

**LABORATORY INVESTIGATIONS AND PERFORMANCE
EVALUATION OF OPEN GRADED FRICTION COURSE
(OGFC): POROUS ASPHALT PAVEMENT**

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DECLARATION

I hereby declare that this work which is being presented in the thesis entitled "LABORATORY INVESTIGATIONS AND PERFORMANCE EVALUATION OF OPEN GRADED FRICTION COURSE (OGFC): POROUS ASPHALT PAVEMENT" in partial fulfilment of the requirement for the degree of Master of Engineering in the field of CIVIL ENGINEERING at THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY (PATIALA) is an authentic record of my own work carried out during the period from 28 July, 2018 to 11 July, 2019 under the guidance of Dr. Tanuj Chopra and Mr. Rajesh Pathak.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma.

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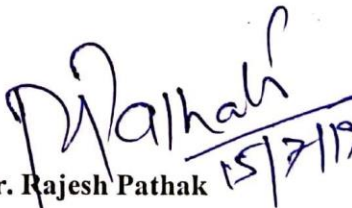
CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct according to the best of our knowledge and belief.



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ABSTRACT

Open graded friction course (OGFC)/porous asphalt mixture consists of an open gradation of coarse size aggregate with less percentage of fines. The OGFC mixture has different benefits such as permeability of surface increases, noise reduction, storage of storm water, skid resistance and many more benefits. For fully understand the properties of porous asphalt mixes, investigation should be conducted from different perspectives. This study has carried out to investigate the different laboratory test that includes the Air Void percentage, Drain Down test, Cantabro Abrasion Loss test, volumetric properties and the performance of OGFC mix simultaneously. In this study, the design gradation of aggregates has selected as per NAPA IS-115. The bitumen of VG-30 has been used for all work done during the study. The Mix design method of Marshall Mix has been used to evaluate the properties of OGFC mix.

For the determination of OBC, the specification as per NCHRP 640 Open Graded Friction Course (OGFC) Mixture has preferred. From the observation, it is clear that the binder content of 5.5% fulfils the entire requirement recommended for OGFC mix. The required experiments have satisfied all the criteria at the binder content 5.5. The result of Air void percentage has maximum voids at the OBC. As the result concluded, the performance permeability test value increases with the increase of binder content percentage upto the optimum value has obtained and further, the permeability decrease with increase of binder content. As the same trend, the stability value has obtained. But the flow value increases with the binder content percentage increase. The test result for Durability has minimum value at OBC and further, the abrasion loss percentage start increases. As the same trend, the Drain down result value has obtained. This study evaluates the performance of OGFC mix in the laboratory and resulted in adequate durability and permeability that suits for Indian climate.

The hydraulic design for depth of reservoir for soil type of sand, gravel and clay are 11.88, 7.65 and 15.24inches. The structural design for thickness of porous asphalt layer for soil type of sand, gravel and clay with respect to reservoir thickness are 7.8, 9 and 7.7inches whereas, with respect to design traffic of (1) 2500000 ESALs are 4.55, 4.87 and 4inches; (2) 1000000 ESALs are 5.9, 6.47 and 5.5inches; (3) 3000000 ESALs are 6.3, 7.05 and 6.25inches.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

Porous asphalt pavement is also known as open-graded friction course (OGFC), open-graded asphalt concrete (OGAC), and permeable asphalt. OGFC mix is one of the surface layers which are used as wearing course. This type of pavement proving their value as the mid-1970s. The present problem is to deal with the apprehension of water quality, stream bed destruction due to the runoff, need to maintain the underground system and different organizations are run to preserve stormwater or rainfall. The planners need to develop the new tool or technique for the stormwater management.

Open-graded friction course mixes are designed with uniformly coarse sized aggregates for achieving the drainage property, either through surface or base of the porous pavement. These types of pavement are mostly used to permit rainfall from the surface layer to the soil. The important use of providing the OGFC mix for parking areas that serves as the drainage layer. The different types of pavements such as Flexible asphalt pavement and Rigid pavements used for different purpose such as providing the high strength surface layer, required for high traffic condition and many other purpose but porous pavements are totally differ from the other asphalt pavements. The porous asphalt pavements are design in such a way that it allow water to pass through the structure and reducing the runoff from nearby areas.

Porous asphalt pavement have to design with proper consideration and installation that can be responsible for various purpose like cost-effective, attractive pavements with more than 20 years of life span and also, at the same time manage the stormwater runoff that increase infiltration property and quality of water improved. The performance of OGFC/porous asphalt mix show similar property as compare with other pavements. And, like other pavements, it can be designed for many other situations.

1.2 CONCEPT OF TECHNOLOGY

The concept of Porous asphalt pavement: detention basins are constructed for the management of controlling stormwater runoff under the parking lots and street. The detention basins are specially designed to collect stormwater from pavements, structures, other development areas. The detention basins are used to hold the stormwater till it can infiltrate water to the soil. These basins are covered with the layer of porous asphalt pavement. The main factor for designing the porous asphalt pavement is to allow water to pass through its surface into the detention basin.

1.3 TECHNICAL SPECIFICATIONS

The concept of constructing the porous pavement that can be used for different purpose such as for low traffic streets, parking areas and roads. The working method of the pavement has shown in Figure 1.1. The different layers of porous pavement are explained below from top to bottom layer:

- **Layer I:** This layer name as Open-graded friction Course/porous asphalt mix and the thickness of the layer is 50 to 100 mm. The important property of constructing porous asphalt layer is to obtain the minimum air voids 16 percentage even after the compaction. The ponding of rainwater on the surface of layer does not occur because it allows water to infiltrate rapidly.
- **Layer II:** This layer name as choker layer and generally, the thickness of choking layer is 25 to 50 mm having the nominal aggregate size of 12.5mm. This layer is usually used as the stabilize surface by placed above the stone bed.
- **Layer III:** This layer works as the water reservoir and normally, the thickness of layer is 8” to 12”. This layer consists of clean crushed aggregates of size 40 to 75 mm and compacted to act as water reservoir storage. The minimum air voids 40 percentage are required so that the rain water easily passed through it. The depth of the layer of reservoir course varies with the storage volume required.
- **Layer IV:** This layer is generally known as Non-woven geotextile that basically act as the separation layer between the water reservoir and soil subgrade. The main function of this layer to prevent the soil particles of subgrade that not mixed with the stormwater reservoir course thus worked as choking it. The other method is to provide the stone filter course of 75 mm thickness that can be provided if the gradation of aggregates can be control or maintained and size of aggregates is 10 to 25 mm.

- Layer V:** This layer consist of natural soil subgrade as an un-compacted layer. The important factor is to maintain the permeability of subgrade bed. Un-compacted natural soil sub-grade (bed) to maintain its permeability. The infiltration capacity of subgrade range from 2.5 mm/hour to 76 mm/hour and the slope should not exceed 5% for finished soil subgrade. A rate of 0.5 mm/hr. is considered very reasonable. The soil type like clay is not desirable for the subgrade layer.

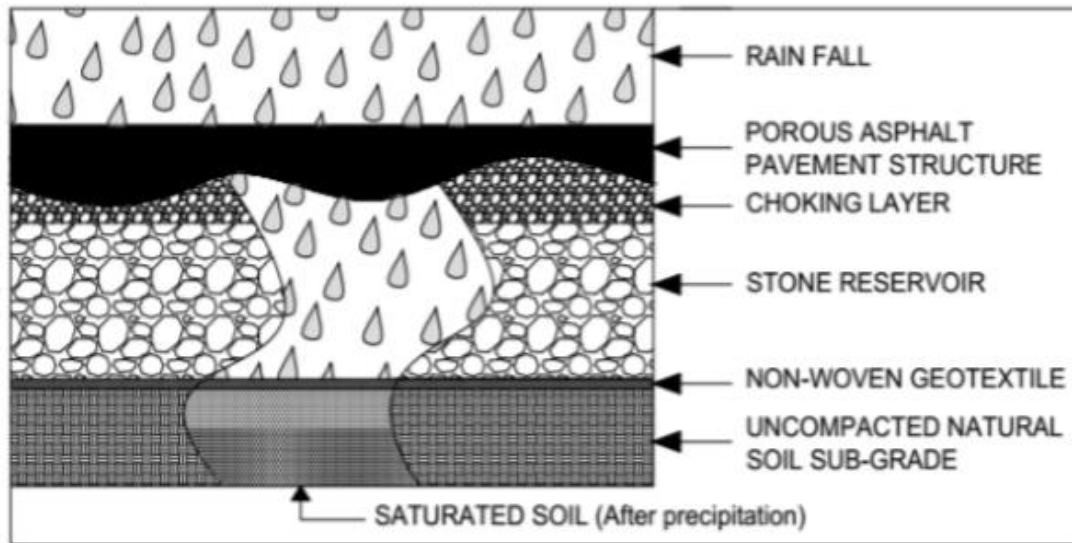


Figure 1.1 Working Process of Porous Asphalt Pavement

1.4 PROPERTIES

1.4.1 Surface Course Material:

The surface course of dense graded asphalt and open graded asphalt generally consist of asphalt cement and other materials such as coarse and fine aggregate with design gradation. For improving the performance of material, the different types of modifier or additives may be used. The main important purpose of providing surface or wearing course is to act as the loading platform, increasing safety of road users, increase ride quality and found to be aesthetically attractive.

1.4.2 Air Void Requirement:

The infiltration and permeability capabilities of porous asphalt pavement are one of the critical properties of the structure. The crucial or important factor is to maintain the porous asphalt pavement so, that the porosity does not affect and the pavement structure to remain functional.

The air voids percentage is different for dense and porous asphalt pavement. Generally, the percentage of air voids for dense graded mix is 3% to 5%. If the percentage of air voids is less than 3% have been resulting in rutting of pavement and the percentage of air voids is greater than 5% have resulted in raveling or cracking due to oxidation of asphalt binder. The percentage of air voids for porous asphalt mixtures is minimum 16% and significantly higher in order to stimulate sufficient permeability and infiltration.

1.4.3 Selection of Asphalt Binder:

The selection process of asphalt binders that required in asphalt concrete pavements are generally categories according to the modified bitumen and viscosity graded asphalt cements (VG).

The viscosity graded bitumen is graded by viscosity at 60°C and classification is based on the viscosity of four grades. Table 1.1 shows stability provided for maximum air temperature.

Table 1.1 Criteria for Selection of Viscosity-Graded Paving Bitumen Based on Climatic Conditions Highest Daily Mean Air Temperature, °C

Lowest Daily Mean Air Temperature, °C	Less than 20°C	20°C to 30°C	More than 30°C
More than -10°C	VG-10	VG-20	VG-30
-10°C	VG-10	VG-10	VG-20

The modified bitumen used for high performance projects such as airfields, highway and for other works like allied maintenance and construction. The modified bitumen consists of different types of polymer and rubber modified binder. The guidelines for selection of viscosity grade of bitumen as shown in Table 1.2 and Table 1.3.

Table 1.2 Viscosity Grades of Bitumen and its Applications

Viscosity Grade (VG)	General Applications
VG-40 (40-60 penetration)	Use for particularly stressed areas e.g. near the toll booths, in intersections, and parking lots of heavy vehicles such as truck in lieu of old 30/40 penetration grade
VG-30 (50-70 penetration)	Use for construction of roads or paving in mostly areas of India in lieu of old 60/70 penetration grade
VG-20 (60-80 penetration)	Use for paving in cold climate, for high altitude areas of North India
VG-10 (80-100 penetration)	Use in spraying applications and for paving in very cold climate in lieu of old 80/100 penetration grade.

Table 1.3 Different Criteria of Selection for Grade of Modified Bitumen Highest Daily Mean Air Temperature, °C

Lowest daily mean air temperature, °C	Less than 20°C	20 to 30 °C	More than 30°C
	Grade of Modified Bitumen		
More than -10°C	PMB/NRMB 120 CRMB 50	PMB/NRMB 70 CRMB 55	PMB/NRMB 40 CRMB 60
-10°C or lower	PMB/NRMB 120 CRMB 50	PMB/NRMB 120 CRMB 50	PMB/NRMB 70 CRMB 55

Where,

PMB = Polymer Modified Bitumen

NRMB = Natural Rubber Modified Bitumen

CRMB = Crumb Rubber Modified Bitumen

When the commercial vehicles exceeds 2000 per day per lane and the highest daily mean temperature exceeds 40°C, VG-40 or modified bitumen of equivalent stiffness are recommended for bituminous concrete and top layers of dense bitumen macadam. VG-30 and VG-40 paving bitumen is used in the conventional paving while stiffer bitumen is needed for porous asphalt parking lot so that-

- At the time of transporting the bitumen from plant to the construction site, there are chances of drain down of bitumen but this is reduced by using stiffer bitumen.
- There is no scuffing when the wheels of vehicle parked are moved using power steering.

1.5 MODIFIERS AND ADDITIVES

One of the main failures related with porous asphalt mix is because of the properties of bitumen such as stiffness. The asphalt modifiers can help in decreasing the temperature susceptibility of the mixture. The additives such as anti-stripping agents help to promote adhesion between the aggregates and binder. The adding of additives and modifiers of different fibre are required to prevent draindown and increase the performance of mixture.

1.6 COMPOSITION OF OGFC/POROUS ASPHALT MIXTURE

1.6.1 Material selection

Material required for OGFC included asphalt binder, aggregate and additives if required such as fibre.

1.6.2 Design Gradation and Aggregates

OGFC/Porous asphalt mix consists of coarse and fine aggregates. The coarse aggregate required for maximize the voids and coarse aggregates are the form of crushed rock that can be retained on sieve size of 2.36 mm. The fine aggregates help to enhance the mix durability. The fine aggregates consist of small size that can be passing through the sieve size of 2.36 mm and should be retained on the sieve size of 0.75 mm. The typically coarse aggregate properties are shown in Table 1.4.

Table 1.4 Physical Properties of Coarse Aggregates of Porous Asphalt Mix

Test	Method	(%)	(%)
L.A. Abrasion	AASHTO T96	-	30
Flat & Elongated	ASTM D4791 (5:1)	-	5
	ASTM D4791 (2:1)	-	20
Fractured Faces (ff)	ASTM D5821 (2ff)	90	-
	ASTM D5821 (1ff)	100	-

The gradation of aggregate is important factor so that high level of permeability achieves. The gradation specification of OGFC/porous asphalt mixes shows in Table 1.5.

Table 1.5 Various Design Gradations Recommended for OGFC/Porous Asphalt Mixture

Sieve Size (mm)	Passing Percentage (%)		
	The Franklin Institute	NAPA (National Asphalt Pavement Association)	Cahill Associates
37.5	100	-	-
19	-	100	-
12.5	-	85-100	100
9.5	95	55-75	95
4.75	35	10-25	35
2.36	15	5-10	15
1.18	10	-	10
0.6	-	-	2
0.075	2	2-4	-

1.6.3 Other Design Gradation**1.6.3.1 Reservoir Course Material Characteristics**

The main purpose of reservoir course to store the water comes from rainfall or stormwater until the water can infiltrate to underlying soil. The reservoir course make sure that the performance of material under the saturated conditions that water could be tapped in this layer for a saturated period of time depending on its drain ability. The porosity of reservoir material should be higher than the surface material of approx. air voids 40%.

The recommended design gradation to obtain the higher percentage of air voids in the reservoir course is shown in Table 1.6.

Table 1.6 Recommended Design Gradation of Reservoir Course

Sieve Size	Percentage Passing
75 mm	100
-	90-100
50 mm	35-75
37.5 mm	0-15
19 mm	0-5
12.5 mm	-
0.150 mm	0-2

1.6.3.2 Fine Course Material Characteristics:

The fine course material used to provide construction or working platform for the surface layer and also provide filtering capabilities to some extent. The recommended of design gradation for the filter course material as shown in Table 1.7.

Table 1.7 Recommended Design Gradations for Filter Course

Sieve Size	Passing Percentage
12.5 mm	100
9.5 mm	0-5

1.6 BENEFITS OF OGFC/POROUS ASPHALT MIXTURES

- **Splash and spray during wet weather is minimized:** Splash like rolling wheels throw up water from puddles in the road surface and spray like throw up fine droplets of surface water in the air, so this splash and spray levels are very low on porous asphalts.
- **Hydroplaning potential during rainstorm is minimized:** It is the major advantages of Porous asphalt pavement and OGFC provides drainage so that water flows from the surface level. The good Tyre-pavement contact is maintained in the presence of large volume of water.
- **Skid resistance at high speeds during wet weather is improved:** Porous asphalt mix have macro texture due to which the friction numbers of these surfaces do not decrease rapidly as the other dense graded surfaces with increasing speed.
- **Wheel-path rutting is minimized:** Porous asphalt depends on the aggregates interlock for its stability and is generally placed at a thickness of approx. 19 mm. Consequently, rutting is minimized because there is no viscoelastic flow in the surface layer.
- **Reduced glaring at night during wet weather:** It is a well significant advantage of porous asphalt mix because most of the water is flowing below the surface, the mirror effect of the water film that occurs on the surface of dense graded pavements does not occur on porous asphalt. Reflected light from oncoming vehicles and light from objects adjacent to the highway are dispersed by the angularity of the porous asphalt surface.
- **There is better visibility of pavement markings, and**
- **Reduce tire-pavement noise.**

1.7 LIMITATION OF OGFC/POROUS ASPHALT

- **Permeability deterioration:** The permeability of porous asphalt surface decreases with increase in time, traffic and also due to clogging.
- **Premature ravelling:** Oxidation or hardening of the asphalt mix due to thin film thickness and air and water movement through the voids causes easily failure of the surface by ravelling or removal of material by traffic action.
- **Deterioration of underlying layer:** This has been a serve problem in areas where local aggregates generally used in base course layers.

