DEVELOPMENT AND EVALUATION OF CEMENT GROUTED BITUMINOUS MIX FOR PAVEMENT APPLICATIONS

A Thesis submitted in Fulfillment of the Requirement for the Award of

The Degree of

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IN

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Submitted By

Ajay Singh

801723002

Under supervision of

Prof. Tanuj Chopra

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

DEPARTMENT OF CIVIL ENGINEERING

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY

(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

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DECLARATION

I hereby declare that that this work which is being presented in the thesis entitled"**DEVELOPMENT AND EVALUATION OFCEMENT GROUTED BITUMINOUS MIX FOR PAVEMENT APPLICATIONS**" in partial fulfillment of the requirement for the degree of **Master of Engineering** in the field of **CIVIL ENGINEERING** with specialization in **INFRASTRUCTURE ENGINNERING** at **THAPAR INSTITUTE OF ENGINEERING &TECHNOLOGY (PATIALA)** is an authentic record of my own work carried out during the period from 2.1.2019 to 15.7.2019 under the guidance of Dr. Tanuj Chopra.

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

Date: 15/07/2019

(AJAY SINGH)

Place:

Roll No. 801723002

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

18/07/2019

Dr. Tanuj Chopra

(Assistant Professor, CED)

Thapar Institute of Engineering & Technology

Patiala, Punjab – 147001

Dedicated to the

Lotus Feet of Lord Shri Krishna

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ABSTRACT

With the augmentation urbanization, the traffic has increased extensively on the urban roads of India. The extensive loading causes rutting and fatigue distress trouble inside the pavements which leads to pavement damage and reduce design life. Moreover, the pavement should full fill the performance and riding quality. The conventional design of pavements needs to be rationalized, to overcome further on challenges. The study finds a solution by investigating and exploring innovative pavement design and its performance parameter.

The new-fangled plan to design semi-flexible pavement, which have property of flexible and rigid pavement both. The repetitive loading on flexible pavement causes fatigue distresses and potholes on surface, whereas the rigid pavement procure heavy cost while construction and riding quality problem due to the numerous joint. The study to solve the above mentioned problem has derived an amalgamation of flexible and rigid pavement properties called Cement Grouted Bituminous Mix design (CGBM). CGBM have unique property of crystalline lattice network of bitumen and cementitious material which makes strong bond inside the network. Several earlier studies showed its efficiency on the roads, but the experimental analysis performance for the Indian conditions was not performed which are essential in understanding the performance evaluation of cement grouted bituminous mix.

The main focus of this study was to characterize several CGBM samples for different variants to analyze and characterize the design mix and performance. The aggregate gradation of the CGBM was done based on the MS2 guidelines of open graded bituminous mix. Specification of open graded surface mix is of Georgia ½’ PEM, with nominal size if aggregate 12.5 mm. The selected gradation had coarser aggregate so as to endow with higher air voids content in the mix. The gradation helped to achieve the air void content of 25-30% in the design mix of open graded bituminous mix. The open graded bituminous mixes are typically simple mixtures, often designed using only one aggregate size and with pre-determined binder content, usually in the range of 1.5 to 3.0% by weight of the total mix. The study emphasized the aggregate should not be soft as to degrade significantly during production, creating fines that will fill the voids necessary for proper grouting. The open graded mix been the combination of large NMAS and lower binder content makes these one of the most cost effective mix type.

The cementitious grout material was formulated based on past research done to increase the performance validation of high performance cement paste as a grouting material for semi-flexible pavement. The requirement of grout material is to provide full depth grouting inside the open graded bituminous mix and strength for formulation performances. The grout material is evaluated on flowability and strength criteria.

The CGBM sample were laboratory evaluated based on the indirect tensile strength, stability, modulus of elasticity and performance evaluation with the help of Cantabro test. The CGBM samples were compared with conventional BC course. The results showed enhanced and superior values of CGBM specimen as compared to conventional surface mix. IITPAVE was used to design the crust consisting of CGBM composition.

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LIST OF ABBREVATIONS

ACI	– American Concrete Institute
ASTM	– American Society for Testing Material
BC	– Bituminous Course
CBR	– California Bearing Ratio
CGBM	– Cement Grouted Bituminous Mix
CL	– Cantabro Loss
CVPD	– Commercial Vehicle per Day
DBM	– Dense Bituminous Macadam
GMCM	– Grouted Macadam Composite Material
HPCP	– High Performance Cement Paste
IRC	– Indian Road Congress
ITS	– Indirect Tensile Strength
kN	– Kilo Newton
LVDT	– Linear Variable Differential Systems
MoRTH	– Ministry of Roads Transportation Highways
MPa	– Mega Pascal
OPC	– Ordinary Portland cement
PQC	– Pavement Quality Concrete
VG	– Viscosity Grade
W/C	– Water-to-cement ratio

