2.4 Aggregates Physical Properties:

For the specification limits, and evaluation of physical properties of the aggregates, all the required laboratory tests were carried out.

The results are shown in the table.

Table 3.2: *Aggregates Physical Properties*

Test Name	Specifications		Results
Impact value test	AASHTO	10--20	15.4
Abrasion test	ASTM C 131	< 40	23.1
Bulk sp. Gravity	ASTM C 127		2.65
Apparent sp. Gravity			2.67
Water Absorption	ASTM C128	< 5	2.30%

3.2.5 Aggregates Sieve Analysis:

Following the specification of NHA, gradation test for each type of aggregate was carried out in the laboratory. The obtained results are shown in the following table.

Table 1.3: *Sieve Analysis of Aggregates*

Sieve No	Sieve size mm	%passing	NHA Specifications Class A	
			Lower limit	Upper limit
3/4"	**19.00**	**90**	**90**	**100**
3/8	**9.00**	**63**	**56**	**70**
# 4	**4.75**	**43**	**35**	**50**
# 16	**1.18**	**8**	**5**	**12**
# 200	**0.075**	**5**	**2**	**8**
Pan	0.0	**0**	0	0.0

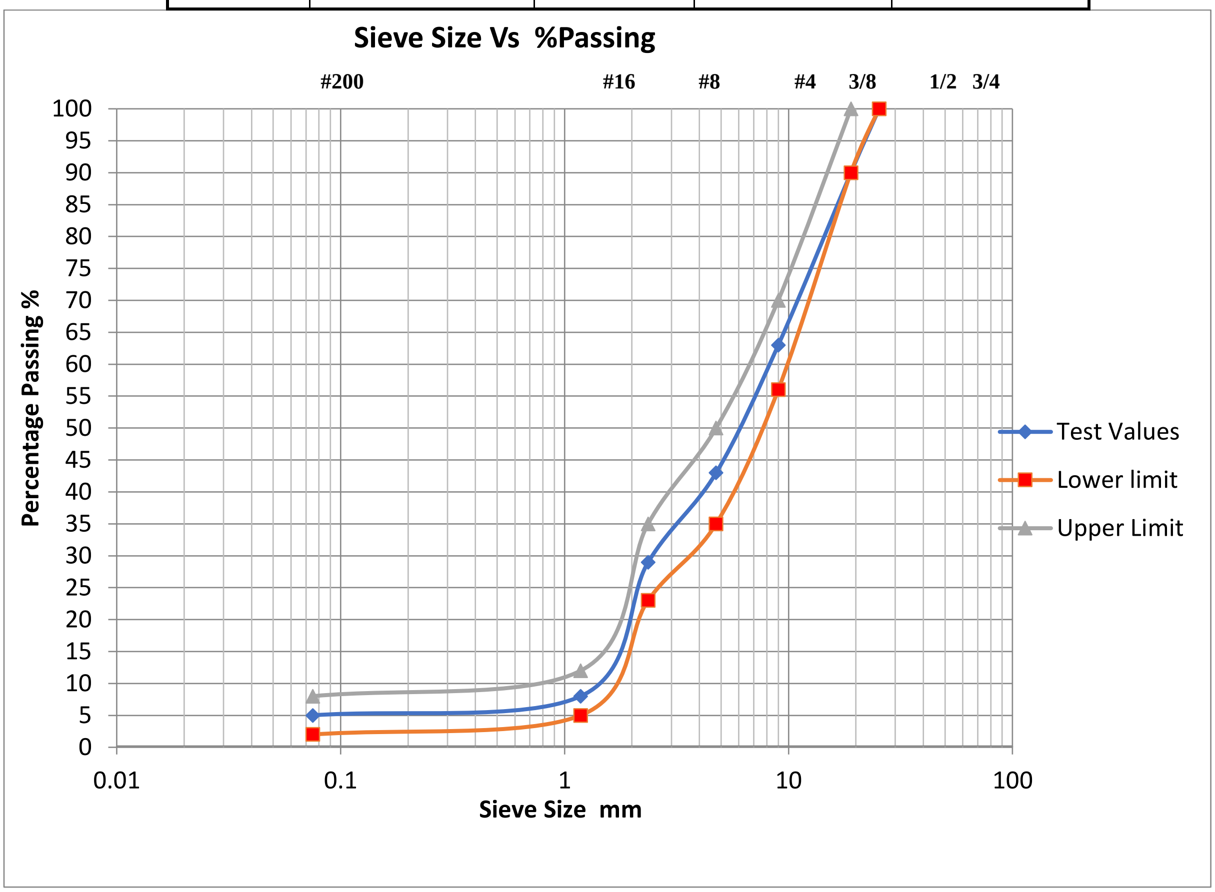


Figure 3.2: *Used aggregate gradation curve*

3.2.6 Waste Glass:

Waste Bottles of Cold Drinks acquired from canteen, were first cleaned with water and all labels were removed, and then dried to sunlight for few hours. These bottles were then carried to laboratory to get them crushed completely and uniformly according to grain size of required aggregates. The crushed glass was finally mixed with aggregate in controlled amount, which was then used in the asphalt mix for producing test specimens.

3.2.7 Properties of Crushed Waste Glass:

This study is based on merely a single glass type i.e. Cold Drinks Glass bottles and all other glass types such as laminated glass, windshields, sheet glass, glass fibers, fused quartz glass ceramic glass, mirrors etc. have no concern with this study.

The properties of crushed waste glass used in this study are as following:

Table 3.4: *Glass Properties*

Properties	Details
Source	Cold Drinks Bottles
Size	Maximum Size 4.75mm
Density	2.5 g/cm3

Figure 3.3: *Used crushed glass*

3.3 Experimental work

This comprehensive experimental work had been conducted in order to study the properties of glasphalt and to study the suitability of asphalt mixtures with waste crushed glass blended in it.

The properties of each material used were analyzed, and gradation for each type of material was performed before blending them to get binder course gradation curve (of blinder course). This gradation curve was then used for the asphalt mix preparation. After that, optimum bitumen content was obtained by performing marshal test, on asphalt mixes with varying bitumen contents. This optimum bitumen content was used in the preparation of test specimen from asphalt mixes having crushed glass in various percentages. The properties of these glasphalt mixes were evaluated by marshal test. Marshal test was conducted on obtained glasphalt mixes for evaluation of their properties. At the end, results from lab tests were acquired and examined.

The whole experimental work of this project is summarized by the following flowchart.

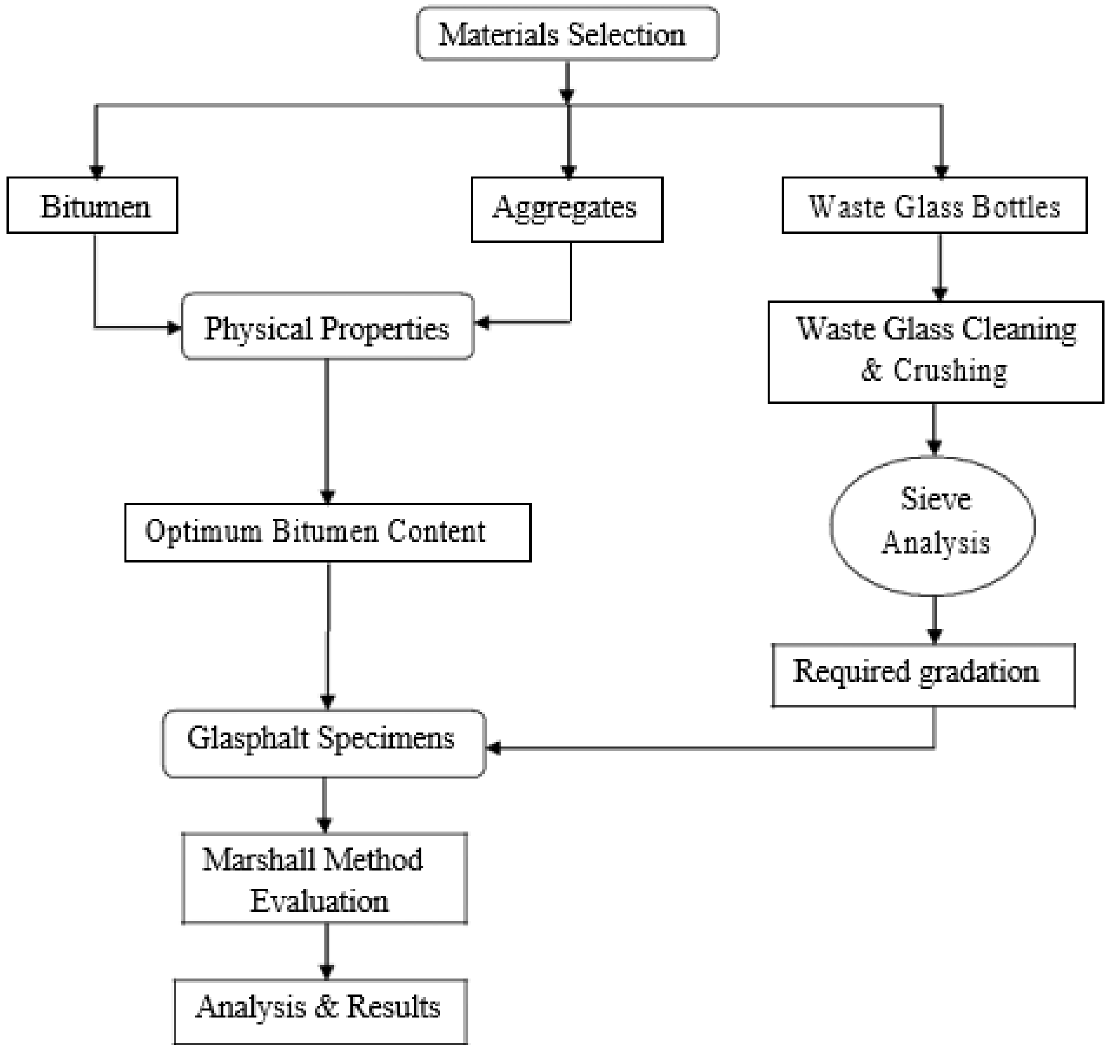


Figure 3.4: *Summary of experimental work*

3.3.1 Preparation of mixtures

For the preparation of mixtures, aggregates are mixed together to obtain proper gradation, following the specification of NHA and adopted mathematical trial method (trial and error methods).