1.8 OBJECTIVE OF THE STUDY

The objective of this study is to carry out:

- The laboratory investigations and performance evaluation of the OGFC/Porous asphalt mixture without using any types of fibres additives and modified binder.
- The laboratory test included such as Air voids test, Cantabro Abrasion Loss test, Drain down test, Marshall Stability test, Marshall Flow test and Permeability test.
- The design gradation follow as per NAPA IS -115 and binder should be used VG-30.
- The result will come under the specified limit as per the guidelines of NCHRP 640 Open Graded Friction Course Mixture Specification.
- The Permeability test, Marshall Stability and flow value test result should be specified the guidelines as per MORTH specification.
- The design thickness of layers with respect to hydraulic and structural design.

1.9 OUTLINE OF THESIS

The thesis has been characterized into five chapters:

- Chapter 1 is about the general introduction of the OGFC/Porous asphalt mix that consists of concept, technical specification, composition, benefits and limitation of the study.
- Chapter 2 provides the explanation of studies which have been conducted for the laboratory investigation and performance of OGFC mix since from the last decade.
- Chapter 3 explain the material that has used in the study and tests performed on these materials. This chapter also explained the experiments conducted on the OGFC mix.

- Chapter 4 conclude the result parts that are obtained from laboratory experiments and discussion of these results.
- Chapter 5 highlights the conclusion of the study and give some recommendations for future work.
- Chapter 6 conclude the design thickness of porous asphalt pavement.

2.1 GENERAL

Open graded friction course mix is the outcome of the effort to improve the surface frictional properties of the bitumen surface. For the last 20 years many studies have been conducted for the laboratory investigations and performance evaluation of Open graded Friction course/porous asphalt mixture. Some of the work done related to the present study is summarized in the following paragraph.

2.2 LITERATURE REVIEW ON THE OGFC/POROUS ASPHALT MIX

Shirke and Shuler (2009) had performed the Reverse Flush process for cleaning porous pavements. In this study, the main focus on the problem observed during the infiltration of water. Thus, the clogging has biggest barrier to the use of porous pavements. In this study, the author discussed the process of removing small particles that were trapped in the pores of the porous pavement by flushing water from bottom of the pavement to the top of the pavement. The clogging material, water pressure, pavement porosity and number of flushes are the four variables that were evaluated in laboratory experiment. Thus, the result indicated that the reverse flush process was independent of the porosity of pavement, effective on the each types of clogging material and work for lowest pressure tested. From the study, it was observed that the highest pressure for removal of particles was 21 kPa and the other highest pressure of 14kPa with equally removed particles at about 80 and 73%.

Liu and cao (2009) worked on the material composition required for porous asphalt pavement and its performance. This research had introduced the empirical equation for the air voids with respect to gradation from uniform experimental so that the required gradation target should be achieved. From the uniform experiment method, it has been found that the percentage of passing material from sieve size 2.36mm having dominant factor affecting the percentage of Air Voids and if the percentage of fine materials passing from sieve no.8 was higher than the Air Voids percentage decreases. The equation for the coefficient of permeability and air voids percentage calculated by using regression technique and the result

was concluded the permeability value increases with the air void increases. This study has highly recommended that the binder used for the porous asphalt pavement was high viscosity because this result in high performances for resistance to moisture damage. The result concludes from this study was helping in the construction of new porous pavement in China.

Putman and Kline (2012) investigated the comparison of different design methods for PA mix. The result of determining OBC was obtained from 14 procedures and all the procedures show different variability for the same source of aggregates. The mix design category of compacted mix sample shows largest variability. In some cases the range for binder content was wide as evaluated in the procedure like 5-7%. In other case, the OBC was observed as the lowest binder content in the range. This study had performed different test at the OBC. Therefore, adequate Permeability of mixture obtained that are required for porous asphalt pavement and other application like Long-Term Durability.

Punith et al. (2012) explained the laboratory investigation of OGFC mix and focusing on the study of mix for investigates the properties and use of OGFC mixes that containing Crumb rubber modified binder (CRMB), Reclaimed polyethylene modified binder (RPMB), and 60/70 grade of bitumen with cellulose fibre use. The laboratory test had explained in detail that include Cantabro Abrasion loss test, Drain Down test, Permeability test, Indirect Tensile Strength test, Rutting test, Skid Resistance test. They had observed that the abrasion loss was significantly lower value with modified binder than unmodified binder. This result shows in increasing the durability of the OGFC mixes. Then, the Permeability test value resulted in decrease with the increase in binder content. It has been observed that the indirect tensile strength for OGFC mix improved by modification of binder with CRMB and RPMB. The result values of ITS for the mix were 20.11 and 34.96% for 25 blows, and 19.36 and 33.5% for 50 blows respectively. Moisture susceptibility value as measured was less with modified binder as compare with unmodified binder and fibres. The TSR value has observed 76, 94 and 96% for OGFC mix with 25 blows on each side, and 78, 95 and 98% with 50 blows on one side of the samples.

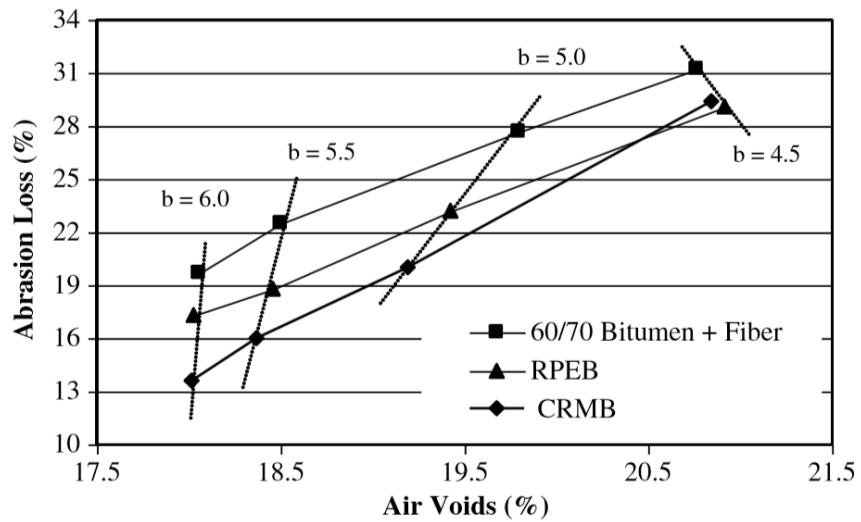


Figure 2.1 Ratio of Air Voids and Abrasion Loss for 25 Blows on each side (Punith et al., 2012)

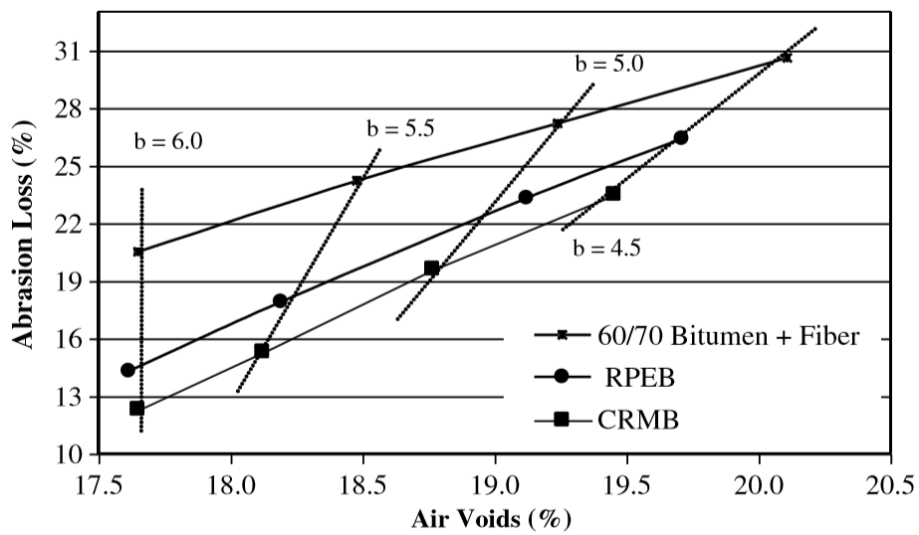


Figure 2.2 Ratio of Air Voids and Abrasion Losses for 50 Blows on one side (Punith et al., 2012)

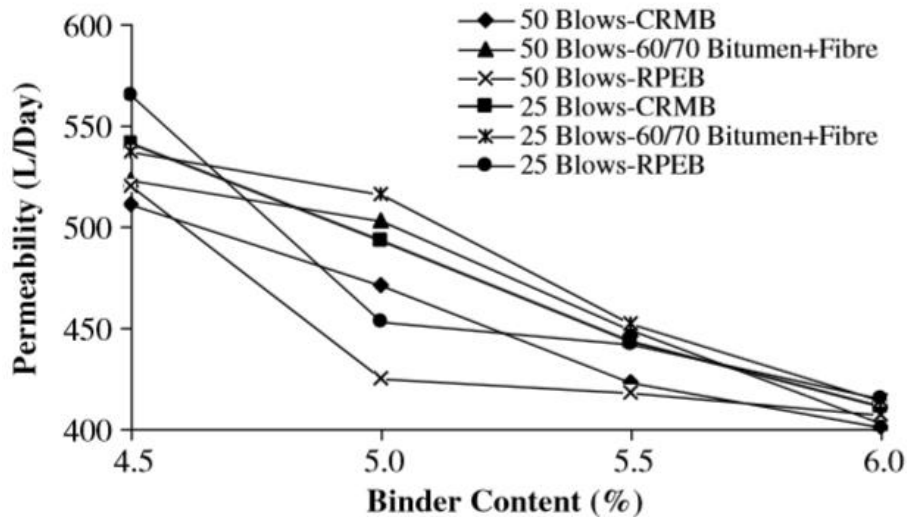


Figure 2.3 Permeability of the OGFC Mixture
(Punith et al., 2012)

Zulkati et al. (2012) had evaluated the properties of asphalt concrete mix by using different fillers. The optimum binder content was determined by adopting the method of Marshall Mix design. This study had evaluated the three wearing course (W3B) mix incorporating hydrated lime, Granite and kaoline as the filler. The kaoline and hydrated lime has relatively higher surface area higher. The W3B with kaoline and hydrated lime mix shows higher resistance in deformation than the other granite mix. The study had concluded that the adding of filler in asphalt concrete mix enhance the performance of mixture in different ways: (1) filler affect the percentage of asphalt in the mix (2) affect the workability at the time of compaction and mixing, and (3) contribute in increasing the performance properties of mixture.

Goh et al. (2012) had evaluated the mechanical properties of the porous asphalt mix with the use of additives such as warm mix asphalt (WMA) and reclaimed asphalt pavement (RAP). In this study, four different porous asphalt mixes were evaluated: (1) control mix (2) mix with 15% containing RAP (3) mixture with warm mix asphalt (4) conventional mix of porous asphalt. The result of gyratory compactor required the compaction energy of 0.25% and it was found the lower as compare to other mix (RAP). The test result for Permeability concluded that the addition of RAP decreases the permeability. The result observed from ITS test shows that the warm mix asphalt was obtained low value. But the addition of WMA and RAP, result in higher permeability value. From the study result, it can be observed that the use of RAP percentage in design mix should be higher.

Lee et al. (2014) determined the hydrologic processes for evaluating the permeable pavement by using new model unit process. The model process used can be arranged with the physically based parameters, which are Manning flow friction parameter, hydraulic conductivity, water content capacity, density and porosity. The high frequency data had used to calibrate the developed model. The model used to simulate the exfiltration from the storage to the surrounding, infiltration through the permeable surface, and clogging impact on exfiltration/infiltration capacity at the surface of the pavement and at the bottom of subsurface storage unit. From the modelling result, it can be concluded that the determination of hydrologic performance where the storage system in a long, narrow shape was totally depend upon the factor of horizontal exfiltration through side walls of subsurface storage unit.

Frigio et al. (2014) investigated the laboratory evaluation of reclaimed asphalt (RA) in Porous asphalt (PA) mix. The objective of the study was evaluating the use of RA from the old porous asphalt as aggregates in new porous asphalt mixes. From the study, the results had concluded that the adding of 15% recycled aggregates in PAM does not compromise the durability and performance of the porous asphalt layers. It has been important to select adequate binder content. From the laboratory experiment, it has been concluded that the recycled mix with binder content of 5.25% and proper mix design perform better result with the standard porous asphalt mix in term of abrasion resistance, workability, repeated loading resistance, moisture sensitivity, and drain down of water.

Kumar et al. (2014) study objective to obtain the mix design procedure of porous asphalt pavement to achieved recommended gradation by NCAT. In this study, the new generation open graded friction course (OGFC) mix design used for obtaining the OBC. This study evaluates the performance of OGFC mixture in the laboratory and resulted in adequate durability and permeability that suits for Indian climate.

**Table 2.1 Determination of Optimum Binder Content for Porous Asphalt Mix
(Kumar et al., 2014)**

Binder Content %	Air Voids %	Cantabro Abrasion Loss(un-aged) %	Cantabro Abrasion Loss(aged) %	Drain Down Potential %
	18% min.	20% max.	30% max.	0.3% max.
5	31.78	54.22	41.22	0.155
5.5	30.81	21.69	30.16	0.219
6	29.03	17.30	24.30	0.298
6.5	30.27	10.65	19.30	0.389
7	27.48	4.40	24.50	0.819
7.5	28.58	13.27	38.77	0.960

Table 2.2 Permeability of Porous Asphalt Specimen (Kumar et al., 2014)

Binder Content %	5.5	6.0	6.5
Co-efficient of Permeability cm/sec	0.49	0.39	0.33

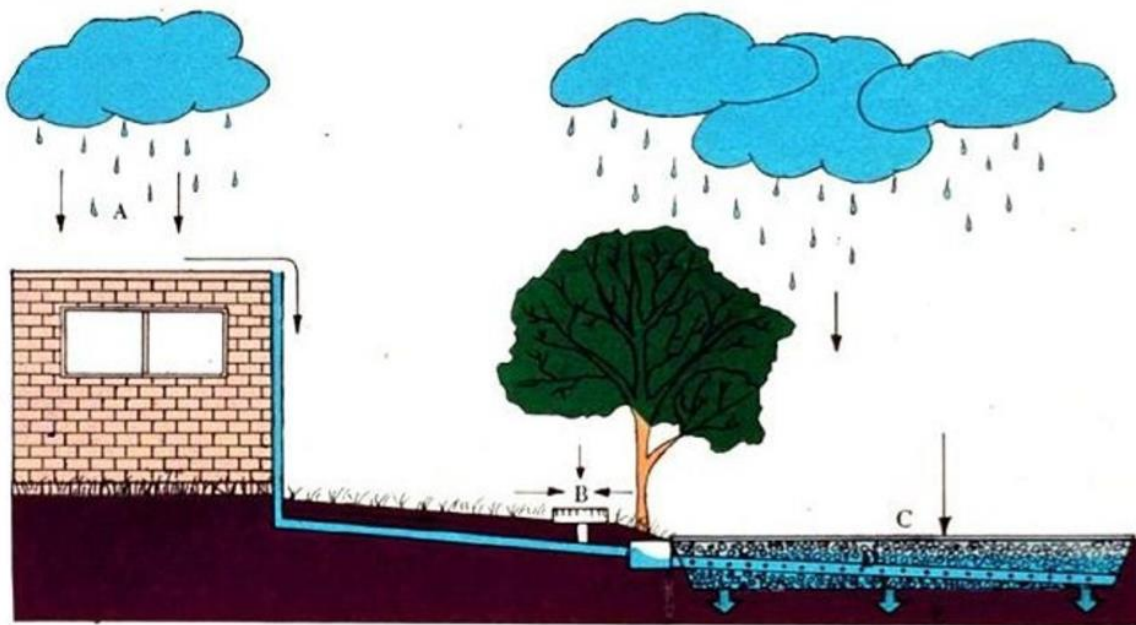
Table 2.3 Marshall Stability and Flow of Porous Asphalt Mix (Kumar)

No. of blows	Marshall Stability Kg	Flow Mm
50	1213.6	4.60
60	1395.3	3.75
75	1607.2	2.36

In this study, the binder used such as Crum rubber or Polymer modified bitumen. It has observed that by using modified binder the Cantabro Abrasion loss reduced by increase of binder content percentage and Drain Down value exceeding after binder content 6% obtain. The result value was observed for the performance Permeability test at different binder content shows that increase in binder content, the value of permeability decreases.

Chen and wong (2014) had investigated the properties of open graded asphalt mix with the use of solid waste aggregates. This study has evaluated the porous asphalt mix (PAM) with the use of recycled concrete aggregates (RCA) and waste glass. The mix containing RCA percentage was 78 and 16% for glass waste particles. The size of glass particles take as medium or smallest. From the result, it has observed that the use of medium size glass waste resulted as weaker in the dynamic creep test but the fine size glass shows higher resistant against the abrasion loss. It has been concluded that the porous asphalt mix with the use of recycled materials have more paving strength or potential and it is a type of conservation resource of waste material.