LIST OF SYMBOLS

ϕ - Phase Angel

E - Dynamic Modulus

G_{app}- Apparent specific Gravity

G_{bulk}- Bulk Specific Gravity

T - Torque

η - Dynamic Viscosity

ζ - Shear Stress

γ - Shear Rate

F_m- Compressive Strength

S_t - Indirect Tensile Strength

epZ - Vertical Strain

epT - Horizontal Strain

1. PROBLEM STATEMENT AND RESEARCH OBJECTIVE

1.1. General

The Road network of India is second largest road network in world with total length of around 4,320,000 kilometers. Indian road network consists of 1000 km -Expressways, 79,243 km -National Highways, 1, 31,899 km -State Highways and Other major district and rural roads. These amazing networks of roads also have Elevated Expressways, Cloverleaf Interchange, River Road Bridge and Flyover, which are longest and largest in India as well as in Asia. The huge networks need optimization and expedition so that it provides longer serviceability and smoother riding quality in roads. The classifications of roads based on the material property are rigid and flexible pavement crust with a design life of 30 and 20 years respectively. The rigid and flexible pavement has their own deficiency; the rigid pavements need to be provided with various joints and flexible pavement suffers through the rutting including potholes as frequent problem arising in them.

To overcome the problems faced in the present scenario we have tried to introduce middle path among both types of pavements i.e. Semi-flexible pavement which is a composite material termed as Cement Grouted Bituminous Mix – CGBM. It consists of higher air voids bituminous mixture, which is filled with suitable grout material. Present study prove grouted mix have significant lesser rutting when compared it with the conventional Bituminous course BC. In addition there was no requirement of joints in construction which is crucial in the reinforced concrete pavements which helps in smoother riding quality.

The previous study on CGBM was carried outside India and it was mainly adopted by the countries which are already developed. The current study was performed to obtain and evaluate the performance and strength characteristic on the cement grouted bituminous mix and comparison is made with the conventional practice surface layer of bituminous mix as per Indian condition.

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The prime factors which are beneficial from the current studies with respect to conventional practice are as follow:

a. Provision of joints in the rigid pavement can be eliminated.
b. Higher traffic causing rutting criteria on pavement can be extinguished.
c. The effect on flexible pavement in moist condition was overcome in CGBM mix.
d. Adopting the CGBM mix construction technique is quite flexible and versatile.

Formulation and recital comparison of grouting materials for cementitious grouted bituminous pavement states that semi-flexible pavement can be used widely nowadays as it seems to be good performance skeleton. (J Zhang, J Cai, J Pei, X Chen 2016). The study provided the formulation and composition of grout material used in open graded bituminous mix by the technical experiments and performance, validation of the obtained values of fluidity, strengthening and drying shrinkage.

Design and performance validation of high-performance cement paste as a grouting materials for semi-flexible pavement. (J Pei, J Cai, D Zou, J Zhang, R Li, X Chen, L Jin 2016). As the CGBM pavement has good pavement performance criteria they were required to investigate in detail. The composition consist in present paper has contents for grout used water cement ratio, superplasticizer polycarboxylate content and air entering additives expansion admixture as 0.55-0.57, 0.5-1.0% and 0.008% respectively. Prepared grout selected was compared and then finalized based on the superior early on strength, low dry shrinkage and better fluidity stability.

Effects of aggregate gradation on properties of grouted macadam composite pavement, (NM Husain, HB Mahmud, MR Karim, N Hamid, 2010). The grouted macadam composite pavement (GMCP) gave levelheaded strength with low porosity, high bulk density and much higher resilience modulus. It shows clearly that it will help in reducing pavement resurfacing thus at the same time helps in reducing the emission of air and noise pollution.

The summarization of above research papers leads to the further study on this topic which was a necessary requirement to attend all the flaws in rigid and flexible pavement crust and rectify it again whether the conventional methods adopted are really on the verge of accepting new method. The CGBM layer proved to be a challenging task as it was never before studied in India. The design criteria for the open graded bituminous mix was adopted and performed as per guidelines of MS2, Asphalt Mix Design Method – 7^{th} revision. Open graded bituminous mixes are intended with evenly sized aggregate such that these aggregate provide with the high air voids content. Open graded surface mixes are being specified more and more for their safety and environmental characteristics. These open graded bituminous mixes are also termed as different terms such as Open Graded Friction Course (OGFC) and Friction course (FC).