In trial and error methods, the percentage for each aggregates type is first calculated and then compared with the specification of NHA, whether it lies in the range specified by NHA or not. If the selected percentage lies within the limits, there is not, then percentage for each aggregate size should be adjusted until it lies within the NHA specification limits.

For every specimen, the aggregate is mixed separately, then dried till approximately 110ºC to get a constant weight. Before mixing asphalt and aggregates are heated up to 145 º C and 135 º C respectively. The heated asphalt and aggregates are then mixed together, in their required amounts, thoroughly for three to four minutes to get a homogeneous mix and then casted in pre-heated (up to 130 º C) standard marshal molds. The molds casted with asphalt mix are compacted with 150 blows (75 on each side) in the compaction machine. The compaction should be done as soon as possible after the sample casting. Excess heat of asphalt should be avoided for the sake of less variability in properties. The samples after compaction were laced for 10-15 minutes at room temperature before ejecting them out from molds.

3.3.2 Determining Optimum Binder Content

3.3.2.1 Marshal Test Method

In this project work, both optimum binder content (OBC) and glasphalt specimen's evaluation is carried out by using Marshal Stability Test. This is an empirical method and is very helpful when mixtures are compared to each other under certain environments.

It evaluates resistance of cylindrical specimen to deformation, when the specimen is loaded along diameter in Marshal Apparatus.

The asphalt mixture samples were placed in pre-heated lubricated Standard Marshal Molds, and compacted by application of 150 blows (75 on each sides), then cooled for 24 hours at room temperature.

Each sample was tested for Marshal Stability and flow. Before testing, each sample was placed in water bath for 30 minutes at 60 º C and then hurriedly placed in Marshal Apparatus, and compressed long diameter at a constant rate 2 in/minute (50.8mm/minute) until sample reaches its max failure load.

The flow values against maximum load resistance are recorded. For each aggregate proportion, 3 sample were produced and the average of their results were recorded. Each specimen was tested for density, bulk specific gravity, Va and VFB.

3.3.3 Optimum Binder Content

Optimum bitumen content (OBC) has been evaluated by marshal test. In this research study, to evaluate best percentage of bitumen for the aggregates,4 percentages (i.e. 3.5,4,4.5,5 %), by weight of mix, of bitumen were analyzed, and 3 samples for each percentage were produced, and OBC of 4.35% by weight of total aggregates was obtained. This 4.35% OBC corresponds to maximum density, stability, and median air voids percentage (Jendia, 2000).

3.3.4 Optimal Crushed Waste Glass Content

For evaluating glasphalt mix properties, numerous laboratory tests were conducted, adopting the procedure of Marshal Test. All samples were produced according to OBC of 4.35% by weight of mix. In order to evaluate the best percentage of crushed waste glass for glasphalt, 6 percentages (i.e. 2.5, 5, 7.5, 10, 12.5, 15%), by weight of total aggregate, of crushed glass were analyzed, and 3 specimens for each percentage were produced.

3.3.4.1 Summary of Glasphalt:

The summary of crushed waste glass for producing Glasphalt specimens is as following:

Cold drinks bottles were collected from canteen, washed with water, labels were scratched off, dried in sun, crushed in lab and then sieved finally.

After sieving, uniform gradation of crushed glass was obtained having particle size distribution of #4 and smaller.

6 percentages (2.5% to 15% with increment of 2.5%), by weight of total aggregate, of crushed glass were analyzed, and 3 specimens for each percentage were produced.

The crushed replaced only those particles retaining on #4 sieve and smaller, and blended with the aggregates.

The aggregates (containing glass) and asphalt were heated to 135ºC and 145ºC before mixing together. Excess heating of bitumen was avoided to avoid variation in asphalt properties.

Pre-heated aggregates and asphalt were then blended together, according to required amount for 3-4 minutes to get a homogeneous mix.

The homogeneous mix was in casted pre-heated (up to 130ºC) Standard Marshal Molds and compacted by 150 blows (75 on each side).

The samples were casted in the molds, compacted by 150 blows, cooled for 24 hours, and then tested for Marshal Stability and flow.

Figure 3.5: *Specimen prepared*

Chapter-4

Results and Analysis

4.1 Introduction

The results and analysis of the successful results of the experiments are mentioned in this chapter. Tests were performed to find the asphalt binder course gradation curve, OBC, asphalt and aggregate characteristics. This chapter also elaborates the properties of dissimilar proportions of crumpled glass in asphalt binder course and Marshall stability, flow and air voids contents in it.

Marshall method is used worldwide to design asphalt mixtures and Optimum bitumen content was determined through this method too. After determining Optimum bitumen content different samples containing different percentages of glass were prepared in order to find out best results i.e. optimum results giving percentage of crushed glass in job mix.

This study is limited to specific type and gradation of glass. While results may vary with using different type and gradation of glass content. Here, we used cold drinks bottles in our study.

4.2 Aggregates in HMA

For this project work, we used purely natural aggregates from Hakeem Abad Plant and their physical properties were checked. We selected the gradation according to NHA Class A specifications and ASTM standards, in order to make similar controlled samples. Final mix proportion of aggregates in asphalt binder and passing percentages of aggregates by sieving are shown in the tables below along the ASTM standard limits.

Table 4.1: *Proportion of Aggregate in asphalt binder*

Sieve No.	Sieve Size (mm)	Proportion of aggregate in mix (%)
3/4	19	10%
3/8	9.5	27%
#4	4.75	20%
#8	2.36	14%
#16	1.18	21%
#200	0.074	3%
Pan	-	5%
Sum		**100%**

Table 4.2: *Aggregates gradation*

Sieve No.	%age Passing	NHA Specification Limit (%)	
		Min	Max
3/4	90%	**90**	**100**
3/8	63%	**56**	**70**
#4	43%	**35**	**50**
#8	29%	**23**	**35**
#16	8%	**5**	**12**
#200	5%	**2**	**8**

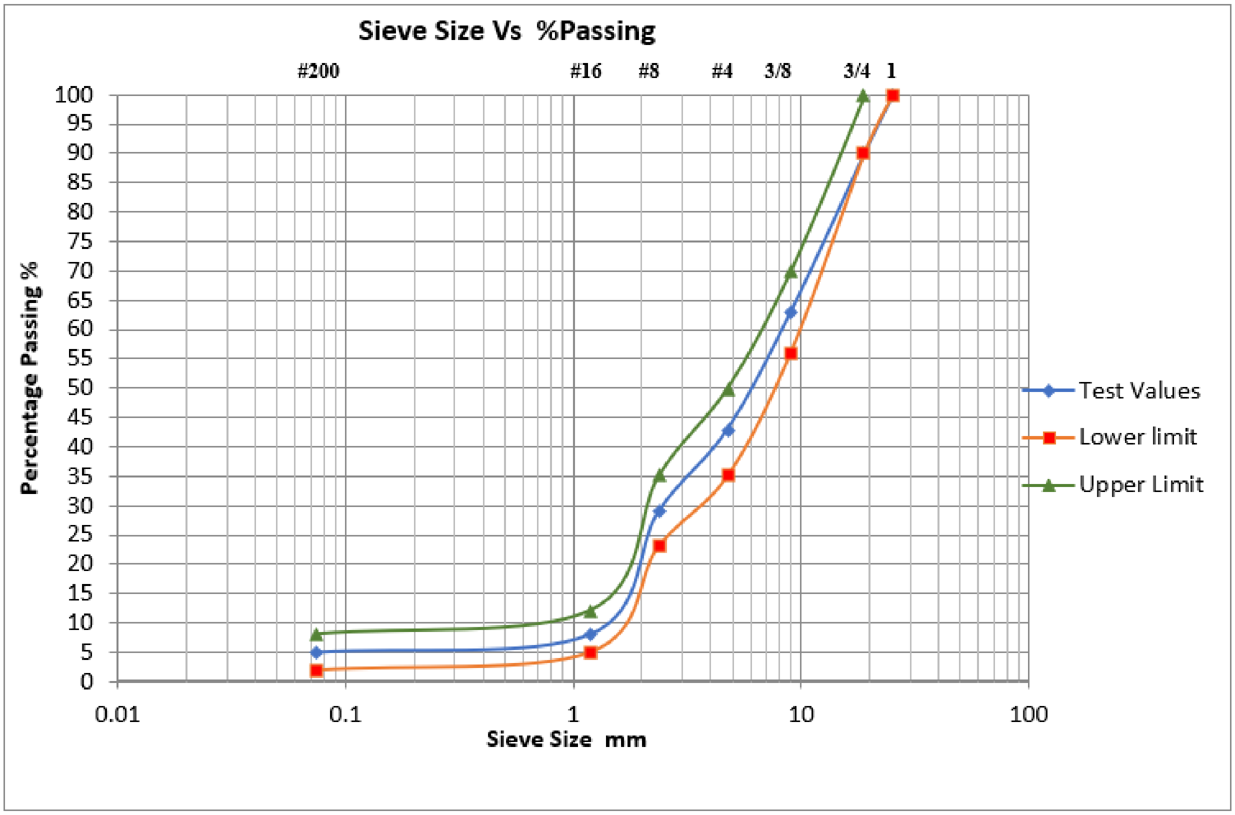


Figure 4.1: *Gradation Curve of aggregate in mix*

4.3 Bitumen Tests and Results

Different type of tests like, Penetration test, Ductility test, Specific gravity, softening point and Flash point and Fire point tests, were done to testify the quality of Bitumen we were using in our work, whether it meets the standard specifications or not.