Kandhal and Misha (2014) focused on the rain water harvesting by constructing the porous asphalt pavement. The parking lot or low traffic roads are useful for the rain water harvesting. This study explain the concept that the porous pavement can be combined with the roof of the buildings or houses for the rainwater harvesting system by diverting the rain water from roof to the porous pavement stone bed as shown in Figure 2.7. The stone bed was constructed of open graded material about 225mm thick.



**Figure 2.4 Roof rainwater harvesting integrated with porous asphalt pavement
(Courtesy NAPA, Kandhal and Misha, 2014)**

Putman *et al.* (2015) had explained the flow of binder in the OGFC mixtures due to the force of gravity experienced at the high temperature of climate. The study has been focused on the long-term drain down in the field observations of OGFC mixtures. In this study, the three different types of OGFC mixtures are used, one made with cellulose fibres, second with ground tire rubber modified binder and other with Evotherm 3G. The Permeability test of the different mixes has done throughout for 84 days conditioning period at 60°C temperature. It has observed that the result for permeability of all the three mixes decreased over the first 56 days after that increased for other remaining 28 days. The result indicated that the long-term drain down for cellulose fibres does not show any type of influence but other mixtures show slightly lower rates of permeability loss.

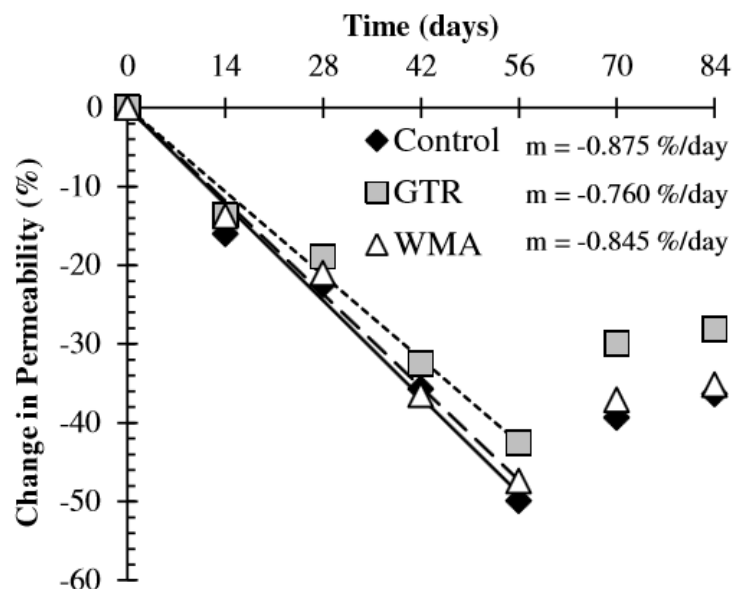


Figure 2.4 Average Changes in Permeability Over Time and Average 56-Day Slope for each OGFC Mix (Putman *et al.*, 2015)

Zhang *et al.* (2015) study the coarse aggregates voids filling (CAVF) method for designing the porous asphalt mix. This paper studies the conflict between the Drainability and Durability of PAM. By using the CAVF method, the high-temperature stability, water stability, skid resistance and permeability of the PAM exceeded the values when compare with the standard requirement values. The stability value of mix has observed good at 70°C temperature also. From this study, the CAVF method introduces a new design for porous asphalt mix.

Winston et al. (2016) had determined the infiltration rate of Permeable pavement to allow the storm water to pass through the surface of pavements. In this study, the different methods for maintenance of surface infiltration rate (IR) for permeable pavements have explained in detail. The ASTM and simple infiltration test (SIT) method was compared by taking a total 873 infiltration rate tests at the same locations on the 12 permeable pavements. It has been observed that if greater lateral movement of water under the ASTM infiltrometer resulted in 30% higher infiltration rate (IR) for ASTM test than the SIT method because it has larger surface area that result in less lateral flow. From this study, it has concluded that ASTM method more accurate than the SIT for newly constructed permeable pavements not exhibiting clogging. In other case, for heavily clogged permeable pavements, the SIT have higher infiltration rate than the ASTM, because the surface area of SIT larger.

Hassan et al. (2016) had evaluated the different open graded mix that are adopted in different countries (Australia, Singapore, Malaysia, United State) for porous asphalt mix. The main focused of this study was to determine the Air Voids properties and Permeability performance of porous asphalt mix. The method adopted in this study to determine the air voids properties of porous asphalt mix was image analysis technique. The image of compacted specimen has capture by using non-destructive scanning technique of X-ray computed Tomograph (CT). This study has evaluated the result between air voids and permeability values. From the study, it has been concluded that the specimen of Singapore gradation show less permeability as compare to other types. Because the fines particles present in the gradation have high percentage than the other and therefore, this result in fill up the voids. The characteristics of air voids was also analysed in horizontal and vertical cut section that describe the formation of air voids within the mix on the rate of permeability for porous asphalt.

Alyaseri and Zhou (2016) had described the study to reduce the volume of stormwater in the combined sewer type system. The better technique required for reduction in water quantity such as permeable pavement. This study has observed that the entire test related to reduction of stormwater runoff. The runoff comparison has been done between the post-construction and reconstruction of the permeable surface. For the comparison of runoff, the three different pavement types are considered that shows the result in different percentage of reduction in runoff. From the observation, the runoff reductions are obtained as 13, 36 and 46% from permeable asphalt, permeable concrete and permeable pavers. From the study, it has been

concluded that the higher percentage was obtained from the permeable paver and the lower percentage value obtained from permeable asphalt for the requirement of reduction in runoff.

Chen et al. (2016) had performed the laboratory experiments and field evaluation of porous asphalt mixtures. The laboratory tests included Drain Down resistance and Durability that are conducted to study the properties of porous asphalt mixes. The binder used for this study of three different types was conventional bitumen (CB), high-viscosity bitumen (HB), polymer modified bitumen (PB) and cellulose fibres also used to enhance the durability and strength of mix.

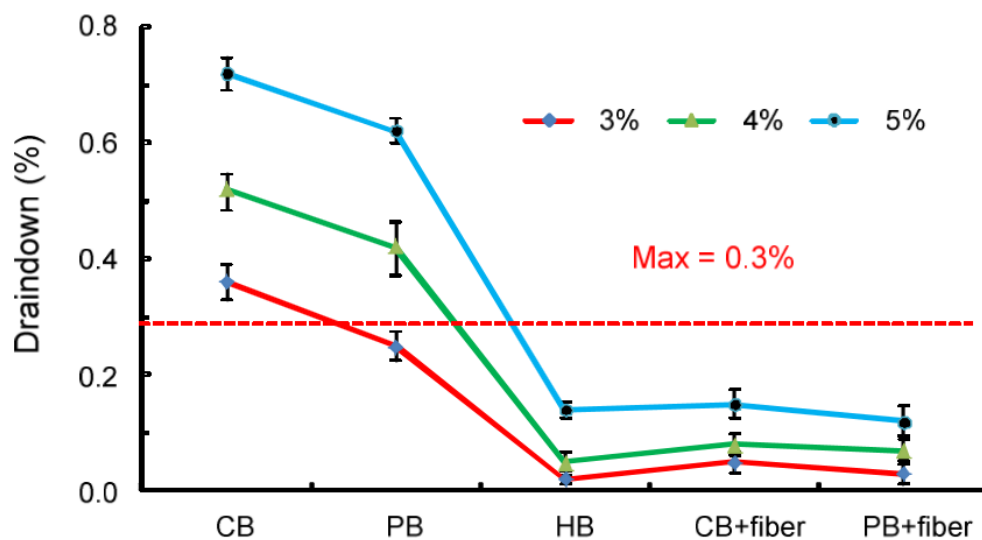


Figure 2.5 Laboratory Results of Drain down Test (Chen et al., 2016)

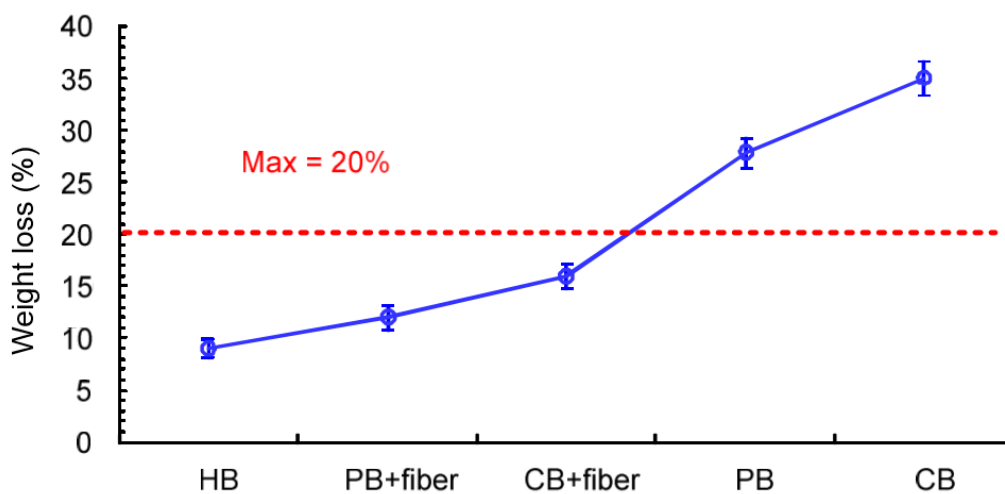


Figure 2.6 Laboratory Results of Abrasion Test (Chen et al., 2016)

From the study, it has been concluded that the Drain Down result values are greater without adding fibres and the use of these additives result in resistance to drain down especially for HR mixtures. The result for Cantabro Abrasion loss also decreases with use of polymeric bitumen. The performance Drainability test result for polymer modified binder was higher than the other asphalt section.

Khilari et al. (2017) had investigated the properties of porous asphalt mixture (PAM) by using Crumb rubber. This study depends on the two steps. First, the determination of OBC for the design mix and the later step was use of rubber content of three different percentages 50, 40 and 30 of bitumen. From the study, it has been concluded that the drainage performance of the mixtures decreases with increase in the rubber content because the pores in the mix filled with particles of crumb rubber. The overall properties increases with the additional use of crumb rubber like strength for the porous asphalt mix.

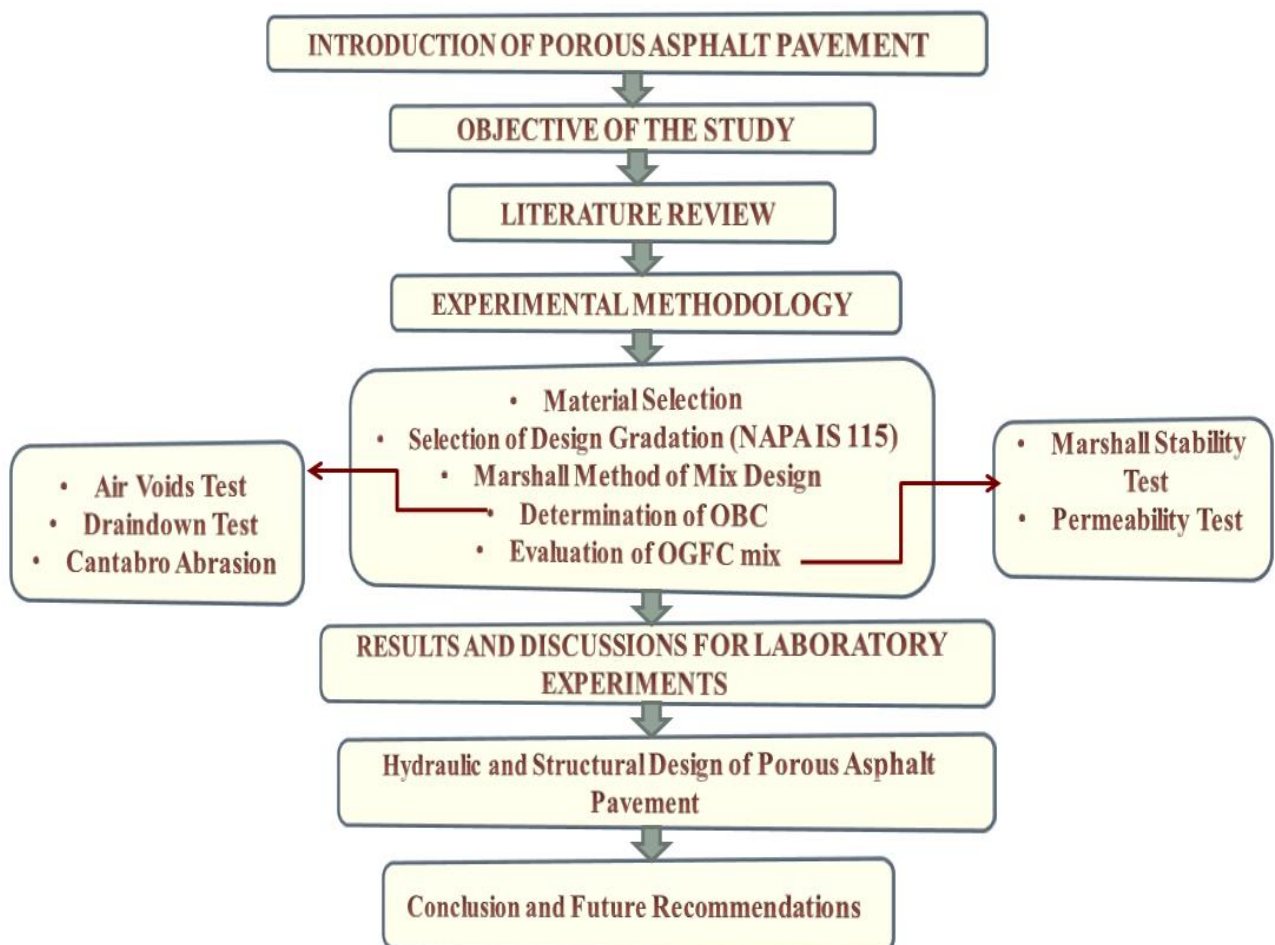
Bala et al. (2017) had evaluated the performance of asphalt mix and modified the asphalt with mixture nanosilica and polyethylene. This study also explained the concept of response surface methodology (RSM) used for the prediction of volumetric properties of marshal sample. From the study, the results indicate that nanosilica and polyethylene increases the properties of asphalt mixtures. This result has concluded the decrease in drain down, decrease in abrasion loss and improves the rutting resistance and indicates the better result for performance of asphalt mix. The other method explain in this study was RSM that developed the model equation and shows a high degree of correlation and ability to predict the volumetric properties of marshal mix.

Patil et al. (2018) had focused on making best quantity and quality of ground water. In this study, the main focus on the constructing pavement model. The pavement model shows the negligible runoff on the surface of pavement top layer that means the water drain through the constructed model. This result conclude that the safety of drivers increase, also vehicles in wet condition.

2.3 GAP IN LITERATURE REVIEW

The previous literature shows that work had been conducted on the OGFC/Porous asphalt mixture by using different types of fibre, modified bitumen, solid waste for laboratory investigation and performance evaluation of open graded mix. The above studies or research work had been focused on the properties Air voids percentage and permeability of the mix. Some research had worked, by using different gradation of aggregates. It was found common that asphalt binder were mainly modified or mixed with other additives for increasing the properties of open graded/porous asphalt mixture. But in case of this research, I have focused on the laboratory testing and evaluation by using basic requirement such as bitumen used is VG-30 and no modified or additives are required because the result of this study, concluded that all the properties of mix are under permissible limits. Therefore, no need adding any type of additives or fibres.

2.4 OUTLINE OF THESIS



EXPERIMENTAL METHODOLOGY

3.1 GENERAL

The purpose of this chapter is to present the research methodology employed in this study. The experimental methodology for this research has performed into two parts. Firstly, the determination of suitable mix for porous asphalt/OGFC and other part has to examine the performance of the mixtures through specific performance testing.

3.3 MIX DESIGN

This part describes the procedures for determining the porous asphalt/OGFC mix design. The mix design is conducted in following steps:

- Material selection
- Selection of design gradation
- Determination of optimum asphalt or binder content
- Evaluation of OGFC mix

3.2.1 Material

The different material has required for the laboratory evaluation of OGFC/porous asphalt mix samples for this research. The materials used for this research has included different types of aggregates and asphalt binder. For evaluating the performance properties of the material that can be used is experimentally tested in laboratory to obtain the recommended result values. All the basic tests are important to perform such as penetration test, softening point test and specific gravity tests.

3.2.4 Bitumen

In this study, the penetration grade of bitumen 60/70 and VG-30 is used. The different test has performed on bitumen in the laboratory for the evaluation of its physical properties. There

are different types of tests that performed to obtain the properties of asphalt binders. These different tests are conducted during the study on asphalt binder are explained below. The source of bitumen in this study is from Ashoka Buildcon Company.

3.2.2.1 Penetration Test

Penetration test is used determine the consistency of the binder. This test is important to obtained the grade of bituminous material by measuring the depth (in units of one tenth of milli-meter) in which a standard needle will penetrate vertically under controlled conditions of standard load, temperature and duration. The principle of penetration test is to measure the penetration of a standard needle in a bitumen sample has maintained at 25°C for 5 seconds that make the bitumen sample soft so that it can be moved easily and transferred into containers. A grade of 60/70 bitumen means the penetration value is in range of 60 to 70 mm at standard conditions.