In general, the design of CGBM includes the selection of aggregates and binder content, meeting which matches to establish a desired property of CGBM. The criteria adopted in the present study follows the MS 2 guidelines. By proper mixing and blending of the materials it helps in precisely achieving the maximum or desired air voids. Furthermore, selection of effective grout mix design is necessary to fill the air voids which will provide effective strength in CGBM, when we compare to both types of conventional pavement.

It is observed that when the air void volume of 30% percent was achieved and filled with cement grout, the results showed a composite type of material characteristics. It was obtained like a semi-flexible pavement which had and profoundly greater strength than the usual flexible pavements. The optimum binder content was 3% which showed an optimum value in further study. The importance and effectiveness of CGBM was observed in Denmark & France airport projects which proved that it could help in the elimination of joints, with skid resistance and low cost. This concept was also adopted by the US which demonstrated that CGBM was beneficial in parking areas which have heavy axel load vehicles and container staging areas along with the stretch where there is maximum braking force applied on the pavements. Previous study show promising result with optimum economic and environmental friendly benefits, leading to the further study in regards to in Indian conditions. This paper is based on the different experimentation carried out to obtain and evaluate Cement Grouted Bituminous Mix.

Table 1.1.Property comparison of CGBM, BC and PQC

Sr No.	Properties	CGBM	BC	PQC
1.	Resistant to rutting/fatigue	Good	Poor	Good
2.	Resistant to skid	Good	Good	Poor
3.	Resistant to oil & chemical	Good	Poor	Good
4.	Resistant to moisture damage	Good	Poor	Good
5.	Safeguarding /Repair	Easy	Easy	Difficult
6.	Life Span	High	Low	High
7.	Flexural strength	High	Low	High
8.	Expansion joints	-	-	Required
9.	Open to traffic	24 – 30 hours	Within hour	0.5-3.0 mnt.
10.	Construction cost	Low	Low	High

1.2. Research Objectives

The objective of the present research was to obtain and appraise the mechanistic properties of CGBM and trend it provides with respect to the performance criteria of pavement. This pavement crust was furthermore correlated and compared with the conventional Bituminous Course (BC) mix. The observation which was examined from the present study is as follow:

a. The properties of CGBM were correlated with the stability, indirect tensile strength, static modulus, compressive strength, and flowability, performance criteria with respect to rutting and fatigue analysis.
b. Assessment of cement grout material based on the water cement ratio and the quantity of superplasticizer and air entering additives to be used along with the curing technique and period.
c. Performance criteria evaluation of CGBM mix.
d. Conventional BC was compared with the CGBM, based on the performance parameters.

1.3. Scope of Research

a) Inclusive study on literature review to define and understand the present learning of research in CGBM and identifying the coherent research gaps.
b) Choice of suitable material to prepare CGBM specimen of different matrices.
c) Investigation of characteristics and properties of CGBM which are associated to different mixtures.
d) Understanding the rutting and fatigue criteria induced in the CGBM.
e) Acknowledging the compressive strength of CGBM with different mixture gradation.
f) Developing and guidance for the best possible result for practicing in field for medium to high volume pavement claim.

1.4. Advantages and Disadvantages

CGBM which is a composite material have both advantages and disadvantages when compared to the conventional or existing pavement crust in India.

Advantages:

a. Higher performance with given weights leads to the fuel savings.
b. Excellent strength to weight and stiffness to weight can be achieved by composite material.
c. The composite material i.e. CGBM is also a good skid resistant surface layer.
d. Production cost is reduced. Composites may be made by a wide range of processes.
e. CGBM contributes as an excellent outdoor monsoon weathering pavement by reducing the glares during wet periods.
f. Reduction in the fatigue and rutting failure parameter when judge against BC mix.

Disadvantages:

a. Composite material produced is more brittle than conventional bituminous mixtures.
b. Repair introduces new problems such as hot curing with special equipment requirements.
c. Adopting the new concept could also leads to improper workmanship leading quality assurances.
d. Usage of CGBM is limited to the urban roads with heavy traffic and heavy loading.

1.5. Report Organization

The report is been characterized in six Chapters. Chapter 1 provides us the preface and brief introduction to the scope of topic and defining the advantages and disadvantages of Cement Grouted Bituminous Mix – CGBM. Chapter 2 provides us with the literature review of the CGBM i.e. the past studies which were performed and enhancements done in this topic with respect to time and needs. Literature review is mainly focused on the grouted macadam application and critical observations which is been discussed regarding the gap in CGBM research. Chapter 3 discusses the material and methodology used in CGBM for the production. The material testing were performed as per the guidelines to provide suitable supports for the usage of adequate and quality assured material in the research work for development of Cement Grouted Bituminous Mix. Chapter 4 explain the in detail concept for the development of CGBM i.e. methodology adopted. It consisting of results of test performed and analysis. Chapter 5 covers the empirical and mechanical approaches which is been carried out evaluate the investigation of CGBM mix for various properties to support the content through IITPAVE design. Chapter 6 is summary of the study carried out on CGBM depicting conclusion based of the study. Appendices are been provided so that to explain the derivations of mathematical relation and producing datasheet for the experiments carried out.