4.3.1 Penetration test

The grade of penetration of the bitumen is found out using this test. This test is essential keeping in mind the different climatic regions for the construction of pavements. Penetration values depict how hard or soft the bitumen is.

This test was performed in accordance to AASHTO T 49-93 specification, and results are tabulated as.

Table 4.3: *Bitumen Penetration test results*

Penetration Value (mm)	Designation	Specification Limit
61.7	AASHTO T 49-93	60-70

Figure 4.2: *Apparatus for Penetration Test*

4.3.2 Ductility test

It is a simple experiment done by measuring the distance to which a briquette specimen of the material can elongate before breaking. It is done to find the tensile properties of the material and ductility.

This test was performed in accordance to AASHTO T 51-93 specification, and the results are tabulated below.

Table 4.4: Bitumen Ductility test results

Sample	Ductility (cm)
1	140
2	149
3	145
Average	**144.67**

Figure 4.3: *Apparatus for Ductility Test*

4.3.3 Specific Gravity test

It was performed in accordance to AASHTO T 228 specifications, to measure the specific gravity of the bitumen used in our research work. The results of this test are tabulated as.

Table 4.5: *Bitumen Specific Gravity test results*

Specific Gravity	Designation	Standard Limit
1.025	AASHTO T 228	1.02 -1.05

4.3.4 Softening point test

This test classifies as a consistency test which consists of the heating of the bituminous materials till, they reach a certain consistency. The softening point will be the temperature at which the material achieves a specific degree of softness at the certain circumstances.

This test was performed in accordance to AASHTO T 53-92 specification, and the results are tabulated below.

Table 4.6: *Bitumen softening point test results*

Softening Point	Designation	Standard Limit
52°C	AASHTO T 53-92	49-56°C

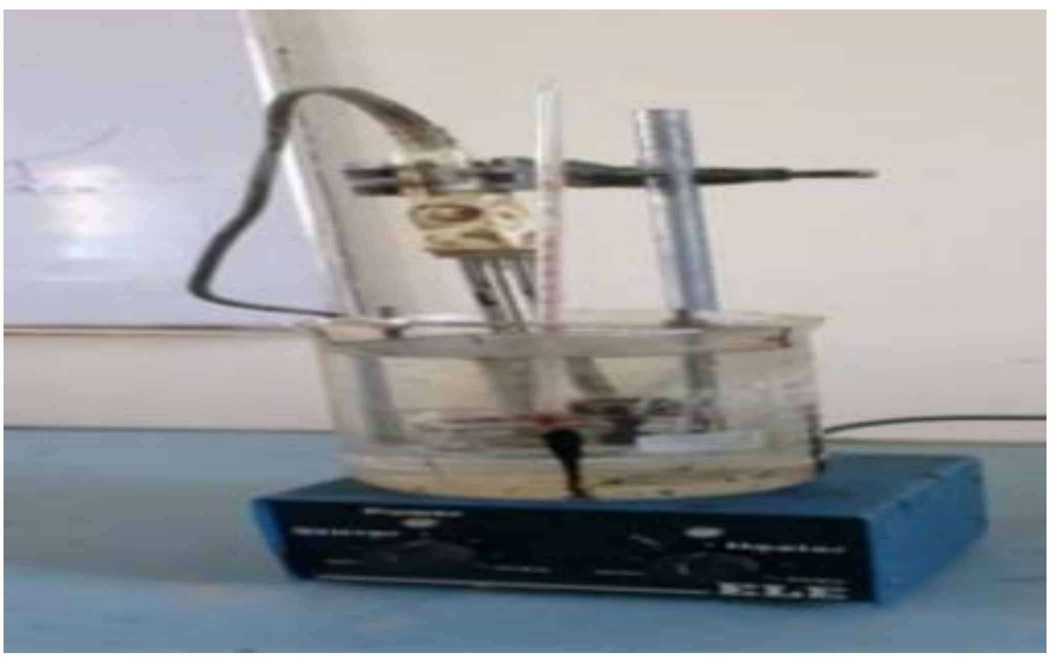


Figure 4.4: *Apparatus for Softening Point*

4.3.5 Flash point test

The flash point is the temperature when flash first appears on the surface of the asphalt during heating.

This test was performed in accordance to AASHTO T48 specification, and the results are shown as.

Table 4.7: *Bitumen Flash point test results*

Flash Point	Designation	Standard Limit
286°C	AASHTO T48	230°C Min

4.3.6 Fire point test

It is the temperature when the bitumen starts catching fire during heating. Care needs to be taken that before heating the flash and fire points are known in the field by testing so that heating may be limited. The flash and fire points are both separate temperatures.

This test was performed in accordance to AASHTO T48 specification, and the results are shown below.

Table 4.8: *Bitumen Flash point test results*

Fire Point	Designation	Standard Limit
298°C	AASHTO T48	260°C Min

4.3.7 Summary of physical properties of asphalt

Following is the summary of results of Asphalt tests:

Table 4.9: *Summary of Bitumen test results*

Test	Unit	Specification	Test result	Specifications limits
Penetration at 25 °C	1/10 mm	AASHTO T 49-93	61.7	70-80
Specific Gravity at 25 °C	g/cm^3	AASHTO T 228	1.025	0.97-1.06
Ductility at 25 °C	cm	AASHTO T 51-93	144.67	Min 100
Softening Point	°C	AASHTO T 53-92	52°C	49-56°C
Flash Point	°C	AASHTO T48	286°C	230°C Min
Fire Point	°C	AASHTO T48	298	260°C Min

4.4 Determining the Optimum Bitumen Content (OBC)

In order to obtain OBC, 12 samples were prepared at four different proportions of Bitumen content i.e. 3.5%, 4%, 4.5% and 5. All these samples were tested by Marshall method and OBC was obtained.

4.4.1 Marshall test results

To determine OBC, total 12 samples were produced at 4 varying percentages of Bitumen content, three samples at each percentage of bitumen content. And each sample weighs 1200 grams approx. The average results and graphs of relation between Bitumen percentages and the properties are shown next.

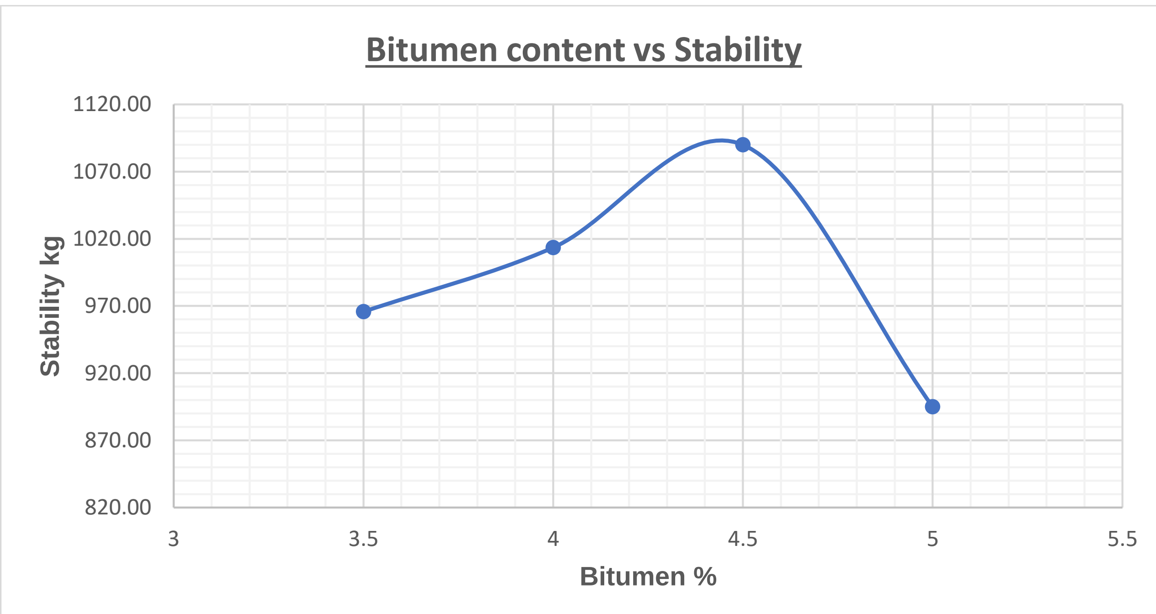
Table 4.10: *Marshall Test Results*

Bitumen (% By weight)	Sample No	Corrected Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
3.5%	1	992.6	2.76	2.368	6.133	13.949	56.033
	2	905.6	1.99	2.37	6.054	13.877	56.371
	3	998.9	2.54	2.356	6.637	14.411	53.945
Average		**965.70**	**2.43**	**2.365**	**6.275**	**14.079**	**55.450**
4%	1	1018.9	2.68	2.354	5.975	14.895	59.884
	2	984.3	3.12	2.368	5.451	14.421	62.2
	3	1037.2	2.52	2.359	5.801	14.738	60.638
Average		**1013.47**	**2.77**	**2.360**	**5.742**	**14.685**	**60.907**
4.5%	1	1011.2	3.1	2.359	5.093	15.182	66.452
	2	1116.5	2.82	2.367	4.77	14.893	67.973
	3	1142	2.8	2.373	4.522	14.671	69.178
Average		**1089.90**	**2.91**	**2.366**	**4.795**	**14.915**	**67.868**
5%	1	935.9	3.6	2.375	3.739	15.056	75.163
	2	919.4	3.1	2.36	4.35	15.595	72.105
	3	829.7	3.1	2.327	5.683	16.771	66.115
Average		**895**	**3.27**	**2.354**	**4.591**	**15.807**	**71.128**

- ρA (g/cm3) = Bulk Density
- Va % = Air Voids Percentage
- VMA % = Voids in mineral aggregate
- VFB % = Percentage of Voids Filled with Bitumen