3.2.2.2 Specific Gravity Test

The specific gravity of bitumen is the fundamental property. The bitumen content has calculated on the volume basis because at time of final mixing the bitumen has mixed with aggregates. Therefore, this test is important for calculation of weight to the volume. By adding some fibres or additives, the chemical composition of bitumen can be affecting the specific gravity of material. The specific gravity of the binder can be measured using Pycnometer and value varies from 0.97 to 1.02.

3.2.2.3 Softening Point Test

The purpose of determining the softening point of bitumen has to obtain the fluidity of binder because it's important for bitumen grade to obtain some sufficient fluidity before mixing with aggregates. The procedure of the test involves the heating of bitumen material and temperature has noted at which point the bitumen obtain particular softening degree under the standard conditions of test. The method has been used for testing is Ring and Ball method. This method consist of equipment like a brass ring which holds the bitumen test sample then suspended in water at a specified temperature. After that, the steel ball has placed over the ring containing bitumen and start heating at a specified rate. The temperature has been noted

at which the softened bitumen touches the metal plate placed at a specified distance of 25 mm below the ring. This temperature is known as the softening point of bitumen test sample.

3.2.2.4 Viscosity Test

This test is used to determine the degree of fluidity of bitumen sample for different temperature that helps to know the properties of bitumen to penetrate, spread and to fill the voids. The viscosity test has performed with the help of MCR 52 Dynamic Shear Rheometer (DSR) as shown in Figure 3.1. The spindle of 25 mm diameter is used to check the viscosity of the bitumen grade VG 30 at temperature of 60°C. The shear rate given to the spindle is 4 revolutions per seconds for the duration of 120 seconds.



Figure 3.1 Dynamic Shear Rheometer

Table 3.1 Specifications of Different Test Conducted on Bitumen

S. No.	Description	Value specified in IS:73-2013
1.	Penetration Test (mm) at 25 ⁰ C	45 minimum
2.	Softening point test, ⁰ C	47 minimum
3.	Specific gravity Test	0.97-1.02
4.	Viscosity Test at 60 ⁰ C, (Poise)	2400-3600

3.2.3 Aggregates

The aggregates required in the OGFC mixture consist of coarse aggregates and fine aggregates. Also, the small percentage of filler has also used in this mixture design. Aggregates are the basic need for paving any pavement. For each layer of pavement, the aggregates are used as stabilized or as an un-stabilized base material or sub-base material. The aggregates have tested for obtained the basic properties values that satisfy the guidelines as per MORTH specifications and IRC codes. The source of aggregates in this study is used from the construction site of Chandigarh to Ludhiana National Highway.

The following tests are conducted to evaluate the properties of the aggregates used in this study.

3.2.3.1 Aggregate Impact Value (AIV) Test

This test method has been followed as per IS: 2386 Part 4. The AIV test provides the result value for aggregates strength property under sudden loading condition. This property shows the toughness of aggregates that defined the ability of material to resist the load or impact. The maximum 18% Impact value is allow. The two trials of test sample are taken for finding the Aggregate Impact value and the average of the trials has been taken as the resulted value of test. The results of Aggregates Impact value test are shown in Table 3.2.

Table 3.2 Results of Aggregate Impact value Test

Description	Trial-1	Trial-2
(a) Wt. of Aggregates before testing, gm	330	330
(b) Wt. of Aggregates that retained on sieve size 2.36mm, gm	289	282
(c) Wt. of Aggregates that pass through sieve size 2.36mm, gm	41	48
Aggregate Impact Value (%), $c/a * 100$	12.42	14.54
Average Aggregate impact value, % (Max 18%)	13.48	

3.2.3.2 Specific Gravity Test

This test method has been followed as per IS: 2386 Part 3. The specific gravity of the aggregate shows the strength of the material. Aggregates having the higher value of specific gravity are seen to be stronger than the other having low specific gravity values. It is the ratio of mass of a unit volume to the mass of an equal volume of gas free distilled water at the stated temperature. It is also expressed as the ratio of the density of the aggregate particles to the density of water. The results of the Specific gravity test are shown in Table 3.3.

Table 3.3 Specific Gravity Result Value for Aggregates

S. No.	Aggregate Size	Bulk Specific Gravity
1	Coarse	2.636
2	Fine	2.621
3	Filler	2.581

3.2.3.3 Water Absorption Test

This test method has been followed as per IS: 2386 Part 3. Water absorption is also one test that determined the porosity and strength property value of the aggregates. Aggregates which shows lower value of water absorption test are result in more stronger but if higher value of water absorption test are obtained that shows the property of more porous and are not suitable for the construction of highways unless they are found to be acceptable based on

strength, impact and hardness tests. The maximum value for water absorption test is allowed 2%. The result value of the water absorption test is shown in Table 3.4.

Table 3.4 Result value of water Absorption Test

Description	Trial 1	Trial 2
(a) Wt. of saturated surface dry weight, g	2024	2028
(b) Wt. of oven dry sample, g	2000	2000
(c) Water Absorption, $100*(a-b)/b$	1.2	1.4
Average Absorption %	1.3	

3.2.3.2 Los Angles Abrasion Test

This test method has been followed as per IS: 2386 Part 5. The aggregates used for surface layer of pavement are resulted in wearing action at the top of the pavement which is due to the heavy traffic movement. The abrasion test used to obtain the hardness value of aggregates and this property shows the resisting value of abrasion due to movement of traffic load. This test describes the durability property of aggregates. The aggregates that are used should be strong or hard. Therefore, the Los Angles Abrasion Test is performed to obtain the resistance to wear. The results value of the abrasion loss is given in Table 3.5

Table 3.5 Results of Los Angles Abrasion Test

Description	Trial 1	Trial 2
Wt. of Specimen, g (W_1)	5000	5000
Wt. of Specimen after Abrasion test, retained on sieve size of 1.70 mm, g (W_2)	4086	4091
Los Angles Abrasion value (%) = $100*(W_1 - W_2)/ W_1$	18.28	18.00
Average (%)	18.14	

3.2.4 Gradation for OGFC/Porous asphalt mix

The gradation for the OGFC/porous asphalt mix has been adopted as per guidelines of NAPA IS-115. The adopted gradation for OGFC/porous asphalt mix has shown in Table 3.6, while the gradation graph has shown in Figure 3.2. The gradation of mid-point has been selected and this gradation has seems to show better properties as compared with lower and upper point gradations.

The OGFC mix must have a coarse aggregates skeleton with stone-on-stone contact to minimize rutting. Coarse aggregate is defined as the aggregates fraction retained on a 4.75mm sieve. The OGFC mixes have nominal maximum aggregate size (NMAS) of 9.5 to 12.5mm.

Table 3.6 Gradation for OGFC/Porous Asphalt Mixture as per NAPA IS-115,

(National Asphalt Pavement Association, Information Series)

Sieve size(mm)	Limits as per NAPA IS-115		Mid-value(Percentage)	Cumulative percentage retained	Percentage retained
	Lower	Upper			
19	100	100	100	0	0
12.5	85	100	92.5	7.5	7.5
9.5	35	60	47.5	52.5	45
4.75	10	25	17.5	82.5	30
2.36	5	10	7.5	92.5	10
0.075	2	4	3	97	4.5

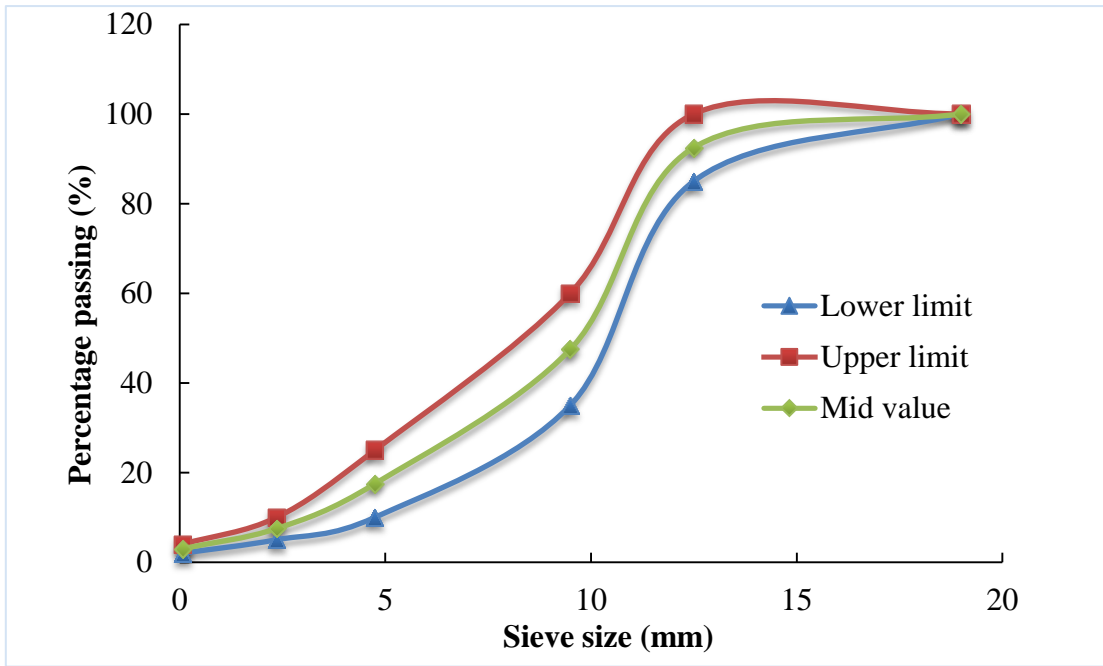


Figure 3.2 Design Gradation for OGFC/porous asphalt mixture as per NAPA IS-115



Figure 3.3 Shows the Different Size of Aggregates used as per the Gradation (NAPA IS-115)

3.2.5 Marshall method of mix design procedure

3.2.5.1 General

Marshall Mix Method has been followed as per guidelines of MS-2 Asphalt Mix Design Methods (7th edition). The concept of the Marshall method of designing bituminous mixtures was first introduced by Bruce Marshall, a former Bituminous Engineer in the Mississippi State Highway Department. The Marshall Mix Design method is commonly preferred to describe the bituminous mixes and used to calculate the Optimum Binder Content (OBC) for different mixes at different binder content. From the Marshall Mix Design method, the different properties of Marshall Mix sample can be concluded.

3.2.6.2 Objective

The Marshall characteristics such as Marshall Flow value, Marshall Stability value, Voids in Mineral Aggregates (VMA), Voids Filled with Bitumen (VFB), Unit Weight in mixture etc., of all these mixes has studied. The main objective for preparing the Marshall sample is to analyse the voids and density of OGFC mix, find the weight loss from the compacted Marshall mix sample through the Cantabro Abrasion test and conducted the Drain Down test for un-compacted mix.

3.2.5.3 Preparation of Test Specimen

- For casting the Marshall Mix sample, the weights of aggregates are taken 1200 grams of specified design gradation as see in Figure 3.3. The aggregates along with the filler were heated to a temperature of 105⁰C to 110⁰C as the temperature was noted with the help of thermometer as see in Figure 3.4.



Figure 3.4 Shows the Aggregates heated to Obtained the Required Temperature.

- After this, aggregates were mixed with the binder content by weight of aggregates and temperature of the binder content about 170°C . The mixing of aggregates should be properly done that seem to be uniformly coated aggregates with the binder content as shown in Figure 3.5.



Figure 3.5 Mixing of Aggregates with Binder

- The mould of Marshall, collar of mould, base plates and the hammer are preheated in the oven about temperature of 95⁰C to 150⁰C. After this, arranged the Marshall mould for the preparation of the mix sample.



Figure 3.6 Marshall Mould Arranged with Collar and Base Plate

- All sample are heated to the obtained the compaction temperature of the mixture and compacted with a Marshall hammer. The mix sample are prepared in the mould should be the size of 101.6 mm in diameter and thickness of 63.5 mm but in case of OGFC/porous asphalt mixture, diameter same as the diameter of mould is 101.6 mm and height or thickness of mix sample varies.
- The variation in the height of the specimens are not in range that resulted in the variation of the volume for mix sample and then the correction factors can be applied if the dimensions are not in the specified ranges.
- The Marshall Mix sample has compacted by giving 50 blows on each face of mix sample and compacted by using the hammer of weight 4.5 kg and a drop of 457 mm.
- After compaction part is completed, keep the specimens to cool for over-night or 24 hours then remove the sample from the mould that looks like as shown in Figure 3.7 and 3.8 by using extrusion jack.



Figure 3.7 Specimen of OGFC Mix



Figure 3.8 Top Surface of Specimen of OGFC Mix

3.2.6 Volumetric Analysis

The volumetric properties of the compacted porous asphalt mixes were calculated by determining the bulk density. Bulk density of compacted specimen has calculated based on the average geometric volume of the specimen and weight. The volumetric property of the compacted specimen includes different terms. In Marshall Mix Design Method, each specimen undergoes the following analysis: Bulk Specific Gravity of the mix, Theoretical Specific Gravity of the mix, Percentage Air Voids, Percentage Voids in Mineral Aggregate and Percentage Voids filled with Bitumen

3.2.6.1 Bulk density (G_{mb})

Bulk density of the compacted specimen was determined based on the average geometric volume of the specimen and weight. The given equation as per AASHTO C29,

$$\text{Bulk Density} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \quad \text{Eq. 3.1}$$

Units,

Weight of specimen in (g)

Volume of specimen in (cm³)

3.2.6.2 Theoretical maximum specific gravity (G_{mm})

The theoretical maximum specific gravity is the specific gravity excluding air voids. If all the air voids has excluded from an OGFC mixture sample, the combined specific gravity of the remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. It can be determined by using following formula as per AASHTO T209. The formula does not account for the bitumen absorbed by the aggregates but it can be used with negligible error:

$$\text{Theoretical Maximum specific Gravity} = \frac{A}{A-C} \quad \text{Eq. 3.2}$$

Where

A = Weight of sample in air (g)

C = Weight of water displaced by the sample (g)

3.2.6.3 Voids in Mineral Aggregate (VMA)

Voids in mineral aggregate are determined on the basis of bulk specific gravity of the aggregates and is expressed as a percentage of the bulk volume of the compacted mix. Therefore, VMA is calculated by subtracting the volume of the aggregates determined by the bulk specific gravity from the bulk volume of the compacted asphalt mix by using equation,

$$\text{Voids in mineral aggregates} = 100 * \frac{(G_{mb} - P_A)}{G_{sb}} \quad \text{Eq. 3.3}$$

Where,

G_{mb} = Bulk specific gravity of mix

G_{sb} = Bulk specific gravity of aggregates

P_A = Percentage of aggregates by total weight of asphalt mixture

3.2.6.4 Voids filled with Bitumen (VFB)

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

$$\text{Voids Filled with Bitumen} = 100 * \frac{(VMA - V_v)}{VMA} \quad \text{Eq. 3.4}$$

Where,

V_v = Percentage of Air Void

3.2.7 Determination of Optimum Binder Content (OBC)

By using the design gradation that has adopted, prepared the OGFC/porous asphalt mix at different binder contents. Atleast prepared three test specimen of each asphalt content that has selected with normally increment of 0.5% of asphalt content but in this research, the increment of 0.25 percentage of binder content has preferred for better accuracy result.

The optimum asphalt binder content is selected when the OGFC mixture meets the following criteria: Drain down, Air voids, Abrasion loss on specimen.

The National Centre for Asphalt Technology recommends the optimum asphalt content for porous asphalt pavement can be achieve from following requirements as given in Table 3.6.

Table 3.7 Open Graded Friction Course Mixture Specification

As per NCHRP 640 Open Graded Friction Course Mixture Specification		
Test	Method	Requirement
Air voids	AASHTO T 331	18%-22%
Cantabro Abrasion	ASTM C 131	20% max.
Drain-down	AASHTO T 305	0.3% max.

3.2.7.1 Drain down Test

The Drain Down test is specially performed for open graded mixtures such as OGFC mix. This test has determined the value of binder that drain down from the un-compacted mixture. Drain Down is defined as the portion of mix which leaves itself from the sample and flows downwards when it is held at high temperatures. This problem can be faced during the transportation of mix and production storage of the mixture and it is significant for the mixes having high coarse aggregate percentage i.e. OGFC/porous asphalt mixture in which voids are larger which results in high drain down as comparison to other conventional mixes. Total 12 mix samples are tested for the drain down test.

Drain Down test is conducted as per AASHTO T305 on the mixture prepared at different percentage of binder content and has poured into the wire basket having a sieve cloth of size 2.5mm. A container or plate has taken and note the empty weight of plate then, the wire basket with the OGFC mix has poured in it is also weighed. The basket is then placed over the empty plate and kept in an oven for 60 minutes at 120 °C to 175 °C of the set temperature.



(a)

(b)

Figure 3.9 (a) and (b) Wire Basket with the OGFC Mix Sample

After 1 hour, the wire basket should remove from the oven and it has been observed that the binder from the OGFC mix has drained into the plate. The binder with fine particles has drained and set on the plate. After that, noted the weight of plate with drain material. The drain down is calculated as a percentage of the mass retained to the total mass of the mixture as in given equation,

$$\text{Drain Down} = \frac{(Z - Y)}{(X - W)} * 100 \quad \text{Eq. 3.5}$$

Where,

W= Weight of empty wire basket, g

X = Weight of wire basket with mix sample, g

Y = Weight of empty plate, g

Z = Weight of plate with drained sample, g

3.2.7.4 Air voids test

Air voids within OGFC mixture are controlled by the binder content and aggregate gradation. If air voids are too low then the asphalt binder content should be reduced. A minimum of 18% is acceptable, although higher values are desirable. The higher the air voids are then the design mix has more permeable.