2. LITERATURE REVIEW

2.1. General

Cement Grouted Bituminous Mix is an idiosyncratic kind of a composite material which is been used as top surface layer in the pavements. The effect or the characteristics could be understood by the fact that it poses the property of flexible as well as rigid pavements. In India, the construction of an pavement is performed by an conventional method which either include an choice of using bitumen as an top surface material called as flexible pavement or using cementitious material to manufacture an rigid pavement. The demand and supply of road links is increasing tremendously as the nation is developing and filled with various contingencies. The evaluation of flexible and rigid pavements is already done which have shown advantages as well as disadvantages in their regards. The problem of fatigue is quite often in flexible pavements which lead to early rehabilitation of such pavements. While the rigid pavements have their own contingencies like the setting time after the construction is very high and also the riding quality tends to degrade due to the various number of joints intended in to it. The developing countries like India has issue to deal with growing traffic flow and overloading of carrier vehicles, which are the prime sources of many issues such as fatigue-rutting and early deterioration of the pavements. Where the economy plays very stringent role we need to optimize the design of pavements by selecting adequate material which proves to be beneficial for the nation. Thus, it leads to the demand of such design which heals the problem in pavements to overcome deficiencies in it. It could be easily understood that we need to adopt or innovate a pavement which gives us the property of flexible as well as the rigid pavement.

The prime user of semi-flexible pavement are European countries, which have invented and also used such crust in the urban roads, airports, shipyards where heavy loading is been applied and on the road stretches where the heavy traffic moves with excessive braking application. The results when evaluated were promising, as the semi-flexible has fulfilled the demands. For such we need to discuss the properties of CGBM with the referred documents and citation papers. The prime emphasis will be done on the development and evaluation on semi-flexible pavements in present study. The literature review consist of four sections which is been briefed in sub-sections. The first section includes the need of the study on CGBM matrix design. The second section consists of the development of CGBM with various different approaches. The third section is an explanation of the experimentation work held to evaluate the pavement. The fourth section is analysis of various conclusions and outcomes from various research paper and citations.