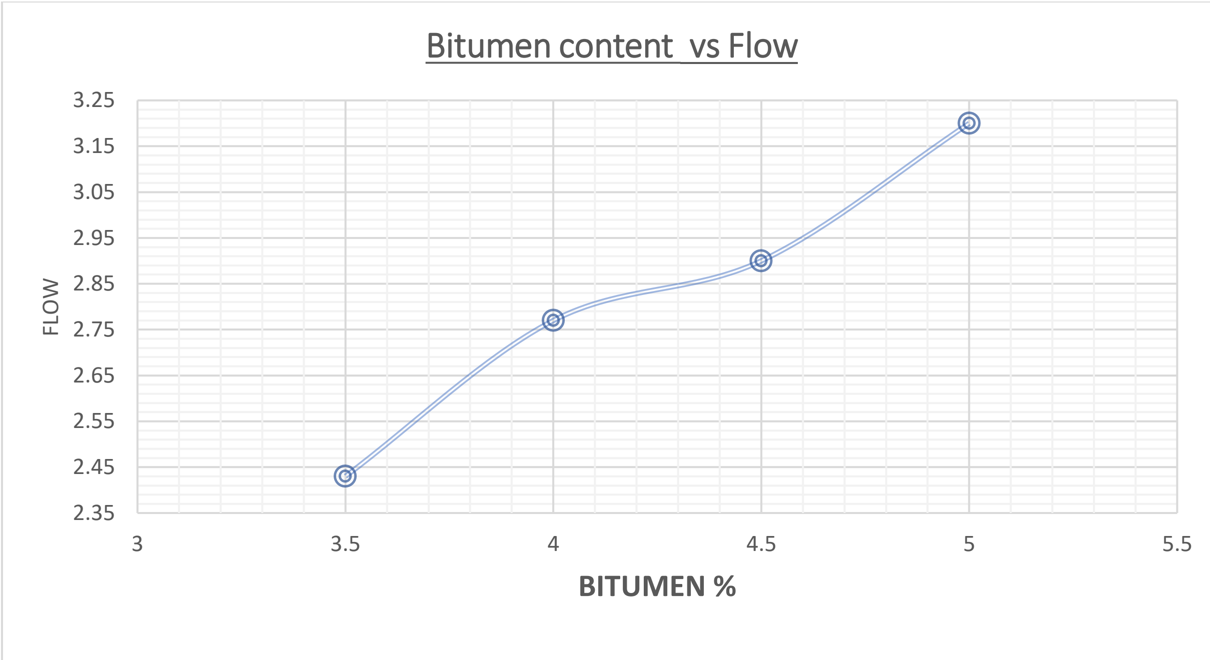
4.4.2 Marshal stability

It determines the extreme force a cylindrical specimen can bear just at the failure point, when the load is applied. From the given graph, it can be observed that **4.45%** of bitumen content gives the maximum stability of simple asphalt mixture.



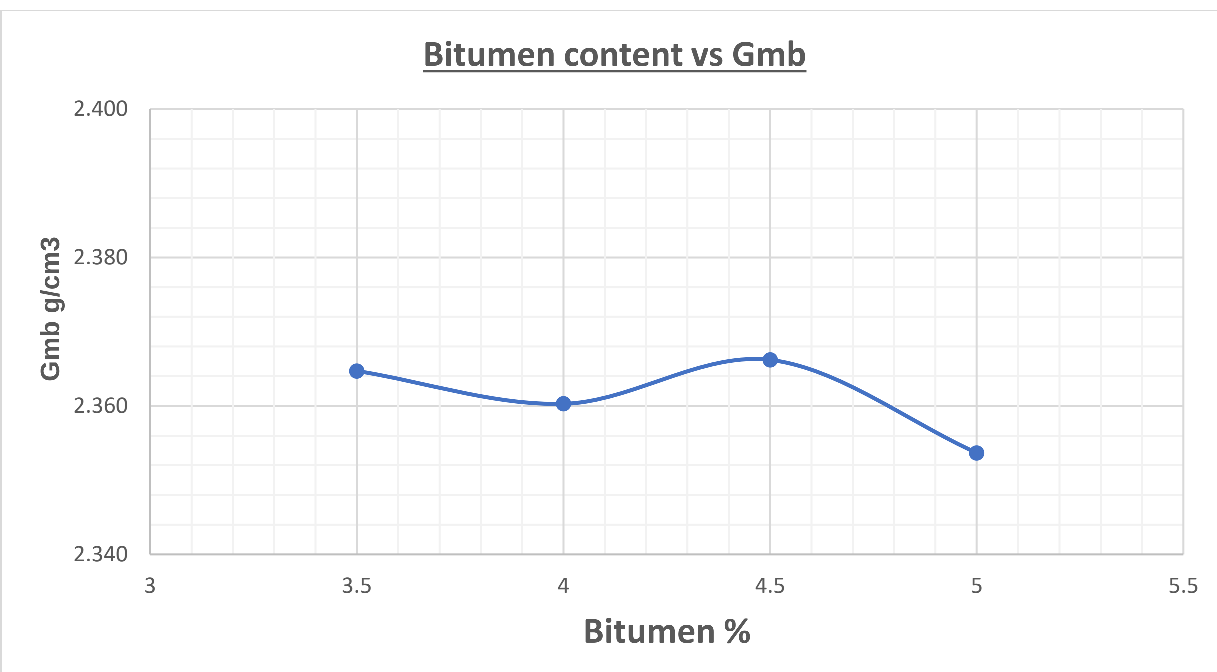
4.4.3 Marshall Flow

It determines the maximum value of distortion that befalls in the specimen at Marshall stability. From the given graph, it can be detected that 5% of asphalt gives the maximum flow of simple asphalt mixture.



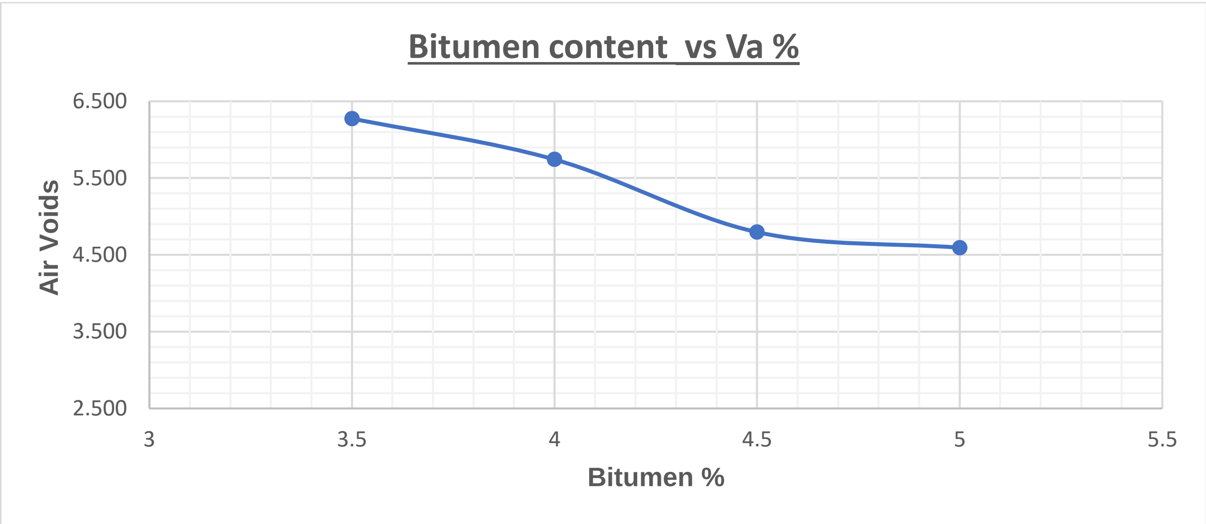
4.4.4 Bulk density

It is the concentration of the mix in compacted form. From the given graph, it can be observed that the bulk density is differing at each bitumen percentage and at OBC it is 2.365 g/cm^3.



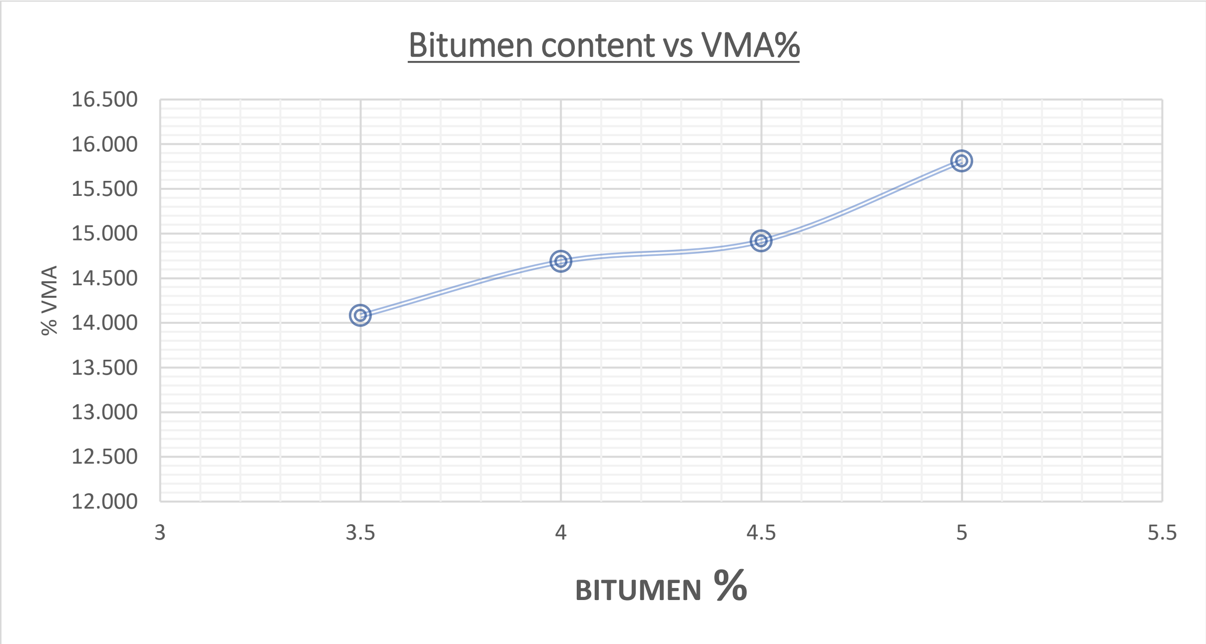
4.4.5 Air Voids content (Va)

It is the ratio of the volume of air content to the total volume if mix. From the plotted graph, we obtained its median i.e. **4.1%**, in order to determine OBC. Its value at OBC was found to be 5%. We can also notice the gradual decrease in air voids with increasing asphalt content.