For finding the air voids in the test specimens of the Marshall Mix of OGFC/porous asphalt, note the weight of the dry specimen and weight of the submerged specimen. It is important that there is no air voids at the time of taking submerged weight i.e. when specimens has fully submerged in water as see in Figure 3.11 only after that the weight has noted. The air voids is calculated as per given equation,

$$\text{Air Voids Percentage (V}_v\text{)} = 100 * \left\{ 1 - \left(\frac{M_{\text{dry}} - M_{\text{sub.}}}{\text{Volume of sample}} \right) \right\} \quad \text{Eq. 3.6}$$

Where,

M_{dry} = Mass of empty dry specimens, g

M_{sub.} = Mass of submerged specimens, g



Figure 3.10 Noted the Weight of Sample Suspending in Water

3.2.7.3 Cantabro Abrasion test

The resistance of compacted porous asphalt specimen to abrasion loss has analysed by means of the Cantabro test. This is an abrasion and impact test carried out in the Los Angeles Abrasion Machine as per ASTM C 131. In this test, compacted porous asphalt mix specimen is used. The mass of the specimen is determined to nearest 0.1gm and is recorded as P₁. The test specimen is then placed in the Los Angeles Abrasion machine without the charge of steel balls. The operating temperature is usually 25°C. The machine has operated for 300 revolutions at speed of 30 to 33rpm. The test specimen is then recorded and it's mass determined to the nearest 0.1gm (P₂). The percentage abrasion loss (P) is calculated according to given equation. The maximum permissible abrasion loss value for unaged compacted specimen is 20% maximum. The formula used as,

$$\text{Abrasion loss Percentage} = \frac{(P_1 - P_2)}{P_1} * 100 \quad \text{Eq. 3.7}$$

3.3.8 Performance Test for OGFC/Porous Asphalt Mix

The following performance test has carried out in this study on the OGFC mix samples. In this study, the two performance tests has conducted which included Permeability and Marshall Stability test

3.3.8.1 Marshall Stability test

The procedure which has used to test the Marshall specimen explains as follow:-

Measure the height of the sample at different three locations of the specimen. The specimen which are to be tested are kept immersed under water in a thermostatically controlled water bath maintained at 60 °C for 30 to 40 minutes. Remove the specimen from the water bath, then quickly dry the specimen and place it in the lower segment of the breaking head. Place the whole assembly in position on the testing machine as see in Figure 3.8. Apply deformation load at the rate of 51 mm per minute. Noted the failure load on the proving ring also, similarly analyse the deformation as see in Figure 3.9, the test specimen are totally bound between the lower and upper part under the applied load condition. The maximum load developed during the test is known as stability and the amount of deformation that takes places up to the movement of maximum load is termed as flow value.



Figure 3.11 Marshall Stability Machine



Figure 3.12 Deformed Mix Sample

3.3.8.2 Permeability Test

The permeability of the OGFC/porous asphalt mixture has measured using Constant head method in accordance to ASTM PS 129. Permeability test has used to determine the rate of permeability that represents the effectiveness of water transmission within the pavement layer. This test method covers the laboratory determination of the water conductivity of a compacted porous asphalt specimen. The laboratory permeability values are recommended greater than 100 m/day. The coefficient of permeability (k) was calculated using equation as stated in ASTM PS 129 for Constant head method is,

$$\text{Coefficient of permeability} = \frac{Q * L}{(A * t * h)} \quad \text{Eq. 3.8}$$

Where,

Q = Quantity of water collected in time (t), ml

A = cross section area of specimen, cm²

L = Height of sample, cm

h = constant hydraulic head, cm

t = time, sec

For determining the permeability of Marshall Specimen, the outer area has cover with tape and the mix sample has inserted in the standpipe of 9cm height as see in Figure 3.12. The sample with the standpipe has been sealed to prevent the leakage of water and so that the flow of water from sample is one direction. In this manually method, the water has poured through saturated asphalt mixture as see in Figure 3.13 and the time taken (t) was recorded for water to fall from fixed initial head of 15mm. The setup for permeability test is shown in Figure 3.14.



Figure 3.13 Marshall Mix Sample Fixed with Pipe



Figure 3.14 Water Maintained for Constant Head



Figure 3.15 Water Percolate through the OGFC Mix sample

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter describe the results performed from the laboratory investigations of the Open Graded Friction Course (OGFC) mix. All un-compacted and compacted mix samples are prepared from Marshall Mix design method.

The National Centre for Asphalt Technology recommends the optimum asphalt content for porous asphalt pavement can be achieve from following requirements that are air voids should be greater than 18%, drain down less than 0.3%, Cantabro Abrasion of un-aged sample less than 20%. For performance test, the laboratory permeability test of compacted OGFC mix is performed. The Marshall stability and Flow value was determined to achieve minimum value. According to MORTH specification 4th revision minimum stability value should be 8.2KN for Porous asphalt for desired temperature of 60°C.

4.2 RESULTS FOR BITUMEN TESTING

The different test was conducted on the bitumen sample. The penetration test was conducted to obtain the consistency of asphalt binder at specified temperature and assign the grade of asphalt while softening point test is used to obtain temperature for particular degree of melting under specified condition of test. The viscosity test indicates the movement or rate of flow. In this study, viscosity is higher so slower the rate of flow for bitumen VG-30. The test results for these different properties of bitumen are shown in Table 4.1.

Table 4.1 conclude that the binder is used having the appropriate properties of bitumen VG-30. In this study, as the binder agent only bitumen VG-30 is used to satisfy all the properties of OGFC mix. Use of only one specific binder agent that satisfied all properties for research make the research cost efficient without any additives.

Table 4.1 Tests Results of Bitumen

S. No.	Description	Value specified in IS:73-2013	Test Results
1.	Penetration Test (mm) at 25 ⁰ C	45 minimum	50
2.	Softening point test, ⁰ C	47 minimum	52
3.	Specific gravity Test	0.97-1.02	1.02
4.	Viscosity Test at 60 ⁰ C, (Poise)	2400-3600	3050

4.3 Results for Aggregate Testing

The aggregate test has conducted to determine the various specified properties of the mineral aggregates and the tests result was compared with MORTH's specifications. The test results are shown with allowable values in Table 4.2.

Table 4.2 Tests Results Conducted on Aggregates Used

S No.	Property	Results	IRC:SP:79-2008 requirements
1.	Aggregate Impact Value	13.48 %	24 % maximum
2.	Los Angles Abrasion Value	18.14 %	25 % maximum
3.	Water Absorption	1.3 %	2 % maximum
4.	Specific Gravity Test	2.638	-

4.4 Results for Air Voids Content

The Air Voids test data are presented in the tabular and graphically form. In this test, the percentage of binder varies from 4.25 to 7.5% on the increment of 0.25%. From Table 4.3, it can be observed that the air voids percentage of the 28 OGFC compacted mix sample varies with respect to binder content. The increase of binder from 4.25 to 6% resulted in increase of air voids. Also, most of the samples has test result that lie within the specified range of air

voids content that is 18 to 22%. With further increase in binder content, it can be observed that the higher binder result in decrease of air voids content. The result indicates the maximum value of air voids is 22.13% for a bitumen content of 5.75% as shown below in Table 4.3.

Table 4.3 Air Voids of Different Binder Content for OGFC/Porous Mix

BC, %	Height of specimen, L (cm)		Air weight (g)		Submerged weight (g)		Volume, V (cm ³)		Air voids, Av (%)		Average Air voids (%)
	S 1	S 2	S 1	S 2	S 1	S 2	S 1	S 2	S 1	S 2	Sample
4.25	8	8.1	1204	1218	680	687.5	628	635.85	16.56	16.56	16.56
4.5	7.6	7.7	1202	1211	706.5	710	596.6	604.45	16.94	17.11	17.03
4.75	7.9	7.7	1210	1211	710	721.5	620.15	604.45	19.37	19.01	19.19
5	7.7	7.8	1195	1210	713.5	715	604.45	612.3	20.34	19.15	19.74
5.25	7.8	8	1194	1203	708	706.5	612.3	628	20.62	20.93	20.78
5.5	7.7	7.1	1174	1090	699.5	659	604.45	557.35	21.49	22.66	22.08
5.75	7.7	7.3	1114	1118	650	665.5	604.45	573.05	23.23	21.03	22.13
6	7.8	7.7	1142	1129	669	645.5	612.3	604.45	22.75	20.00	21.38
6.25	8.1	8	1201	1205	660	668	635.85	628	14.91	14.49	14.70
6.5	8	8.1	1204	1201	662.5	654	628	635.85	13.77	13.97	13.87
6.75	7.8	8	1200	1215	663	668	612.3	628	12.29	12.89	12.59
7	8	8.1	1209	1217	657	659.5	628	635.85	12.10	12.32	12.21
7.25	8.2	8	1241	1236	663	671.5	643.7	628	10.20	10.11	10.15
7.5	7.9	8.1	1239	1243	679	670.5	620.15	635.85	9.69	9.96	9.83

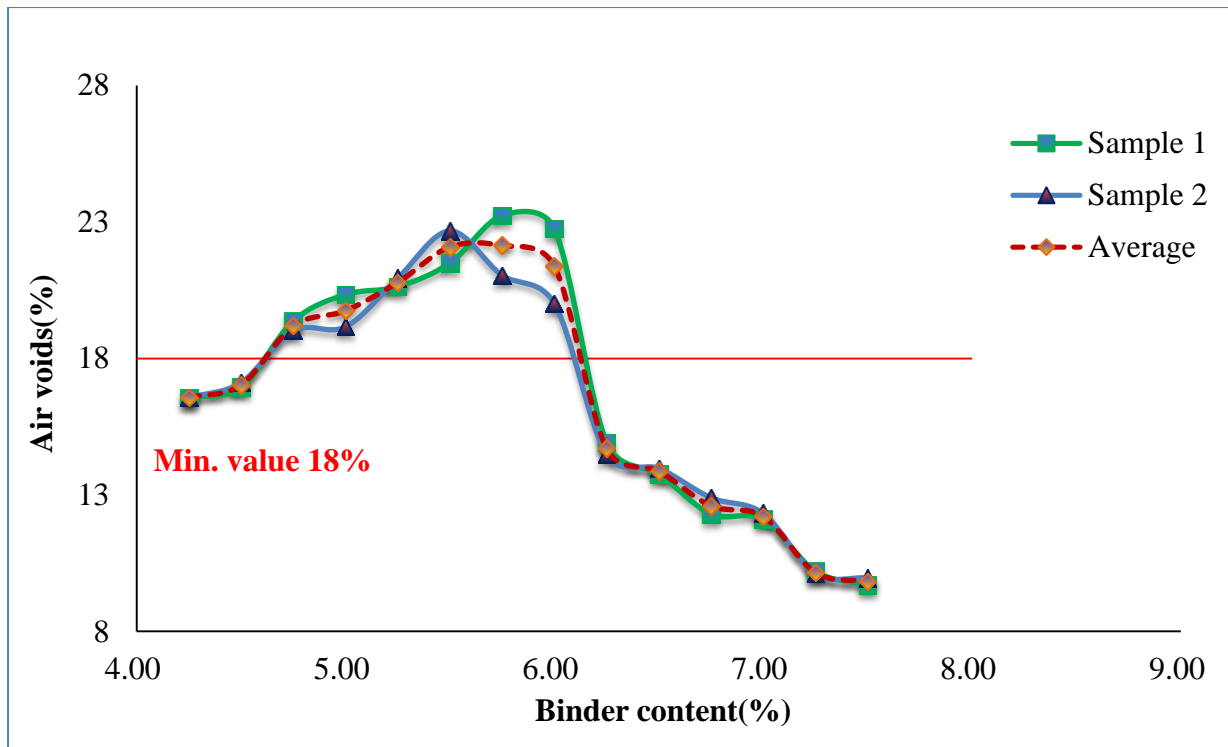


Figure 4.1 Variation of Air Voids with Binder Content

4.5 Result for Drain down

The Drain down test has conducted on loose mix samples for binder content range from 4.25 to 7.5%. The increase of binder content in OGFC mix have a tendency to cause drain down of the bitumen content during the time of mixing of mixture, storage and transportation. If the drain down result values in excess of 0.3%, the type of binder or amount or fiber additives can be adjusted or added. But in this study, there is no need of adding any type of fibers because the result indicates the value for drain down lie within the minimum range required. From the Table 4.4, it can be observed that the drain down result values come in range between the binder content of 4.5 to 5.75%. Further, the result indicates the drain down values increase with the increase of binder content. The minimum value for Drain Down test is 0.16% for the bitumen content of 5.5% as shown in Table 4.4.

Table 4.4 Drain Down Test Values for OGFC mix

Binder content (%)	Weight of basket with sample (g)	Weight of sample (g)	Weight of plate with material drain (g)	Weight of material drain (g)	Drain down (%)
4.25	1497	1232	300	5	0.40
4.5	1504	1239	298	3	0.24
4.75	1510	1245	298	3	0.24
5	1510	1245	297	2	0.16
5.25	1513	1248	297	2	0.16
5.5	1512	1247	297	2	0.16
5.75	1509	1244	298	3	0.24
6	1511	1246	300	5	0.40
6.25	1498	1233	302	7	0.56
6.5	1508	1243	303	8	0.64
6.75	1513	1248	305	10	0.80
7	1496	1231	307	12	0.97

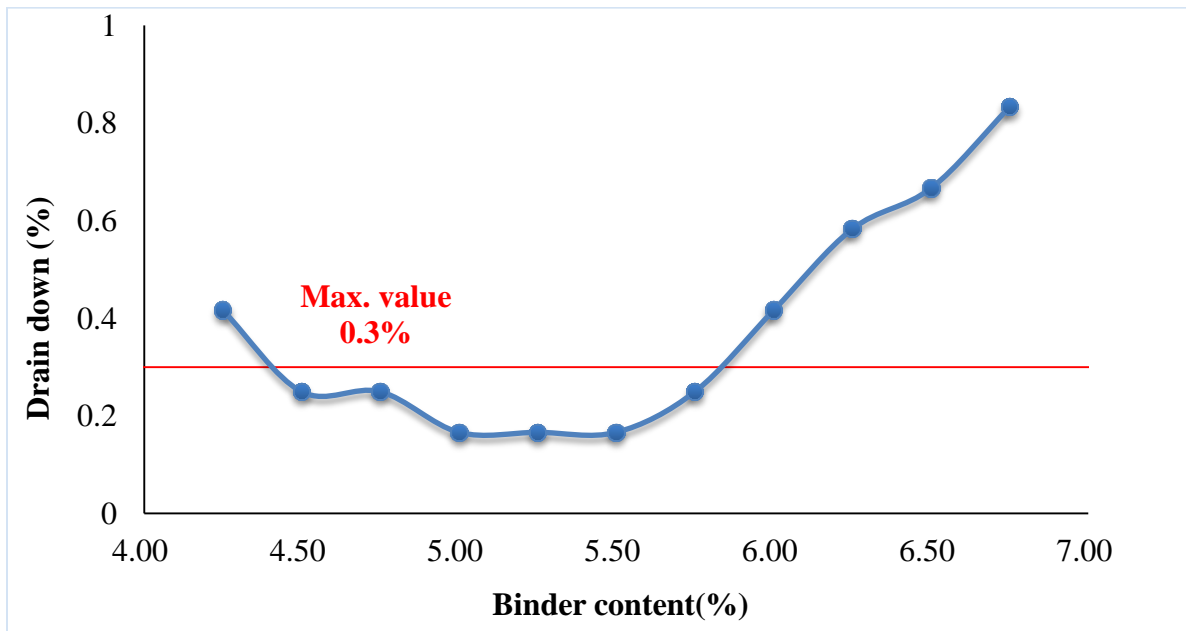


Figure 4.2 Variation of Drain Down losses with Binder content

4.6 Result for Cantabro Abrasion test

This test has used to evaluate the durability of OGFC mix. The resistance to abrasion improves with increase of binder content. The increase of binder content is required if the abrasion loss on unaged samples is more than 20%. The Cantabro Abrasion has performed for the 12 un-compact loose mixes and are explained in the Table 4.5. The result indicates that the increase in binder content from 4.5 to 6% resulted in decrease in percentage of Cantabro loss. Further, the percentages of Cantabro loss are increases with increase in binder content. The result indicates that the minimum value of Cantabro loss is 13.34% for binder content of 5.75% as shown in Table 4.5.