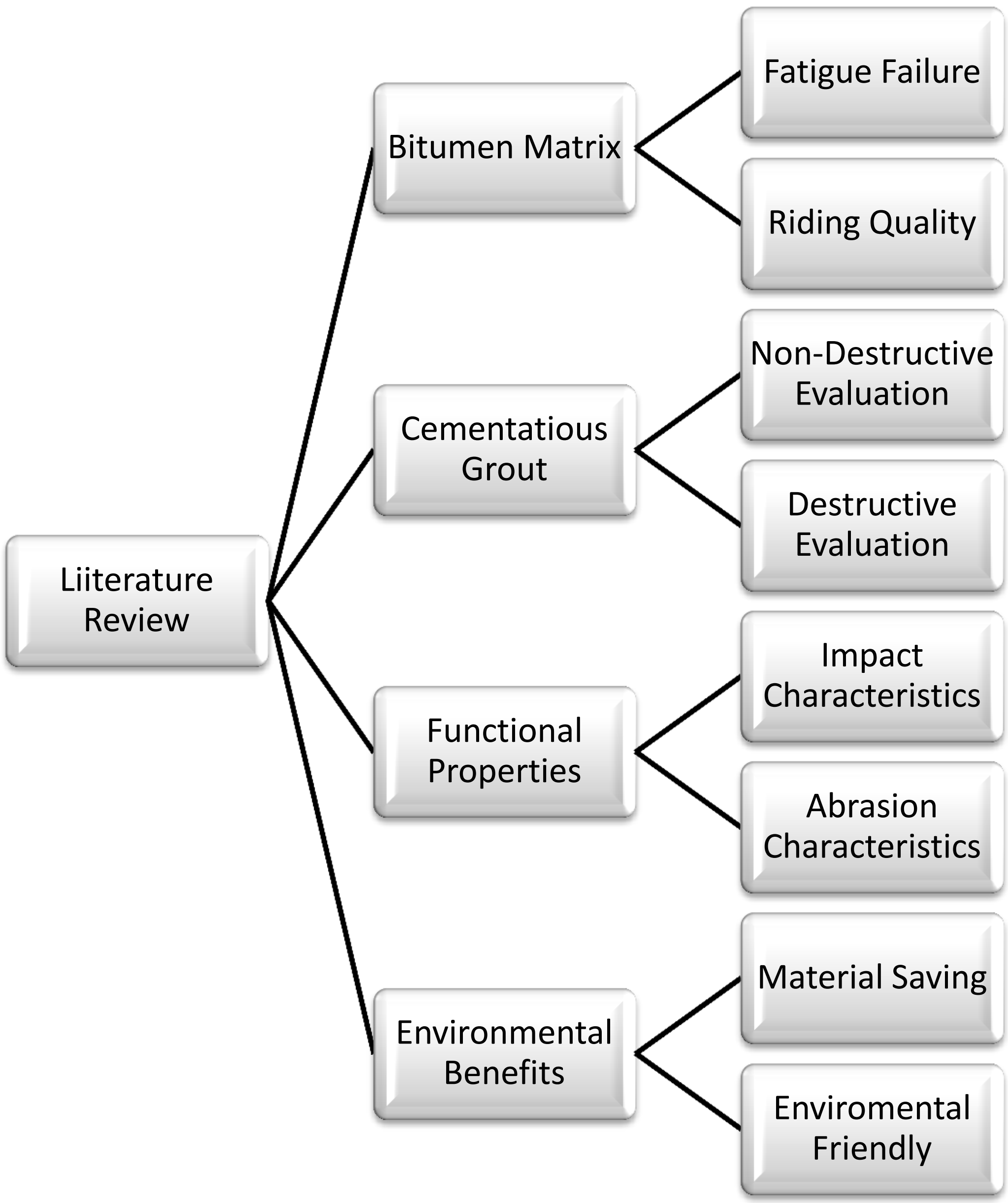


Figure 2.1. Literature Review Outline

2.2. Cement Grouted Bituminous Mix Pavement

CGBM is amalgamated material, which has the tendency and ability to resist fatigue failure under heavy axle loading. The behavior and characteristics of CGBM is like bituminous as well as rigid pavement both. The pavement are directly exposed to tough weather conditions where it has to undergo high intensity of heat which is been stored in it and leading the pavement to cross failure criteria for further detritions. The pavement also undergo heavy loss when exposed to water during precipitation, predominantly the flexible crust get most affected. In the case of rigid pavement they have their own complications like dealing with the setting time after the construction and muddle with amount of joints present in rigid pavement leads it to downgrade the riding quality. It was perceive that the adaptation of CGBM would definitely tend to overcome above complication in the conventional mixes.

However, it was also observed that the functional characteristic of CGBM was limited to urban roads as it required due considerations in design mix of grout material to perform adequately in heavy axle loading. Earlier research needed further study and customization in mix design to make it applicable for expressway and highways in Indian conditions. The research papers on CGBM had showed that it was been adopted by the developed countries and it had significant performance criteria which furthermore appreciated other countries to adopt this technique. Research steered by Hassan AL. (2002) presented that selection of preeminent grout mixture can lead to higher strength and workability in CGBM pavement. Utilization of CGBM was adopted in many infrastructure divisions like airports runways and parking facilities, industrial areas, harbor and ports and also in bus terminal facilities. The effect of aggregate gradation plays fundamental function for the design of CGBM.

The typical CGBM system is a combination of embankment, sub grade, granular layer and composite material i.e. Cement Grouted Bituminous Mix. The archetypal thickness observed from the previous literature showed thickness up to 150-200 mm, which is the top surface layer on pavement. It is necessary to have optimal CBR value for the beneath soil sub grade, with required resilient modulus of different layers to uphold proper load distribution in pavement layer. The CGBM consist of the coarser grade aggregate by eliminating the finer particles so that we get voids in the Marshall skeleton. The voids ratio was defined from 25-35%, which needed to be evaluated by suitable experimentation. The voids then filled or grouted with the high performance cement paste. The cement paste is a mixture of cement, superplasticizer, air entering additives and water which make the grout adequate enough to enter inside the voids gravitationally or by external force.

Figure 2.2. Application of CGBM in Pavements

2.3. Materials

CGBM is a composite material filled with bitumen as well as cementitious materials, but the gradations of aggregate play very vital role in construction of cement grouted bituminous mixes. The relative literature on CGBM showed that the adaptation of coarser aggregates and elimination of finer aggregates will lead to maintain the void ratio as per the permissible norms. The higher percentage of coarser aggregate with right amount of compaction will make the composite structure to achieve proper void ratio i.e. 25-35%. The nominal size of aggregate was adopted around 13.2 - 9.5 mm by evaluating many research papers. It was been observed that finer aggregate will lead to reduction of void content. The aggregate structure for the CGBM mixture is quite exclusively in coarser aggregates gradation. In some instance the selection of finer aggregates are taken so that the enhancement of the mix durability could be increased. The adaptation of appropriate aggregate in the field of CGBM by various researchers was made on trial and hit techniques till it gains or reaches required void content.