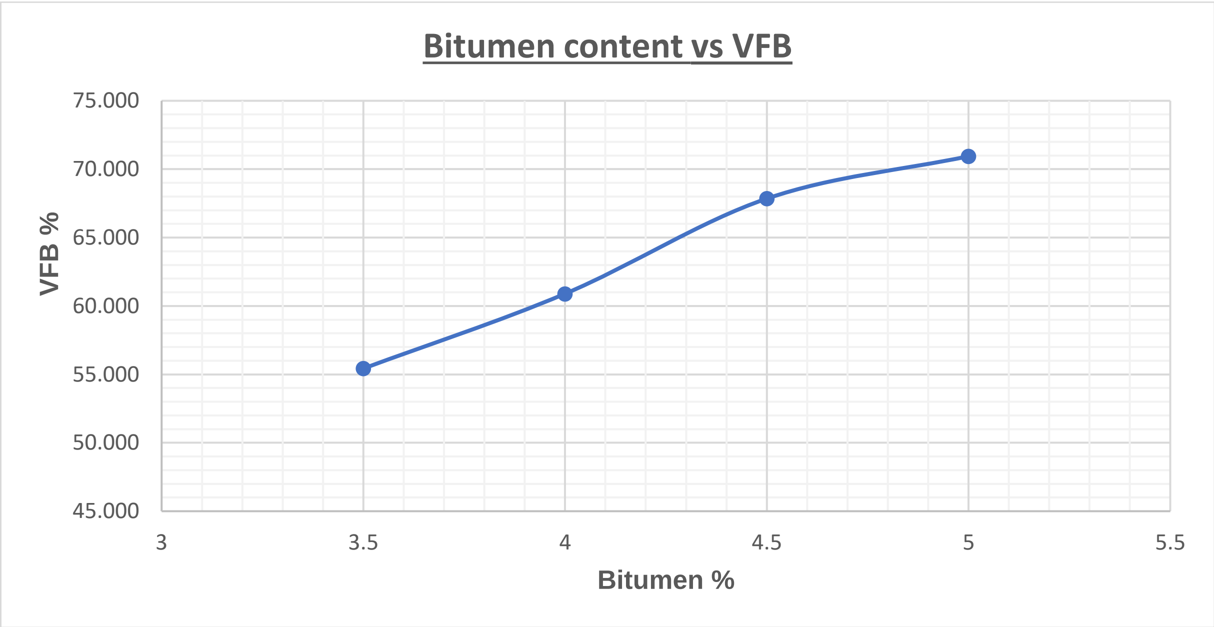
4.4.6 Voids in Mineral Aggregates (VMA)

These are the spaces between the aggregate particles, containing air packets and bitumen content. We can see its trend in the plotted graph. Its value at OBC is **14.8%**.



4.4.7 Voids Filled with Bitumen (VFB)

These are the voids in the mineral aggregate of the compacted blend that are filled with the bitumen particles. From the graph, we can analyze that there is gradual increase in its value with growing proportion of asphalt.



4.4.8 Optimum bitumen content (OBC)

We plotted different graphs, a shown above, to obtain OBC. From average values of Bitumen content at maximum stability, bitumen content at maximum bulk density and bitumen content at median air voids percentage, Optimum Bitumen Content was calculated to be **4.35%**.

Bitumen Percentage @ Maximum Stability = 4.45%

Bitumen Percentage @ Maximum Bulk density = 4.5%

Bitumen Percentage @ median air voids percentage = 4.1%

OBC % = (4.45+4.5+4.1)/3 = **4.35 %**

The table shown below gives the different properties at OBC.

Table 4.11: *Properties of the asphalt mix at Optimum bitumen content i.e.* ***4.35%***

Test	Test Results	International Specifications (Asphalt Institute,1997)	
		Min	Max
Stability (kg)	1085	817	-
Flow (mm)	2.85	2	4
Bulk Density (gm/cm3)	2.365	2.3	-
Air voids (%)	5	3	-
VMA (%)	14.8	13	-

4.5 Glasphalt results

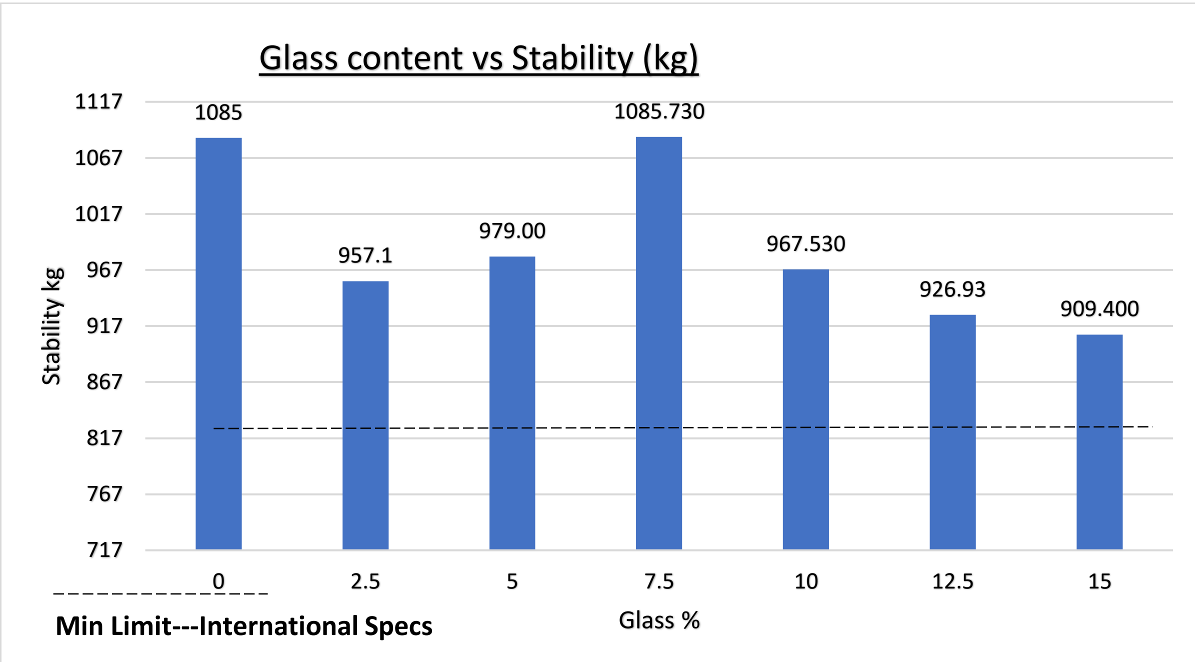
Three samples were prepared at each percentage of crushed glass. The selected percentages were 2.5%, 5%, 7.5%, 10%, 12.5% and 15%, and the mixes were prepared at optimal bitumen content, 4.35%.

Table 4.12: Properties of the asphalt mix at different percentages of glass.

Glass (% By weight)	Sample No	Corrected Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
0 % (OBC)		1085	2.85	2.365	5	14.8	66
2.5%	1	960.1	2	2.350	5.66	15.36	63.17
	2	979.6	1.85	2.368	4.94	14.72	66.46
	3	931.6	2	2.384	4.300	14.14	69.63
Average		957.10	1.95	2.367	4.97	14.74	66.42
5%	1	998.60	2.45	2.354	5.5	15.22	63.9
	2	1000.80	3	2.365	5.06	14.83	65.9
	3	937.70	4.7	2.339	6.1	15.76	61.3
Average		979	3.38	2.353	5.55	15.27	63.70
7.5%	1	1056.80	2.5	2.362	5.18	14.93	65.33
	2	1138.90	1.8	2.358	5.34	15.08	64.6
	3	1061.50	2.2	2.366	5.02	14.79	66.08
Average		1085.73	2.17	2.362	5.18	14.93	65.34
10%	1	924.20	2.05	2.363	5.14	14.9	65.5
	2	983.00	3	2.376	4.62	14.43	68
	3	995.40	2.25	2.357	5.38	15.11	64.4

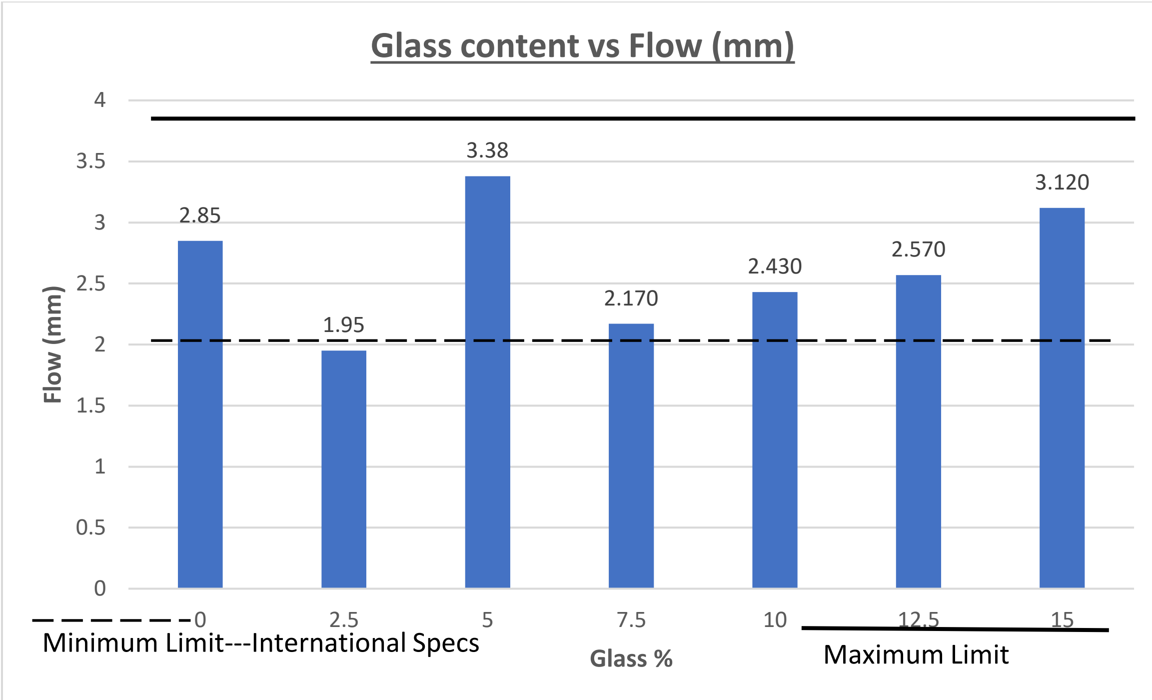
4.5.1 Marshall stability – Glass content relationship