Table 4.5 Cantabro Abrasion Test Values

Binder content (%)	Initial weight of test sample (g)	Final weight of test sample (g)	Canatabro Abrasion loss (%)
4.25	1210	978.5	19.13
4.50	1215	996.5	17.98
4.75	1207	1015	15.90
5.00	1213	1021	15.82
5.25	1207	1035	14.25
5.50	1197	1034	13.61
5.75	1203	1042.5	13.34
6.00	1193	1017	14.75
6.25	1194	985	17.50
6.50	1205	930.5	22.78
6.75	1209	873	27.79
7.00	1189	824	30.69

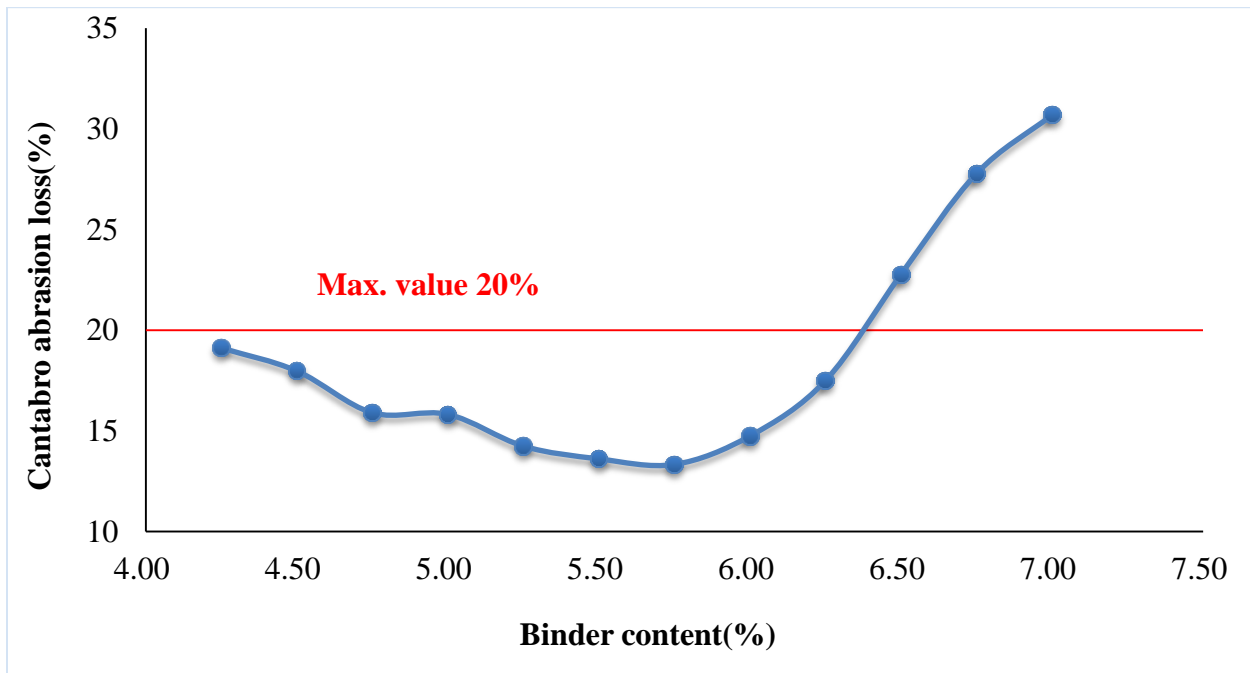


Figure 4.3 Variation of Cantabro Particle Losses with Binder Content



Figure 4.4 Sample of OGFC Mix obtained after Cantabro Abrasion Test

4.7 Results for Determination of Optimum Binder Content for OGFC/Porous Asphalt Mix

The test result of various experiments has conducted on OGFC/Porous Asphalt mix samples for determining optimum binder content, namely- Air Voids content, Cantabro Abrasion Loss, Drain Down percentage are tabulated below as shown in Table 4.6.

Table 4.6 shows that 12 of 28 mix samples satisfied the criteria for Air voids content, 9 of 12 mix samples satisfied the Cantabro loss criteria and 6 of 12 mix samples satisfied the Drain down criteria. None of the total mix samples satisfied all the three criteria.

Table 4.6 Determination of Optimum Binder Content for OGFC/porous asphalt mix

S No.	Binder content (%)	Average Air voids (%)	Cantabro Abrasion loss (%)	Drain Down Potential (%)
		Min. 18%	Max. 20%	Max. 0.3%
1	4.25	16.56	19.13	0.40
2	4.50	17.03	17.98	0.24
3	4.75	19.19	15.90	0.24
4	5.00	19.74	15.82	0.16
5	5.25	20.78	14.25	0.16
6	5.50	22.08	13.61	0.16
7	5.75	22.13	13.34	0.24
8	6.00	21.38	14.75	0.40
9	6.25	14.70	17.50	0.56
10	6.50	13.87	22.78	0.64
11	6.75	12.59	27.79	0.80
12	7.00	12.21	30.69	0.97
13	7.25	10.15	-	-
14	7.5	9.83	-	-

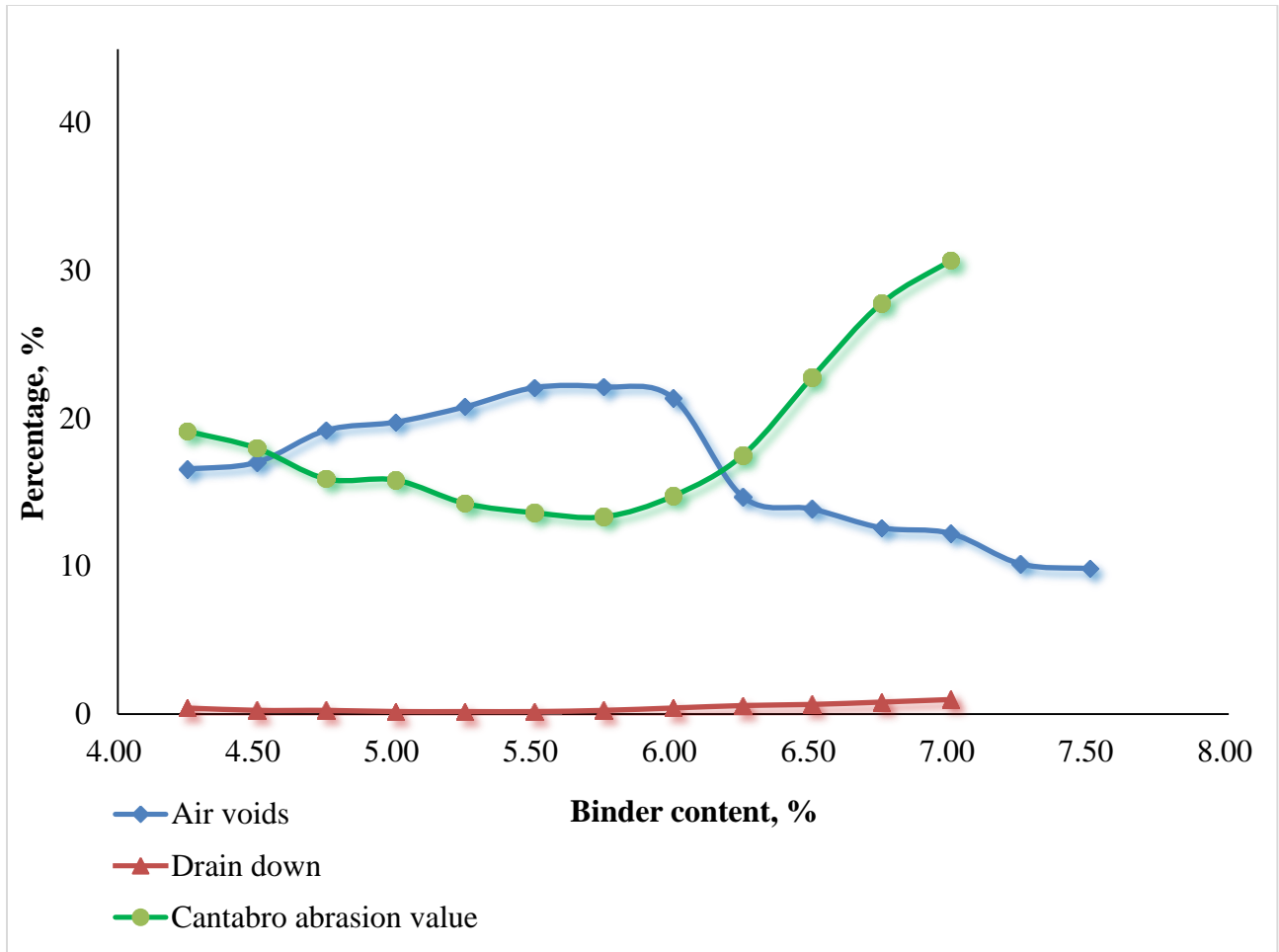


Figure 4.5 Variation of Different Test for Determination of Optimum Binder Content for OGFC Mix

From the above graph and observation it is clear that the binder content of 5.5% fulfils the entire requirement recommended by NCAT for OGFC mix. Therefore, the binder content of 5.5% is finalized as the optimum binder content for OGFC/Porous asphalt mix throughout the study and has been adopted for the performance evaluation of mix.

4.8 Performance Tests Result

The following are the performance tests results carried out in this study on the OGFC mix samples. In this study, the two performance tests have conducted which included Permeability and Marshall Stability test.

4.8.1 Marshall Stability Test

This test evaluates the different properties of the OGFC/porous mix samples that include volumetric properties, stability value and flow value. All of these are explained below.

4.8.1.1 Volumetric Properties

The test result for volumetric properties of compacted samples included the bulk density, theoretical maximum specific gravity, air voids percent, voids in mineral aggregates and voids filled with bitumen are shown in Table 4.7.

The resulted value for Theoretical maximum specific gravity (G_{mm}) is 2.439. Table 4.7 indicates the mean Bulk Density for 28 mix samples are ranged between 1.767 to 2.088 gm/cc and the Bulk Density increases up to 5.5% of the binder content. Further these value decreases with increase in the binder content after obtaining the optimum value. As the mean value obtained from the calculation of VMA has indicated the range between 24.35 to 35.73% and the mean values of VFM ranged between 20.276 to 32.95%.

Table 4.7 Volumetric Properties of OGFC Mix

Binder content (%)	Average Bulk Density (gm/c³)	Average of Void in mineral aggregates, VMA (%)	Average of Voids Filled with Bitumen, VFB (%)
4.25	1.767	35.139	32.313
4.5	1.851	32.220	29.138
4.75	1.887	31.099	27.908
5	1.922	29.990	26.681
5.25	1.985	27.887	24.330
5.5	2.088	24.354	20.276
5.75	2.056	25.707	21.763
6	2.027	26.967	23.283
6.25	1.965	29.363	25.974
6.5	1.925	30.985	27.778
6.75	1.902	32.016	28.913
7	1.840	34.381	31.494
7.25	1.828	34.985	32.145
7.5	1.812	35.738	32.959

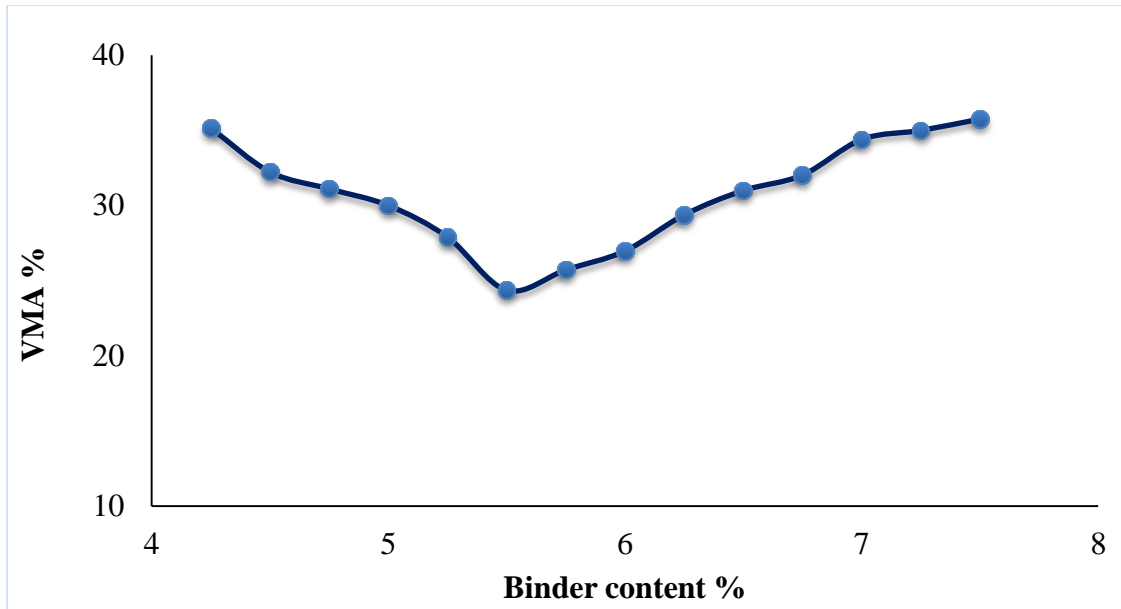


Figure 4.6 Variation of VMA with respect to Binder content

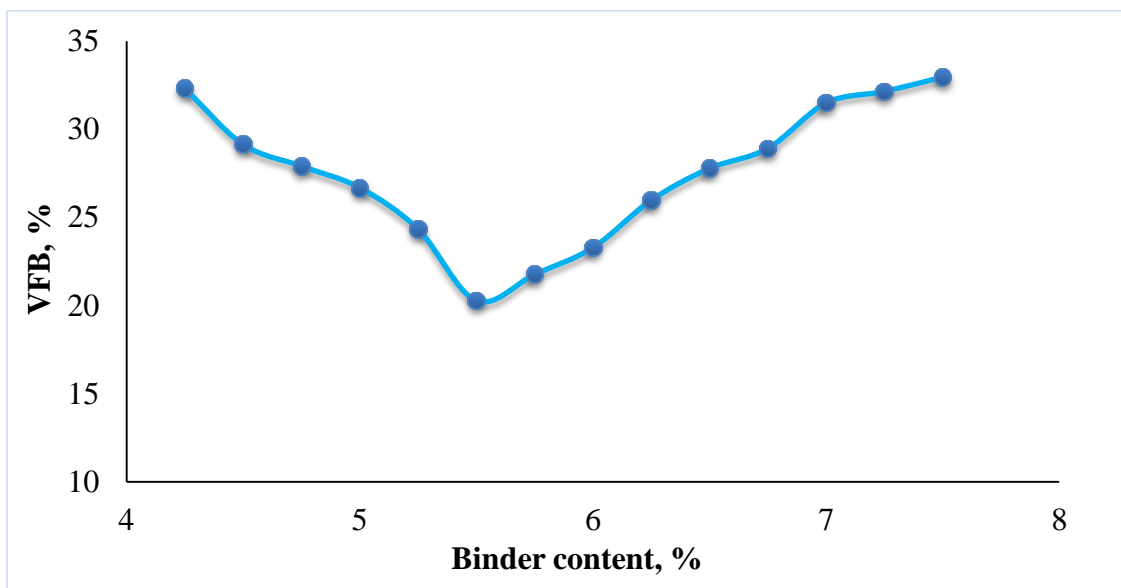


Figure 4.7 Variation of VFB with Binder content

4.8.1.2 Stability test

Marshall Stability test has conducted on 28 compacted sample of OGFC/Porous asphalt mix of different thickness or height. According to the MORTH specifications 4th revision, the minimum stability value should be 820kg for open graded asphalt mix. In this study, the value of the

stability increases with respect to increase in binder content. After a certain point, the result observed the decrease of stability values. Table 4.8, indicates that the stability test value increases up to 5.5% of binder content. Further the stability value starts decreasing. From the result table, it has observed that the maximum stability value is 1511.23 kg for 5.5% of optimum binder content (OBC).