Study on the mechanical performance and application of the composite cement-asphalt mixture. (H. Zhang Et Al). (2016). Used bitumen of VG 30 grade, with an coarser aggregate of greater than 4.75 mm size of regular crushed stone. Finer aggregate of 2.36 mm is been used and the property were depicted. The material used for the grout material were ordinary Portland cement with natural river fine sand and water fit for drinking in the test.

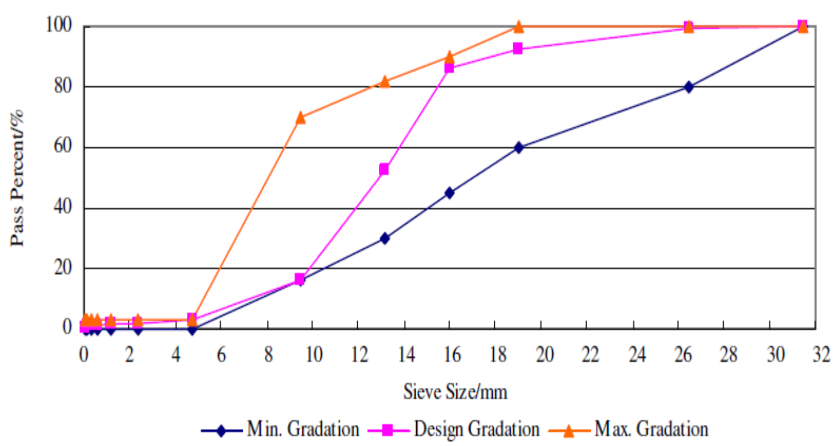


Figure 2.3. Aggregate Gradations (H. Zhang et al.2016)

The test design comprises of ratio of water and cement which is been determined as 0.6, Cement: sand: water = 1:0.5:0.6.*Investigation into engineering properties and strength mechanism of grouted macadam composite materials. (S. Hou et al). (2015),* Paper presented in his research paper that the material used for the preparation grouted macadam consists of bitumen grade of SK-90 with all the basic properties depicted. Aggregate used was for preparing porous asphalt was from crushed matrix stone. And the filler used have the following properties. The material used for the grout was Portland cement with the additives to prepare the modified mixed cement grout.

Table 2.1. Properties of Bitumen (S. Hou et al.2015)

Properties	Standard	Testing results
Penetration (25°C, 100 g, 5s)	ASTM D5-06	8.6 mm
Ductility at 10°C	ASTM D113-07	87 cm
Ductility at 15°C	ASTM D113-07	>100 cm
Softening point (R&B)	ASTM D36-06	48°C
Viscosity at 60°C	ASTM D4402-06	153.6 Pa s
Flash point	ASTM D92-05	320°C
Wax content	DINEN 12606-1-2007	1.2%
Solubility in trichloroethylene	ASTM D2042-09	99.7%
Density	ASTM D70-09	1.033 g/cm^3

Table 2.2. Properties of Aggregate (S. Hou et al.2015)

Properties	Standard	Testing results
Coarse aggregate angularity (%)	ASTM D5821	108
Fine aggregate angularity (%)	AASHTO T304	49.2
Flat/elongated particles (%)	ASTM D4791	2.9
Clay content (%)	AASHTO T 112	0.6
Coarse aggregate specific gravity (g/cm^3)	ASTM C-127	2.783
Coarse aggregate absorption (%)	ASTM C-127	0.44
Fine aggregate specific gravity (g/cm^3)	ASTM C-128	2.768
Fine aggregate absorption (%)	ASTM C-128	0.71
Sand equivalent (%)	AASHTO T 176	81
Abrasion loss (Los Angeles) (%)	ASTM DC-131	15.3
Frost action (with Na_2SO_4) (%)	ASTM C-88	1.1
Polishing value	BS-813	0.73

Table 2.3. Aggregate Sieve Size (S. Hou et al.2015)

	Sieve size (mm)										
Mixture type	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Porous AC-16	100	78.2	59.1	45.2	12.1	8.8	6.1	4.9	3.8	3.3	2.9
AC-16	100	95.1	87.6	77.8	43.5	28.0	19.8	14.5	11.1	9.3	5.9

Laboratory and field evaluation of cement grouted bituminous mixes. (G. Bharath et al). (2019). Aggregate worn in this study were procured by Agra quarry in the state of UP. The properties of the aggregate were suitable to use them as wearing course. The bitumen used to make open graded skeleton was of VG30 grade, the corresponding viscosity requirement were checked as per the guidelines of MoRTH. The grout material used in the study consists of cement, sand and polymer. The grout fabricated is been checked based on compression and workability criteria. The grout material was performed to find the optimum quantity of water content inside it such that it can be easily grouted to the full depth in the mix which provides an adequate strength.