From the graph, we can see that the value of stability gradually decreases after 0% glass, and the rises at 7.5%. and after 7.5% it starts decreasing again. It is maximum at **7.5%**, just a little higher than 0% glass content. The dashed line in the graph shows the minimum limit of stability according to international standards.



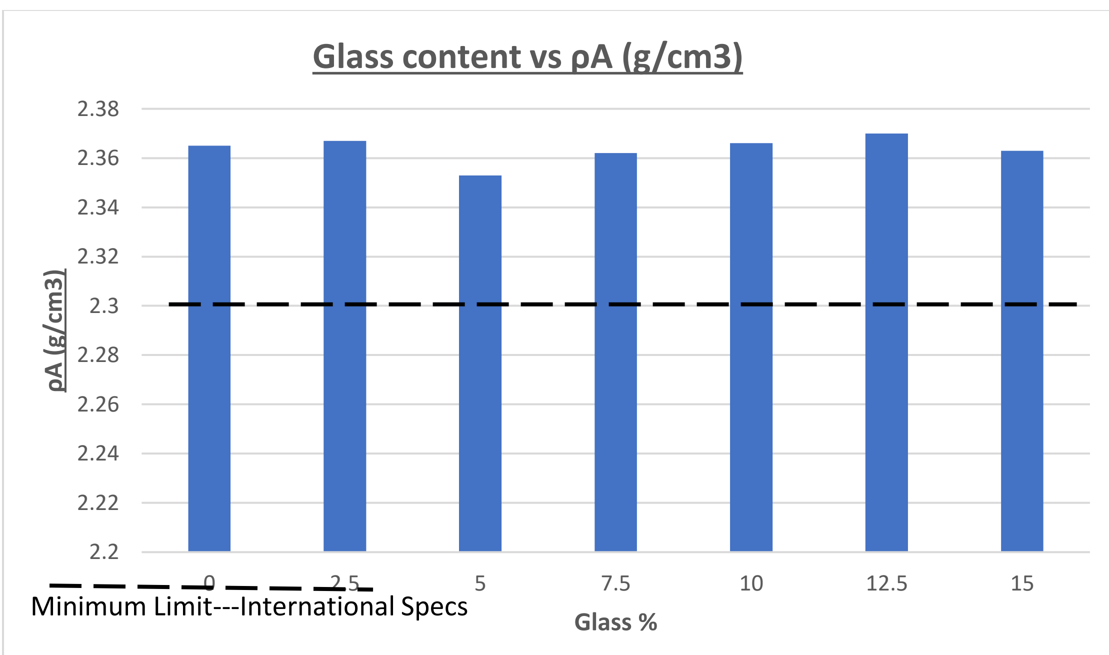
4.5.2 Flow – Glass content relationship

The flow at each percentage of glass can be seen in the graph below. All the values are acceptable according to International standards, except at 2.5%, which is just 0.05 mm lesser than the minimum value limit. The solid line is displaying the higher boundary while the dashed line is displaying the lower limit of value of flow according to international standards.



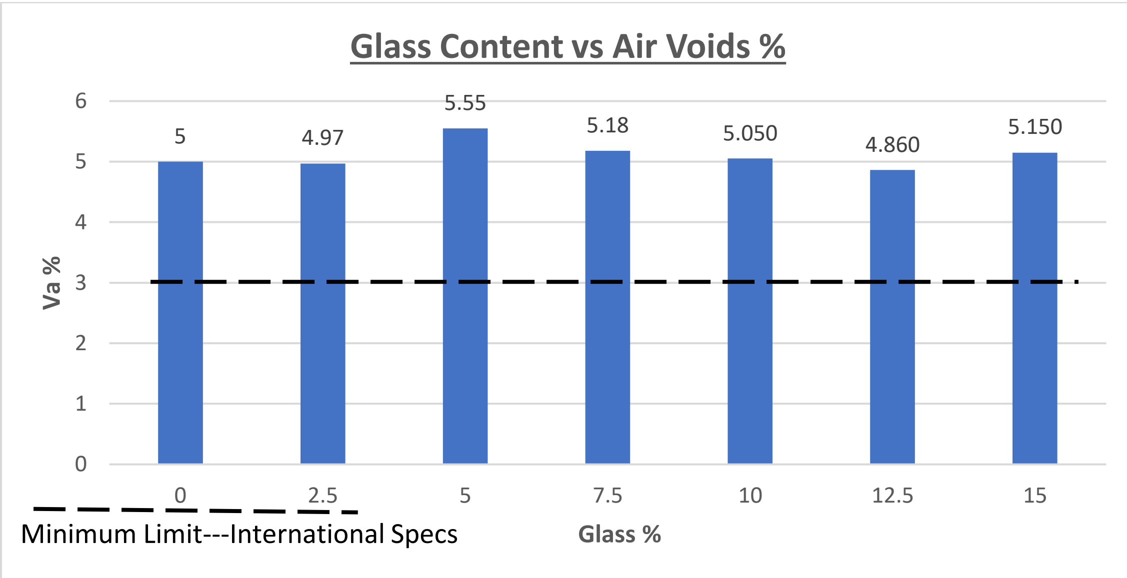
4.5.3 Bulk density – Glass content relationship

Its value is also varying with varying proportions of glass. All the values are acceptable according to International standards.



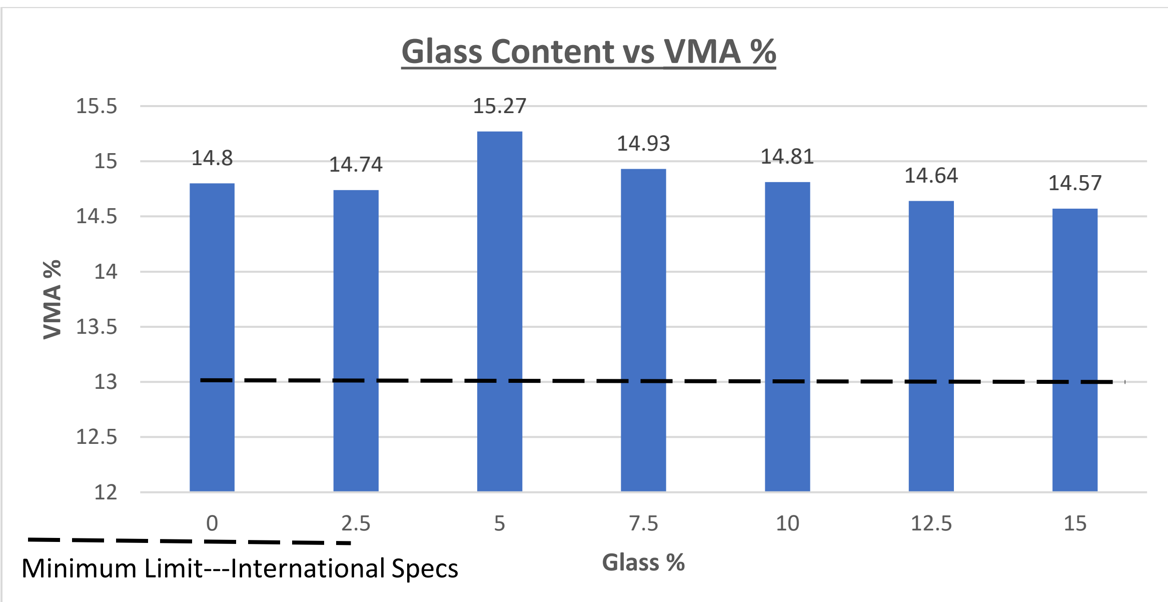
4.5.4 Air voids (Va) – Glass content relationship

Its value in the mix is also varying with varying glass percentage. These values are also acceptable according to International standards.



4.5.5 VMA – Glass content relationship

These values also meet the international requirements, as shown in the graph.



4.5.6 Summary of Glasphalt properties

Given table elaborates the different properties at different percentages of glass in mix.

Table 4.13: *Properties of the asphalt mix at different percentages of glass.*

Glass %	Property					
	Stability (kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
0.0%	1085	2.85	2.365	5	14.8	66
2.5%	957.10	1.95	2.367	4.967	14.74	66.420
5%	979	3.38	2.353	5.553	15.270	63.700
7.5%	**1085.73**	**2.17**	**2.362**	**5.18**	**14.933**	**65.337**
10%	967.53	2.43	2.366	5.05	14.81	65.97
12.5%	926.93	2.57	2.37	4.86	14.64	66.96
15%	909.40	3.12	2.36	5.15	14.57	65.55

4.6 Optimum Glass Content

After performing the Marshall test at different samples containing different percentages of Glass, we were able to formulate some graphs. By these graphs (shown above), we can analyze that the stability at 7.5% of glass content is a little higher than that of at 0% glass content. But at all other percentages, the stability has decreased. So, 7.5% glass content is said to be the optimum percentage of glass in mix. All values of stability, flow, bulk density, percent air voids and VMA are meeting standards of Asphalt Institute.