Table 4.8 Stability Values for Different Binder Content for OGFC Mix

Binder Content (%)	Stability correlation ratio as per volume of samples		Stability value measured (kg)		Average stability value corrected (kg)
	S 1	S 2	S 1	S 2	
					Sample
4.25	0.74	0.74	1204	1142	868.02
4.5	0.81	0.78	1279	1152	967.275
4.75	0.76	0.78	1576	1497	1182.71
5	0.78	0.76	1675	1574	1251.37
5.25	0.76	0.74	1854	1746.5	1350.725
5.5	0.78	0.89	1759.5	1854	1511.235
5.75	0.78	0.83	1476.5	1484	1191.695
6	0.76	0.78	1675	1265	1129.85
6.25	0.74	0.74	1243.5	1475	1005.845
6.5	0.74	0.74	1397.5	1257	982.165
6.75	0.76	0.74	1286	1165	919.73
7	0.74	0.74	1053	1146.5	813.815
7.25	0.72	0.74	890	985	684.85
7.5	0.76	0.74	912	832	654.4

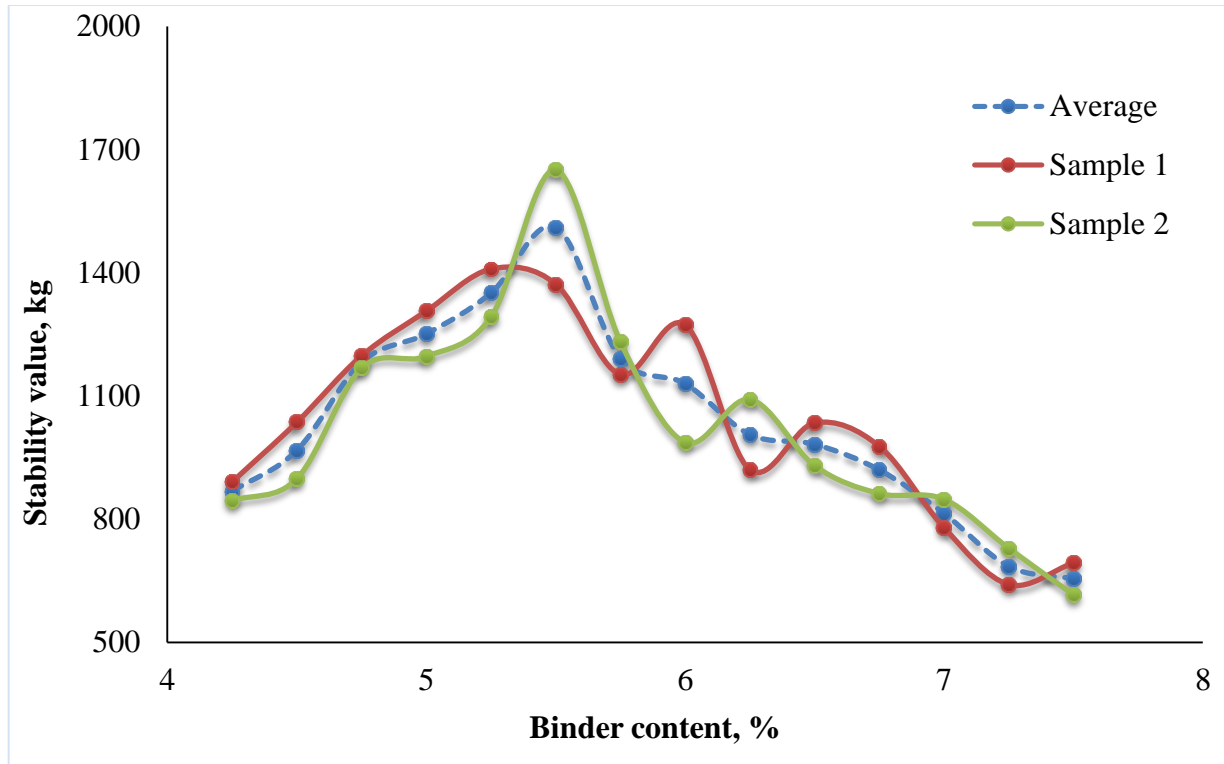


Figure 4.8 Variation of Stability Value with Binder Content

4.8.1.3 Flow values

Marshall Flow value for 28 compacted mix samples vary with increase of binder content. The result has been concluded that the flow value increase with increase of binder content. The resulted flow values are shown in Table 4.9.

Table 4.9 Flow Values of Different Binder Content for OGFC Mix

Binder content (%)	Average Flow Value (mm)
4.25	2
4.5	2.5
4.75	3
5	3.8
5.25	4.6
5.5	5
5.75	6
6	7.4
6.25	8
6.5	9
6.75	9.6
7	10
7.25	11
7.5	11.6

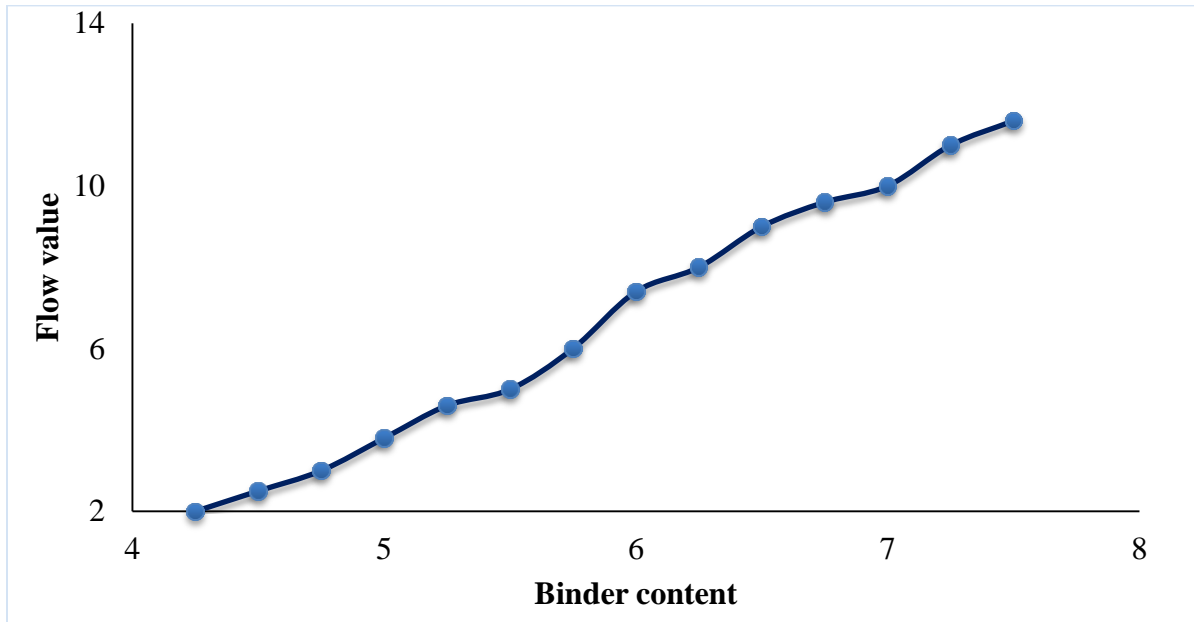


Figure 4.9 Variation of Flow Value with Binder Content

4.8.2 Permeability Test

The resulted value of coefficient of permeability for OGFC mix is directly related to its drainage characteristics. The permeability test value should be more than 100m/day for good drainage condition. The value observed for coefficient of permeability (K) varied in the range from 247.69 to 501.48 m/day. From Table 4.10, it has observed that 11 mix samples at each percentage of binder content satisfied the permeability criteria. Table 4.10 indicates, the maximum value of k is 501.48 m/day for binder content of 5.75%. Generally, it has observed that the permeability is directly proportional to the percentage of air voids and the result concluded that the similar variations in the air voids to that of trends of permeability.

Table 4.10 Permeability Test Values

Binder content (%)	Height of sample, L (cm)	Constant hydraulic head, h (cm)	Quantity of water collected in time, Q (gm)	Time, T (sec)	Coefficient of permeability, k (cm/sec)	Coefficient of permeability, k (m/day)
4.25	8	9.5	915	26	0.37012	319.78
4.50	7.8	9.3	921	26	0.37104	320.58
4.75	7.6	9.1	935	22	0.44329	383.00
5.00	7.7	9.2	938	23	0.42629	368.31
5.25	8	9.5	942	21	0.47176	407.60
5.50	7.6	9.1	938	20	0.48918	422.65
5.75	7.6	9.1	946	17	0.58042	501.48
6.00	7.8	9.3	939	18	0.54643	472.11
6.25	8	9.5	921	29	0.33400	288.58
6.50	7.9	9.4	919	33	0.29230	252.54
6.75	7.6	9.1	907	33	0.28667	247.69

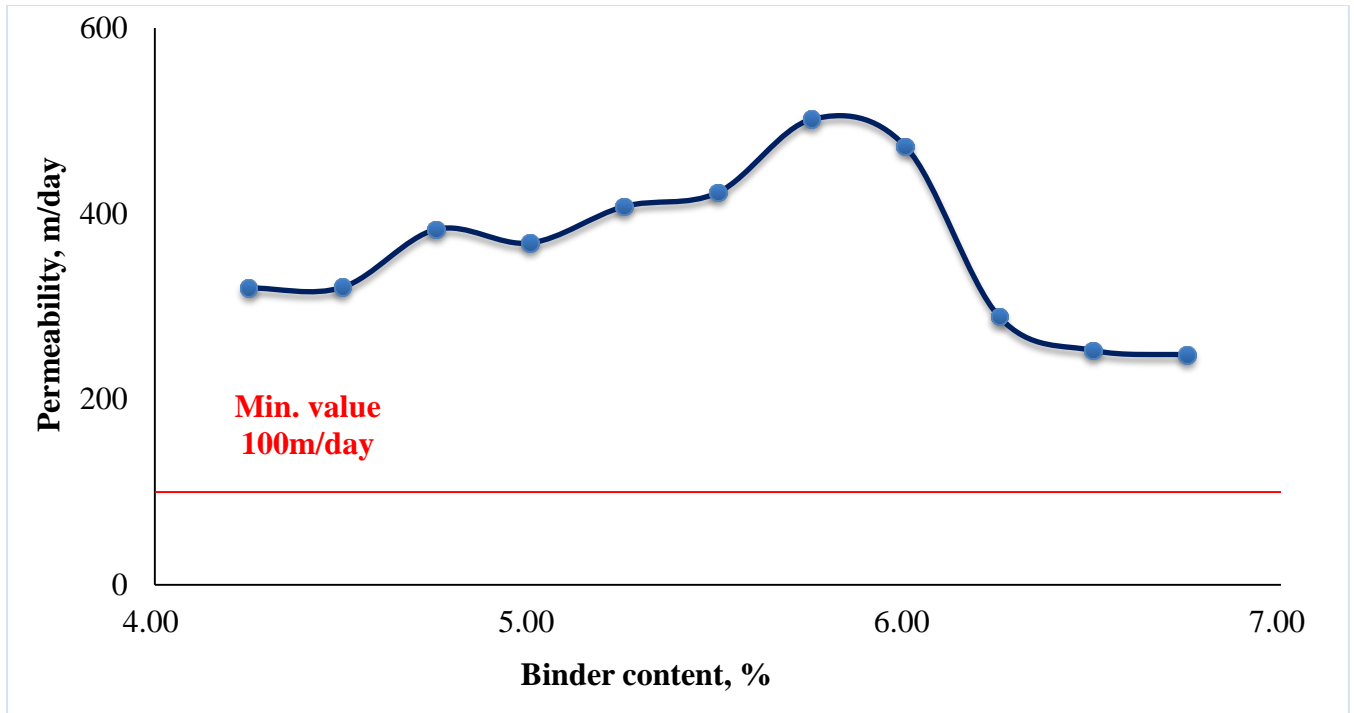


Figure 4.10 Variation of Permeability Value with Binder Content

**HYDRAULIC AND STRUCTURAL DESIGN OF POROUS ASPHALT
PAVEMENT**

5.1 HYDRAULIC DESIGN

Porous Pavement is typically sized to store the larger design storm volume in the reservoir layer. The storage volume in the pavements must account for the underlying infiltration rate and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer needed to store the design storm can be determined by using equation,

$$d_p = \left[\left(\frac{P \cdot R_v \cdot DA}{A_p} \right) - \frac{i}{2} * t_f \right] / n_r \quad \text{Eq.5.1}$$

Where,

d_p = Depth of the reservoir layer (ft)

DA = Total contributing drainage area. (ft²)

A_p = Permeable pavement surface area (ft²)

P = The rainfall depth for the SWRv or other design storm (ft)

R_v = Runoff coefficient for impervious cover (0.95)

i = The field-verified infiltration rate for the subgrade soils (ft/day).

t_f = The time to fill the reservoir layer (day), assume 2 hours or 0.083 day

n_r = The effective porosity for the reservoir layer

5.1.1 Design of Porous Pavement for Sandy Soil

1. Depth of reservoir layer, d_p

Required parameters:

P = 236mm as per District Patiala part of Punjab have been recording good rain. In the July month, Patiala has recorded 236mm of rain for 5 days against the normal of 225mm for the month of July. Therefore, take the average as per day for rainfall depth.

P = 47.2mm

Therefore, P = 0.15ft

$R_v = 0.95$

DA = Assume, 100*100mm = 107639.11 ft²

$A_p = 53819.55$ ft²

i = For Sandy soil = 1.598 ft/day

t_f = Assume 2 hours or 0.083 day

$n_r = 0.22$, according to the Air voids at OBC

Using equation,

$$d_p = \left[\left(\frac{P * R_v * DA}{A_p} \right) - \frac{i}{2} * t_f \right] / n_r$$

$$d_p = 0.99 \text{ ft or } 11.88 \text{ inches}$$

$$\text{or } d_p = 302 \text{ mm}$$

Therefore, the depth of reservoir by using above equation is 0.99 ft

2. Drain down time, t_d

The equation used,

$$t_d = \frac{d_p * n_r * 2}{i} \quad \text{Eq.5.2}$$

$$t_d = 0.27 \text{ Days or } 6.48 \text{ hours}$$

t_d Value must be < 2.0

3. Porous Pavement Storage Volume, S_v

The equation used,

$$S_v = (d_p * n_r * A_p) + \left(\frac{i * t_f}{2} \right) \quad \text{Eq. 5.3}$$

$$S_v = 18724.12 \text{ ft}^3$$

5.1.2 Design of Porous Pavement for Clay Soil

1. Depth of reservoir layer, d_p

Required parameters:

$$P = 236\text{mm}$$

Therefore, $P = 0.7742\text{ ft}$

$$R_v = 0.95$$

$$DA = \text{Assume, } 100 * 100\text{mm} = 107639.11\text{ ft}^2$$

$$A_p = 53819.55\text{ ft}^2$$

$i = \text{For Clay soil} = 0.118\text{ ft/day}$

$t_f = \text{Assume } 2\text{ hours or } 0.083\text{ day}$

$n_r = 0.22$, according to the Air voids at OBC

Using equation,

$$d_p = \left[\left(\frac{P * R_v * DA}{A_p} \right) - \frac{i}{2} * t_f \right] / n_r$$

$$d_p = 1.27\text{ ft or } 15.24\text{ inches}$$

Therefore, the depth of reservoir by using above equation is 1.27 ft

2. Drain down time, t_d

The equation used,

$$t_d = \frac{d_p * n_r * 2}{i}$$

$$t_d = 4.74\text{ days}$$

t_d value must be < 2.0

3. Porous Pavement Storage Volume, S_v

The equation used,

$$S_v = (d_p * n_r * A_p) + \left(\frac{i * t_f}{2} \right)$$

$$S_v = 23982.96\text{ ft}^3$$

5.1.3 Design of Porous Pavement for Gravel Soil

1. Depth of reservoir layer, d_p

Required parameters:

$$P = 0.7742 \text{ ft}$$

$$R_v = 0.95$$

$$DA = \text{Assume, } 100 * 100 \text{mm} = 107639.11 \text{ ft}^2$$

$$A_p = 53819.55 \text{ ft}^2$$

$$i = \text{For Gravel soil} = 3.25 \text{ ft/day}$$

$$t_f = \text{Assume 2 hours or 0.083 day}$$

$$n_r = 0.22, \text{ according to the Air voids at OBC}$$

Using equation,

$$d_p = \left[\left(\frac{P * R_v * DA}{A_p} \right) - \frac{i}{2} * t_f \right] / n_r$$

$$d_p = 0.682 \text{ ft or } 7.65 \text{ inches}$$

Therefore, the depth of reservoir by using above equation is 0.682 ft

2. Drain down time, t_d

The equation used,

$$t_d = \frac{d_p * n_r * 2}{i}$$

$$t_d = 0.092 \text{ days or } 2.20 \text{ hour}$$

$$t_d \text{ value must be } < 2.0$$

3. Porous Pavement Storage Volume, S_v

The equation used,

$$S_v = (d_p * n_r * A_p) + \left(\frac{i * t_f}{2} \right)$$

$$S_v = 12854. \text{ft}^3$$

Table 5.1 Result Values for Hydraulic Design

Hydraulic Design parameters			
Design Parameters	For Sandy soil	For Gravel soil	For Clay soil
Depth of reservoir layer, d_p	0.99 ft or 11.88 inches	0.682 ft or 7.65 inches	1.27 ft or 15.24 inches
Drain down time, t_d	0.27 days	0.092 days	4.74 days
Porous pavement storage volume, S_v	18724.12 ft ³	12854. ft ³	23982.96 ft ³

5.2 STRUCTURAL DESIGN METHODOLOGY

Pavement design relies on engineering calculations based on established design equations, such as the empirical equations found in the 1993 AASHTO *Guide for Design of Pavement Structures*.

Equation used as per Empirical AASHTO Flexible Pavement Design Equation (1993),

$$\log_{10}W_{18} = Z_R * S_0 + \log_{10}(SN + 1) - 0.2 + \frac{\log_{10}\left(\frac{\Delta Psi}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 * \log_{10}M_R - 8.07 \quad \text{Eq. 5.4}$$

Where,

SN = required Structural Number (structural capacity) of the pavement

W_{18} = number of 18-kip equivalent single axle loads (ESALs) expected over design life

Z_R = standard normal deviate (level of design reliability)

S_0 = standard deviation

ΔPsi = allowable change in the Present Serviceability Index (Psi) over design life

M_R = subgrade resilient modulus (psi)

5.2.1 Design Structural Number of the pavement (SN)

A critical element of the flexible pavement equation is the Structural Number, which represents the overall structural requirement needed to sustain the loads anticipated in the design. The required Structural Number depends on a combination of existing soil support, total traffic loads, pavement serviceability, and environmental conditions.