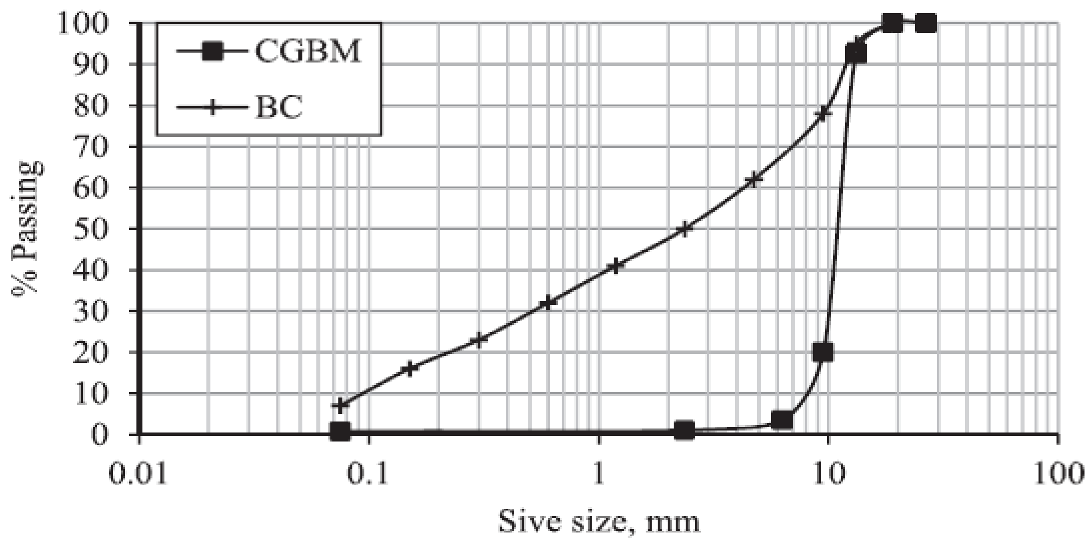


Figure 2.4. Sieve Size and Passing for Aggregate (G. Bharath et al.2019)

Table 2.5. Bituminous Properties (G. Bharath et al.2019)

Property	Value obtained	Test method (BIS)
Specific gravity, 27°C	1.02	1202 (1978)
Penetration, 25°C,100 g, 5s (dmm)	61	1203 (1978)
Softening point (°C)	50	1205 (1978)
Ductility, 27°C (cm)	Above 100	1208 (1978)
Viscosity at 60°C (Poise)	2894	1206 (1978)
Viscosity at 135°C (cP)	575	ASTM D4402-15

The performance and analysis of semi-flexible pavement by the volume parameter of matrix asphalt mixture. (Q. Ding et al). (2011). The research used coarser aggregate and fine aggregate which had an crush value of 11%, Los Angeles abrasion value of 14%, Flakiness and elongation index of 4%, water absorbing capacity of 0.4%. The bitumen used in the study is of VG30 grade. Whereas, the cement choose was Hua xin P.O42.5 silicate cement.

Table 2.6. Used Bituminous Properties (Q. Ding et al.2011)

Qualification		Result
Penetration degree（25℃ ,100g,5s）/0.1mm		51
Softening point /℃		82
Ductility (5℃ ,5cm/min)/cm		32.1
Flash point (COC)/ ℃		310
Solubility (trichloroethylene)/%		99.9
Elastic restitution /%		97
RTFOT	Ductility (15℃)/cm	21.8
	Mass loss rate /%	0.04

Table 2.7. Grout Proportion (Q. Ding et al.2011)

Cement (%)	Flyash (%)	Expansion Agent (%)	Sand (%)	Water (%)	Water Reducing Agent (%)
46.5	7.0	14.0	27.9	4.7	0.6

Laboratory and field evaluation of a novel cement grout asphalt composite. (S. An et al). (2018). This paper had used aggregate material mixture which is trodden hard basalt aggregate, consistent, clean, waterless, free of wearing impurities, and of promptness angularity. Asphalt binder used in the study was developed in his previous study which is been served here as binder. The basic properties of binder were tested as per JTG E20-2011 and DBJ/CT065-2009. The grout material consists of 20% water cement ratio. The properties of grouting material were appraised in the study used British standard specification.