Table 4.14: *Properties of the mix at optimum glass content (7.5%)*

Property	Test Results @ 7.5% Glass	International Specifications (Asphalt Institute,1997)	
		Min	Max
Stability (kg)	1085.73	817	-
Flow (mm)	2.17	2	4
Bulk Density (gm/cm3)	2.362	2.3	-
Air voids (%)	5.18	3	-
VMA %	14.93	13	-

Chapter-5

Conclusions & Recommendations:

5.1 Conclusions:

The key aim of our study was to study the effects of crushed glass when added to the asphalt mix. And to prove this method an effective one like other methods of recycling of waste glass. From experimentation, we can conclude as follow:

- The maximum size of crushed glass that proves effective in replacement of aggregate, sizing from pan material to 4.75 mm, is 4.75 mm.
- We obtained **7.5%** of glass as the **optimum proportion of glass** content that can be added to aggregate mix, giving maximum stability.
- At this optimum percentage of glass added to the mix, all the values of stability, flow, density and % air voids were meeting the International standards.
- All other percentages of glass were in standard limits, except the value of flow at 2.5%, which was a little lesser than the Asphalt institute standards.
- This study is limited to the size and type of glass. The maximum glass size used was 4.75 mm as the replica of aggregate sizing, 0 to 4.7mm.
- Crushed glass obtained by soda glass bottles was used. The results may vary using different type and size of glass.

5.2 Recommendations:

- This study recommends to investigate the properties of crushed glass in other layers of pavement e.g. AWC.

- Behaviour of HMA can be analysed by changing the type and gradation of glass.
- Glass from windscreens, windows, lab apparatus and tube lights etc. can be used for study.
- Further studies may also include mixing glass with other waste materials like, plastics, in HMA.
- As glass is contributing 6% to the 77,000 tonnes per day of the total urban waste in Pakistan (that makes it almost 4620 tonnes per day), it is recommended to commercialize the use of glass in pavements to consume that waste glass that is creating environmental problems.
- Like glass, other waste materials must also be used in construction works.

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Appendix

- **Aggregate Physical Properties**

- **Bulk Specific Gravity (Gsb)**

  Gsb = A / (B-C)

  Where: A = Oven dry weight.

  B = SSD weight.

  C = Weight in water.

SSD Sp Gravity= B/(B-C)

Apparent Sp Gravity= A/ (A-C)

Effective = (Gsb+ Apparent)/2

Absorption = (B-A)/A

Table 3.2: *Aggregate Physical Properties*

Test Name	Specifications		Results
Impact value test	AASHTO	10--20	15.4
Abrasion test	ASTM C 131	< 40	23.1
Bulk sp. Gravity	ASTM C 127		2.65
Apparent sp. Gravity			2.67
Water Absorption	ASTM C128	< 5	2.30%

- **Sieve Analysis**

Table 4.1: *Proportion of Aggregate in asphalt binder*

Sieve No.	Sieve Size (mm)	Proportion of aggregate in mix (%)
3/4	19	10%
3/8	9.5	27%
#4	4.75	20%
#8	2.36	14%
#16	1.18	21%
#200	0.074	3%
Pan	-	5%
Sum		**100%**

Table 4.2: *Aggregates gradation*

Sieve No.	%age Passing	ASTM Specification Limit (%)	
		Min	Max
3/4	90%	**90**	**100**
3/8	63%	**56**	**70**
#4	43%	**35**	**50**
#8	29%	**23**	**35**
#16	8%	**5**	**12**
#200	5%	**2**	**8**

Table: Sieve Analysis Results

Sieve size mm	Wt Ret (gm)	Cum.Ret wt (gm)	Cum ret %	%passing	NHA Specifications Class A	
					Lower limit	Upper limit
38	0	**0**	**0**			
25.40	0	**0**	**0**	**100**	**100**	
19.00	115	115	**10.0**	**90**	**90**	**100**
9.00	311	426	**37.0**	**63**	**56**	**70**
4.75	230	656	**57.0**	**43**	**35**	**50**
2.36	161	817	**71.0**	**29**	**23**	**35**
1.18	241	1058	**92.0**	**8**	**5**	**12**
0.075	34.5	1093	**95.0**	**5**	**2**	**8**
0.0	57.5	1150	**100**	**0**		

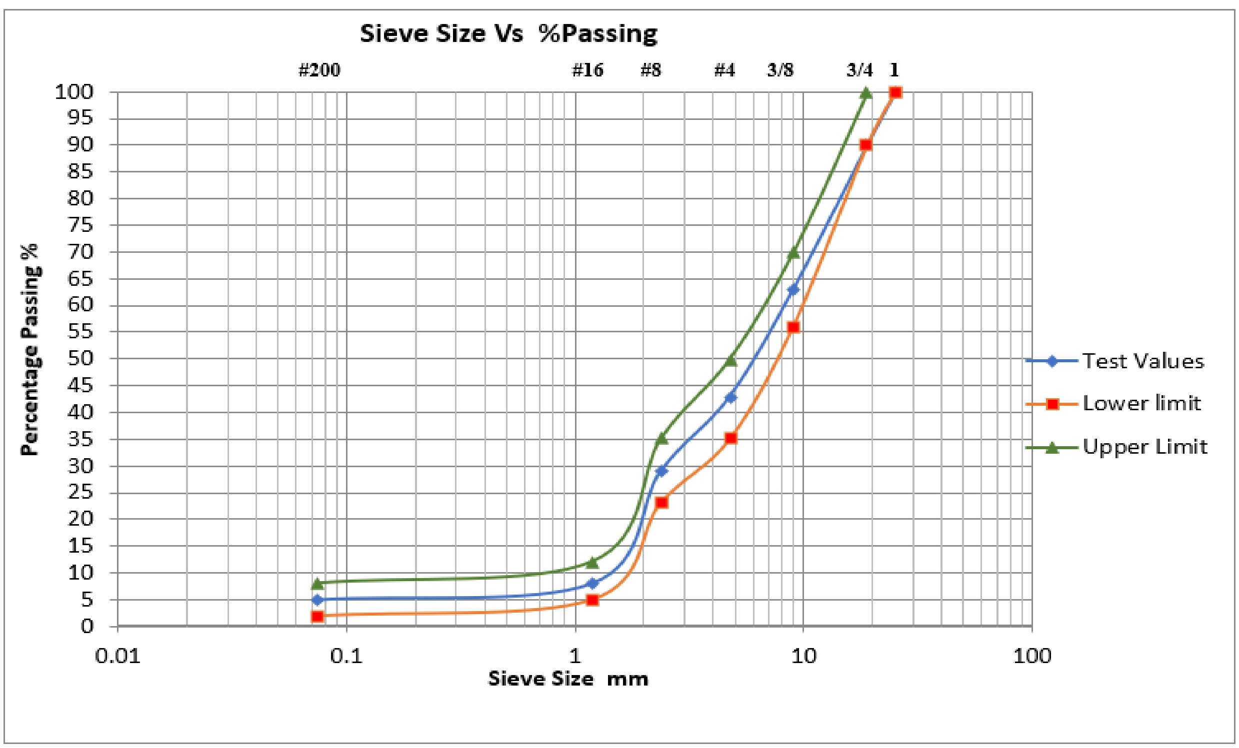


Figure 4.1: *Gradation Curve of aggregate in mix*

Figure: Aggregate Gradation Curve

- **Asphalt Tests Results:**

  - **Penetration test**

Table 4.3: *Bitumen Penetration test results*

Penetration Value (mm)	Designation	Specification Limit
61.7	AASHTO T 49-93	60-70

  - **Ductility test**

Table 4.4: Bitumen Ductility test results

Sample	Ductility (cm)
1	140
2	149
3	145
Average	**144.67**

- **Specific Gravity test**

Table 4.5: *Bitumen Specific Gravity test results*

Density of Asphalt/Specific Gravity		
A	Wt. of Flask+Bitumen (gm)	72.00
B	Wt.of Flask (gm)	35.00
C	Wt.of Bitumen (A-B) (gm)	37.00
D	Wt of Flask + Water (gm)	62.10
E	Wt of Flask + Water + Bitumen (gm)	63.00
F	Wt of water replaced by Bitumen(C+D-E)	36.10
G	Specific Gravity of Bitumen (C/F)	**1.025**
	Temp. of water	20C^{o}
	Gs of water	1.000
	Corrected Gs. =Gs.of Asphalt x Gs.of Water	**1.025**
	Range 1.02 to 1.04	

- **Summary of physical properties of bitumen**

Table 4.9: *Summary of Bitumen test results*

Test	Unit	Specification	Test result	Specifications limits
Penetration at 25 °C	1/10 mm	AASHTO T 49-93	61.7	70-80
Specific Gravity at 25 °C	g/cm^3	AASHTO T 228	1.025	0.97-1.06
Ductility at 25 °C	cm	AASHTO T 51-93	144.67	Min 100
Softening Point	°C	AASHTO T 53-92	52°C	49-56°C
Flash Point	°C	AASHTO T48	286°C	230°C Min
Fire Point	°C	AASHTO T48	298	260°C Min

- **Asphalt Mix Test results:**
  - ρA (g/cm3) = Bulk Density
  - Va % = Air Voids Percentage
  - VMA % = Voids in mineral aggregate
  - VFB % = Percentage of Voids Filled with Bitumen
  - A = Oven dry weight.
  - B = SSD weight.
  - C = Weight in water.