As design output,

$$SN_{pvmt} = d_1 a_1 + d_2 a_2 m_2 \quad \text{Eq. 5.5}$$

d_1 = thickness of asphalt layer

a_1 = structural layer coefficient for asphalt

d_2 = thickness of granular base (stone recharge bed)

a_2 = structural layer coefficient for granular base

m_2 = moisture/drainage coefficient for unbound granular base

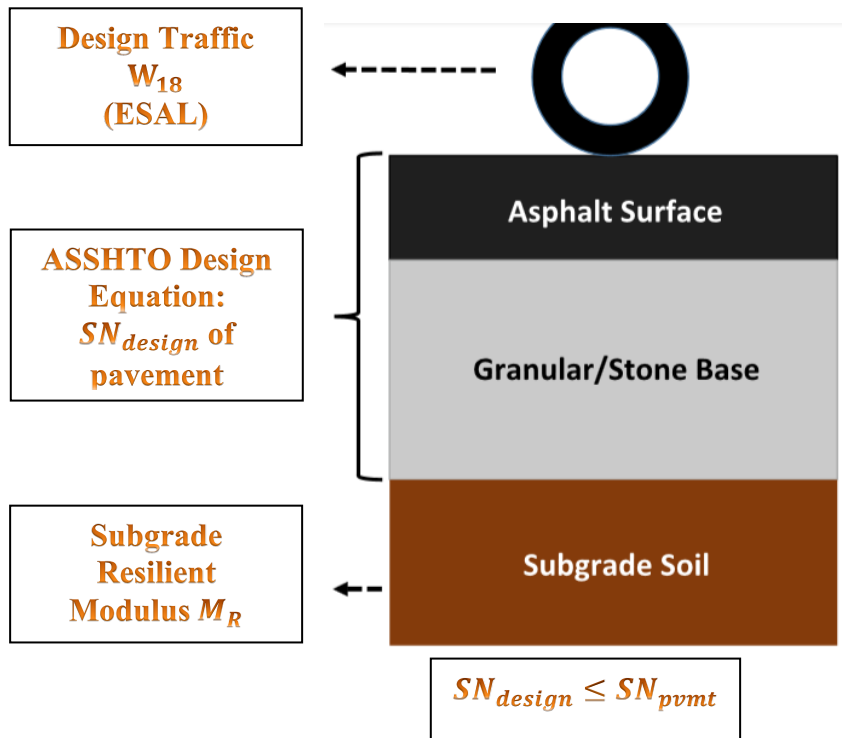


Figure 5.1 Composition of Pavement

5.2.2 Structural Design Input parameter

For calculating the structural design equation the following parameters has considered,

5.2.2.1 Design traffic W_{18} (ESALs)

Assuming three case of different design traffic that function for different types of facility as in Table 5.2,

Table 5.2 Design Traffic for Different Requirement

Consider design traffic (ESALs)	Types of facility and vehicles types	Design period
250000	For parking lots, residential driveways	15 years
1000000	For residential streets without truck movements	15 years
3000000	Urban roads with less commercial vehicles (less than 20 CVPD)	15 years

5.2.2.2 Values recommended for Reliability, Standard Deviation, $\Delta\Psi$

In the study, Reliability = 80% with respect to this, Standard normal deviation = -0.842 as shown in Table 5.3

$$\Delta\Psi = p_o - p_t$$

Where,

p_o Initial serviceability index; values range: 4.2 – 4.5

p_t Terminal serviceability index; values range: 2.0 – 2.5

Values for $\Delta\Psi$ should be between: 2.0 –2.5

In this case, $p_o = 4.35$ and $p_t = 2.25$

Therefore, $\Delta\Psi = 2.1$

Table 5.3 Design Reliability

Reliability (%)	Standard Normal Deviate
50	0.000
75	-0.674
80	-0.842
90	-1.282
95	-1.645
99.99	-3.719

5.2.2.3 Subgrade Resilient Modulus (M_R)

Resilient modulus for existing subgrade soil for three different types of soil as per NAPA subgrade classification guide as shown in Table 5.4,

Table 5.4 Resilient Modulus With Respect to Soil Type

Soil type	CBR value	Porous asphalt pavement M_R (Psi)
For sandy soil	17	20000
For gravel soil	8	9000
For clay soil	5	2250

5.2.2.4 Layer coefficients (a_i)

For porous asphalt, $a_1 = 0.40$

Coarse Aggregate Base (Stone Recharge Bed), $a_2 = 0.07$ to 0.10

In this case, $a_2 = 0.085$

5.2.2.5 Drainage Coefficient (m_2)

For porous pavement design, use $m_2 = 1.0$ for all situations.

5.2.3 Design Thickness of Porous Asphalt Layer by Two Parameters

In this study, the two methods have been used for calculating the design thickness of porous asphalt layer. One method provides the design thickness as per the base thickness of reservoir layer and other calculate the design thickness as per the design traffic.

5.2.3.1 Effective Thickness of Porous Layer as per 1993 AASHTO Design Approach

The porous asphalt thickness has calculated by using the Figure 5.2 with respect to base thickness provided according to the hydraulic design.

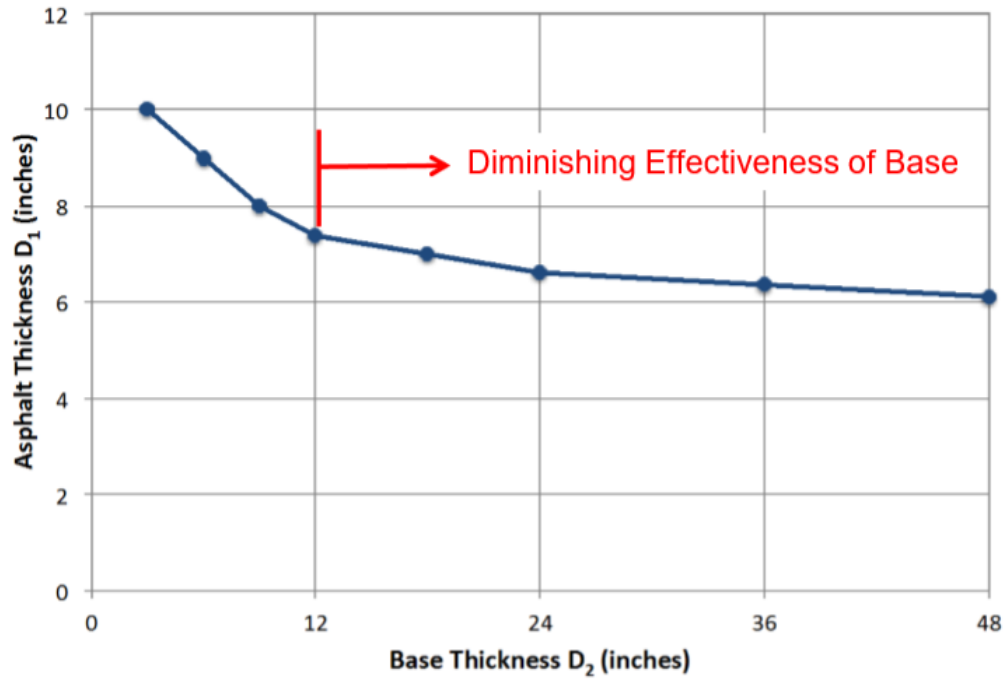


Figure 5.2 Thickness of Porous Asphalt Varies With Base Thickness

Table 5.5 Resulted Thickness of Layer as per Figure 5.2

For soil type	Design Thickness of layer (inches)	
	Design porous pavement thickness	Design base thickness
Sandy soil	7.8	11.88
Gravel soil	9	7.65
Clay soil	7.7	15.24

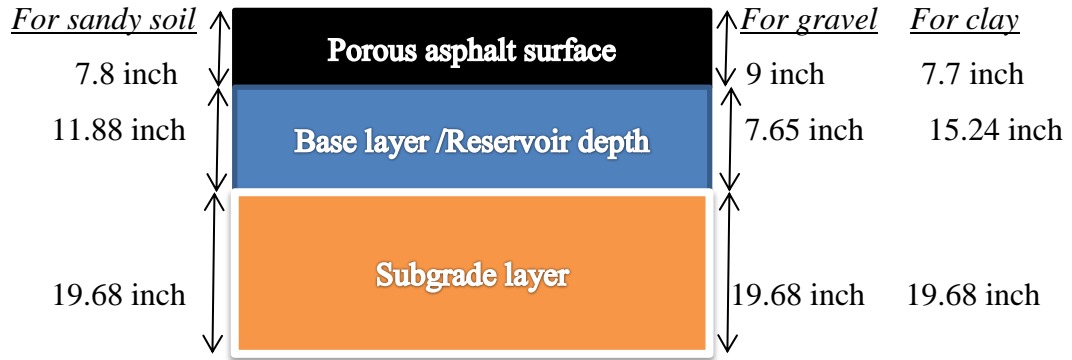


Figure 5.3 Typical Section of Porous Asphalt Pavement Evaluated by Hydraulic Design

5.2.3.2 Design thickness of base layer as per design traffic

By using empirical AASHTO flexible pavement design equation (1993), calculate the SN value for different design traffic with respect to resilient modulus of subgrade soil type and Table 5.6 provide minimum design thickness of porous asphalt layer.

Table 5.6 Provide Minimum Thickness of Porous Asphalt with Respect to Design Traffic

W₁₈ (ESALs)	Porous Asphalt Thickness (inches)
50,000	3.0
100,000	3.5
250,000	4.0
500,000	4.5
750,000	5
1,000,000	5.5
2,000,000	6.0
4,000,000	6.5

Table 5.7 Resulted Thickness of Layer as per Design Traffic

For soil type	Thickness of layer (inches)	Design Traffic (ESALs)		
		250000	1000000	3000000
	Minimum Porous Asphalt Thickness (inches)	4.0	5.5	6.25
Sandy soil	Design porous asphalt thickness	4.55	5.9	6.3
	Design base thickness	11.88	11.88	11.88
Gravel soil	Design porous pavement thickness	4.87	6.47	7.05
	Design base thickness	7.65	7.65	7.65
Clay soil	Calculated porous pavement thickness	3.85* Provide design thickness 4.0	5.07* Provide design thickness 5.5	5.02* Provide design thickness 6.25
	Design base thickness	15.24	15.24	15.24

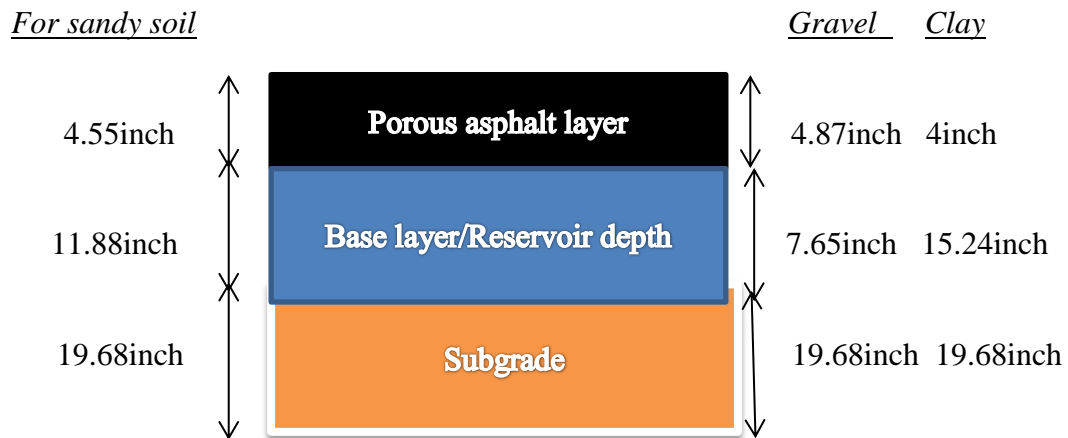


Figure 5.4 Section of Porous Asphalt Pavement as per Design of 25000 ESALs

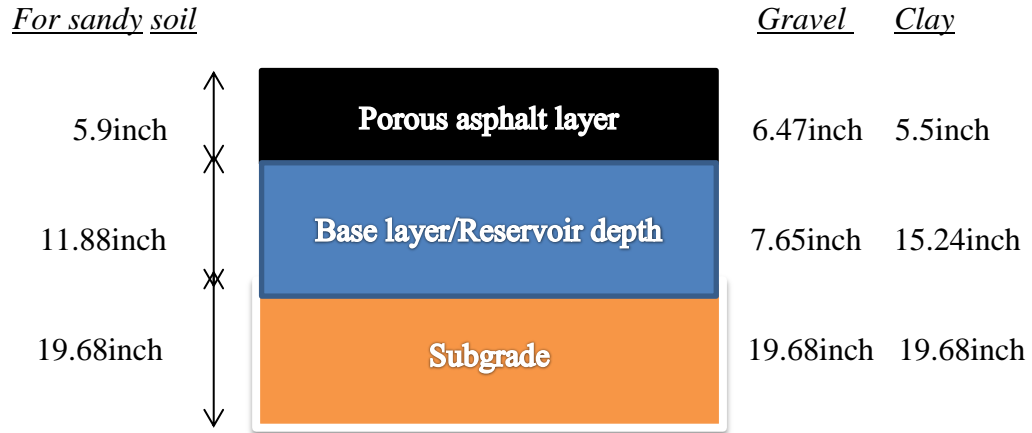


Figure 5.5 Section of Porous Asphalt Pavement as per Design of 1000000 ESALs

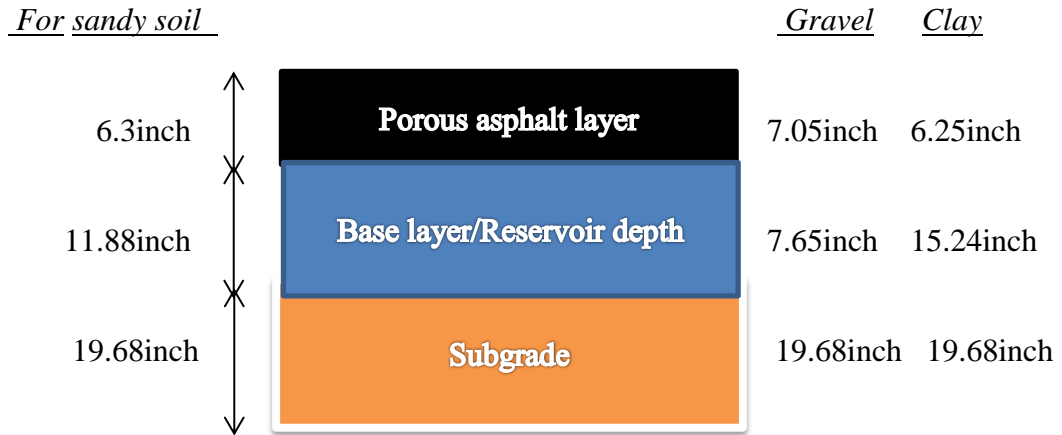


Figure 5.6 Section of Porous Asphalt Pavement as per Design of 3000000 ESALs

6.1 CONCLUSIONS OF THE STUDY

The major conclusion which can be drawn based on the laboratory evaluation of test results obtained under the present study can be summarized as below:

1. From the laboratory studies conducted, it can be concluded that the NAPA IS 115 specified grading for OGFC mix is suitable for Indian condition with 60/70 grade of bitumen with no additives.
2. The optimum binder content for the open graded friction course mix adopted as per the air void test, Cantabro abrasion test and drain down test is 5.5%.
3. It can be observed that the increase of binder from 4.25 to 6% resulted in increase of air voids. The specified range of air voids content that is 18 to 22%. With further increase in binder content, it can be observed that the higher binder result in decrease of air voids content. The result indicates the maximum value of air voids is 22.13% for a bitumen content of 5.75%.
4. The resulted value for Theoretical maximum specific gravity (G_{mm}) is 2.439. Bulk Density increases up to 5.5% of the binder content. Further these value decreases with increase in the binder content after obtaining the optimum value. VMA values are observed in the range between 24.35 to 35.73% and values of VFM are ranged between 20.276 to 32.95%.
5. From the Cantabro abrasion loss test, the result has been concluded that the increase in binder content from 4.5 to 6% resulted in decrease in percentage of Cantabro loss. Further, the percentage of Cantabro loss has increases with increase in binder content. The result indicates that the minimum value of Cantabro loss is 13.34% for binder content of 5.75%.

6. It can be observed that the drain down values increase with the increase of binder content. The minimum value for Drain Down test is 0.16% for the bitumen content of 5.5%.
7. For Marshall Stability test, it can be concluded that the value increases up to 5.5% of binder content. Further the stability value starts decreasing. It has observed that the maximum stability value is 1511.23 kg for 5.5% of optimum binder content (OBC). The Flow value result has been concluded that the flow value increases with increase of binder content.
8. For permeability test result, it can be observed that samples at each percentage of binder content satisfied the permeability criteria. The maximum value of k is 501.48 m/day for binder content of 5.75%. Generally, it has observed that the permeability is directly proportional to the percentage of air voids and the result concluded that the similar variations in the air voids to that of trends of permeability.
9. The hydraulic design for depth of reservoir for soil type of sand, gravel and clay are 11.88, 7.65 and 15.24inches.
10. The structural design for thickness of porous asphalt layer for soil type of sand, gravel and clay with respect to reservoir thickness are 7.8, 9 and 7.7inches. The design thicknesses of porous asphalt pavement with respect to design traffic of 2500000 ESALs are 4.55, 4.87 and 4inches. For design traffic 1000000 ESALs are 5.9, 6.47 and 5.5inches. For design traffic 3000000 ESALs are 6.3, 7.05 and 6.25inches.

6.2 Recommendations for Future Research

This study has vast scope for future needs. The following recommendation describes the further research work will be pursued in this field:

- Further the study can be conducted by adding the fibres or additives in the bitumen for evaluating more properties of OGFC/Porous asphalt mixture.
- The trial section can be laid down with porous asphalt pavement.
- The IRC standard codes should be introduced for porous asphalt pavement.

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