  Following are 3 different trials of Marshal Tests for OBC: -

- **Trial-1:**

Trial 1	3.50%	4%	4.50%	5%
A (gm)	1196	1189	1203	1204
B (gm)	1202	1195	1211	1209
C (gm)	697	690	701	702
Stability kg	992.6	1018.9	1011.2	935.9
Flow mm	2.76	2.68	3.1	3.6
pA g/cm3	2.368	2.354	2.359	2.375
Va %	6.133	5.975	5.093	3.739
VMA %	13.949	14.895	15.182	15.056
VFB %	56.033	59.884	66.452	75.163

- **Trial-2:**

Trial 2	3.50%	4%	4.50%	5%
A (gm)	1197	1198	1200	1194
B (gm)	1202	1204	1207	1199
C (gm)	697	698	700	693
Stability kg	905.6	984.3	1116.5	919.4
Flow mm	1.99	3.12	2.82	3.1
pA g/cm3	2.37	2.368	2.367	2.36
Va %	6.054	4.451	4.77	4.35
VMA %	13.877	14.421	14.893	15.595
VFB %	56.371	62.2	67.973	72.105

- **Trial-3:**

Trial 3	3.50%	4%	4.50%	5%
A (gm)	1199	1203	1196	1198
B (gm)	1208	1210	1201	1201
C (gm)	699	700	697	690
Stability kg	998.9	1037.2	1142	829.7
Flow mm	2.54	2.52	2.8	3.1
pA g/cm3	2.356	2.359	2.373	2.327
Va %	6.637	5.801	4.522	5.683
VMA %	14.411	14.738	14.671	16.771
VFB %	53.945	60.638	69.178	66.115

- **Average of all trials:**

Table 10: *Marshal Test Results*

Bitumen (% By weight)	Sample No	Corrected Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
3.5%	1	992.6	2.76	2.368	6.133	13.949	56.033
	2	905.6	1.99	2.37	6.054	13.877	56.371
	3	998.9	2.54	2.356	6.637	14.411	53.945
Average		**965.70**	**2.43**	**2.365**	**6.275**	**14.079**	**55.450**
4%	1	1018.9	2.68	2.354	5.975	14.895	59.884
	2	984.3	3.12	2.368	5.451	14.421	62.2
	3	1037.2	2.52	2.359	5.801	14.738	60.638
Average		**1013.47**	**2.77**	**2.360**	**5.742**	**14.685**	**60.907**
4.5%	1	1011.2	3.1	2.359	5.093	15.182	66.452
	2	1116.5	2.82	2.367	4.77	14.893	67.973
	3	1142	2.8	2.373	4.522	14.671	69.178
Average		**1089.90**	**2.91**	**2.366**	**4.795**	**14.915**	**67.868**
5%	1	935.9	3.6	2.375	3.739	15.056	75.163
	2	919.4	3.1	2.36	4.35	15.595	72.105
	3	829.7	3.1	2.327	5.683	16.771	66.115
Average		**895**	**3.27**	**2.354**	**4.591**	**15.807**	**71.128**

- **Optimum bitumen content (OBC):**

Bitumen Percentage @ Maximum Stability = 4.45%

Bitumen Percentage @ Maximum Bulk density = 4.5%

Bitumen Percentage @ median air voids percentage = 4.1%

OBC % = (4.45+4.5+4.1)/3 = **4.35 %**

Table 4.11: *Properties of the asphalt mix at Optimum bitumen content i.e.* ***4.35%***

Test	Test Results	International Specifications (Asphalt Institute,1997)	
		Min	Max
Stability (kg)	1085	817	-
Flow (mm)	2.85	2	4
Bulk Density (gm/cm3)	2.365	2.3	-
Air voids (%)	5	3	-
VMA (%)	14.8	13	-

- **Glasphalt Mix Test Results:**

  - **Batching of samples at each percentage of Glass:**

Table: *At 0% Glass*

0% Glass	
Size	**Agg Retained Wt. (gm)**
3/4"	115
3/8"	310.5
#4	230
#8	161
#16	241.5
#200	34.5
Pan	57.5
Sum	**1150**

Table: *At 2.5% Glass*

2.5% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	220.88	9.12
#8	154.6	6.4
#16	231.9	9.6
#200	33.14	1.36
Pan	55.23	2.27
Sum	1121.25	28.75
Total	**1150**	

Table: *At 5% Glass*

5% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	211.76	18.24
#8	148.2	12.8
#16	222.3	19.2
#200	31.78	2.72
Pan	52.96	4.54
Sum	1092.5	57.5
Total	**1150**	

Table: *At 7.5% Glass*

7.5% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	202.64	27.63
#8	141.63	19.2
#16	212.6	28.8
#200	30.42	4.08
Pan	50.69	6.81
Sum	1063.48	86.52
Total	**1150**	

Table: *At 10% Glass*

10% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	193.52	36.48
#8	135.4	25.6
#16	203.1	38.4
#200	29.06	5.44
Pan	48.42	9.08
Sum	1035	115
Total	**1150**	

Table: *At 12.5% Glass*

12.5% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	184.4	45.6
#8	129	32
#16	193.5	48
#200	27.7	6.8
Pan	46.15	11.35
Sum	1006.25	143.75
Total	**1150**	

Table: *At 15% Glass*

15% Glass		
Size	**Agg Retained Wt. (gm)**	**Glass retained wt. (gm)**
3/4"	115	-
3/8"	310.5	-
#4	175.28	54.72
#8	122.6	38.4
#16	183.9	57.6
#200	26.34	8.16
Pan	43.88	13.62
Sum	977.5	172.5
Total	**1150**	

- **Specific gravity test results at different percentages of glass**

Table: *pA of Glasphalt*

sample number	Weight in Air gm	Weight In water	SSD Weight	pA g/cm3
0%A	1198	699	1204	2.372
0% b	1196	698	1203	2.368
0 % c	1200	699	1208	2.358
Average	1198	698.7	1205	2.366
2.5%A	1208	704	1218	2.350
2.5% b	1198	699	1205	2.368
2.5 % c	1197	699	1201	2.384
Average	1201.0	700.7	1208.0	2.367
5%A	1196	696	1204	2.354
5% b	1199	701	1208	2.365
5 % c	1200	694	1207	2.339
Average	1198.3	697.0	1206.3	2.353
7.5%A	1200	701	1209	2.362
7.5% b	1198	697	1205	2.358
7.5 % c	1195	698	1203	2.366
Average	1197.7	698.7	1205.7	2.362
10%A	1203	703	1212	2.363
10% b	1200	702	1207	2.376
10 % c	1202	699	1209	2.357
Average	1201.7	701.3	1209.3	2.365
12.5%A	1196	702	1202	2.392
12.5% b	1198	700	1209	2.354
12.5 % c	1201	702	1210	2.364
Average	1198.3	701.3	1207.0	2.370
15%A	1195	696	1205	2.348
15% b	1201	700	1204	2.383
15 % c	1195	699	1206	2.357
Average	1197.0	698.3	1205.0	2.363

- **Marshal test results of Glasphalt:**

Table 4.12: Properties of the asphalt mix at different percentages of glass.

Glass (% By weight)	Sample No	Corrected Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
0 % (OBC)		1085	2.85	2.365	5	14.8	66
2.5%	1	960.1	2	2.350	5.66	15.36	63.17
	2	979.6	1.85	2.368	4.94	14.72	66.46
	3	931.6	2	2.384	4.300	14.14	69.63
Average		957.10	1.95	2.367	4.97	14.74	66.42
5%	1	998.60	2.45	2.354	5.5	15.22	63.9
	2	1000.80	3	2.365	5.06	14.83	65.9
	3	937.70	4.7	2.339	6.1	15.76	61.3
Average		979	3.38	2.353	5.55	15.27	63.70
7.5%	1	1056.80	2.5	2.362	5.18	14.93	65.33
	2	1138.90	1.8	2.358	5.34	15.08	64.6
	3	1061.50	2.2	2.366	5.02	14.79	66.08
Average		1085.73	2.17	2.362	5.18	14.93	65.34
10%	1	924.20	2.05	2.363	5.14	14.9	65.5
	2	983.00	3	2.376	4.62	14.43	68
	3	995.40	2.25	2.357	5.38	15.11	64.4

- **Properties of Optimum Glasphalt content:**

Table 4.14: *Properties of the mix at optimum glass content (7.5%)*

Property	Test Results @ 7.5% Glass	International Specifications (Asphalt Institute,1997)	
		Min	Max
Stability (kg)	**1085.73**	817	-
Flow (mm)	2.17	2	4
Bulk Density (gm/cm3)	2.362	2.3	-
Air voids (%)	5.18	3	-
VMA %	14.93	13	-

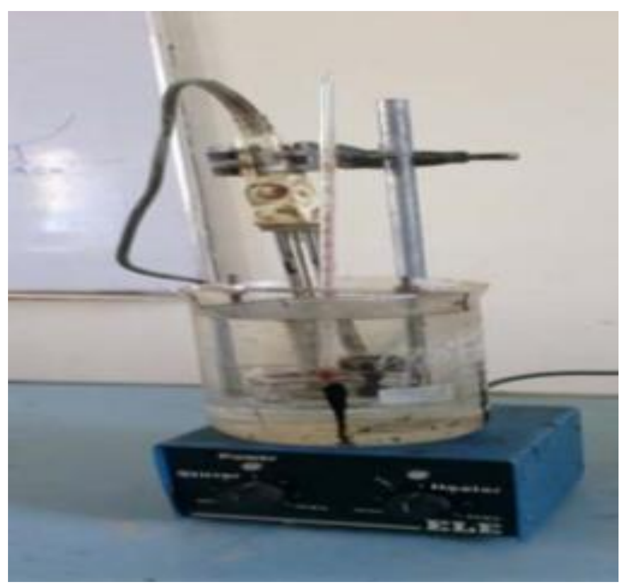
Photos:

Crushed glass of bottles

2. Aggregate

3.Apparatus for Ductility Test

4. Apparatus for softening point test



5. Apparatus for Penetration Test

6. Specimens preparation

7. Compaction of specimen by compactor

8. Determining the weight of specimens in air, water and dry SSD, for Bulk density

9. Specimens placed in oven for Marshal test

10. Testing on Marshal test apparatus