Table 2.8. Aggregate Passing (S. An et al.2018)

Sieve size (mm)	Percent passing
16.0	100
13.2	92
9.5	65
4.75	18.0
2.36	10
1.18	8
0.6	7
0.3	6
0.15	5
0.075	4

Table 2.9. Aggregate Properties-Open Graded (S. An et al.2018)

	Value				
Property	9.5–16	4.75–9.5	2.36–4.75	Specification limit	Standard
Apparent density (g/cm^3)	2.890	2.877	2.870	≥2.6	T0304-2005
Water absorption (%)	1.467	1.858	—	≤2	T0304-2005
Ruggedness (%)	1.91	1.52	3.14	≤12	T0314-2000
Aggregate crushing value (%)	—	9.3	—	≤26	T0316-2005
Los Angeles abrasion (%)	—	4.1	—	≤28	T0317-2005
Content of weak particles (%)	1.80	1.13	—	≤3	T0320-2005
Needlelike particle content					
Particle size larger than 9.5 mm (%)	5.58	—	—	≤12	T0312-2000
Particle size smaller than 9.5 mm (%)	—	7.07	—	≤18	

Mechanical properties of cement-bitumen composite for semi-flexible pavement surfacing. (S. Koting. Et al). The material used in this paper for grout material study was ordinary Portland cement, white cement and silica fume. To provide sufficient strength inside the grout the superplasticizer was used of Polycarboxylate base with 10% by weight of total mix and an additive of 5% which was an mineral admixture. Open graded bitumen skeleton was made of trodden aggregate, filler (3%) and bitumen content of 3.62% by weight of mix. The observation concluded that the percentage of coarser aggregate were higher to obtain higher air voids. *The application of semi-flexible pavement on heavy traffic load. (Ling et al).(2009).* The crumb rubber was used from natural source and ground at room temperature. The bitumen used is AC-16 mixture of AH-70 from Zhong-hai Company. The bitumen rubber was prepared using the virgin bitumen. The grouting material consist of ordinary Portland cement from La-fa-ji company of grade 2 fly ash and river super fine sand. The polymer used ion the grout was styrene-butadiene emulsion from the BASF company. The study had produced two types of mortar which is been evaluated simultaneously on open graded bituminous mix.

Formulation and performance comparison of grouting material for semi-flexible pavement. (J Zhang et al). (2016). The study was based on grout material performance which was been evaluated with different proportion of composition. The study had used ordinary Portland cement, which convene the technological requirement according to the test methods. The fly ash was used in the grout material as per the requirement pavement base construction. Mineral powder was used to meet technical requirement of ground granulated blast furnace slag utilize in cement and concrete in China. The standard sand was used along with the Silicon dioxide content in it to meet the technical requirement of grout.

Table 2.10. Mix Design of Grout (J. Zhang et al.2016)

Factor level	A: water-cement ratio (W/C)	B: fly ash content (%)	C: mineral powder content (%)	D: standard sand content (%)
1	0.55	0	0	10
2	0.60	10	10	15
3	0.65	20	20	20

Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement. (J Pie et al). (2016). Study inhibits material establishing on the production of grout material used to impregnate inside the open asphalt mix. Portland cement is used which meet the technical requirement of testing method of cement and concrete for highway engineering. Polycarboxylate superplasticizer and expansion admixture with high performance triterpenoid saponin air entering agent was used as additives to quantify the performance criteria of grout material. Open graded bituminous mix was prepared with different porosity values of 18%, 21% and 24%, for which different gradation of aggregate were designed with different bitumen content for the optimum determination.

Table 2.11. Mix Design for Slurry (J Pie et al.2016)

Factor level	X: Water-cement ratio (W/C)	J: TH-928 polycarboxylate superplasticizer content (%)	P: UEA expansion admixture content (%)	Q: ZY-99 Triterpenoid saponins air-entraining agent content (%)
1	0.57	0	0	0
2	0.54	0.5	10	0.008
3	0.51	1	12	0.012

2.4. Experimental Analysis

Study on the mechanical performance and application of the composite cement asphalt mixture. (H Zhang et al).(2016). The test performed on the composite cement asphalt mixture showed that; Rut test of the specimen after pouring showed less rutting than the specimen without filled with grout. The rutting depth was fewer than 1 mm and dynamic stability was more than 15,000 times/mm. The test has confirmed that amalgamated cement asphalt mixture has the superior performance in high temperature stability. Split test was performed in this study to evaluate the sample for the low temperature cracking resistance before and after pouring the grout material. The loading rate was around 1 mm/min. The test result has showed that tensile strength after driving grout is high and modulus of stiffness is small. It showed that lower temperature performance of the bitumen medium was influenced by the bigger brittleness of the material in the low temperature. And the rigidity of the specimen was increased after pouring the grout material. Based on tensile test it is observed that larger voids in bitumen matrix when filled with grout show negligible cracking in lower temperature. Saturated Marshall Experiment was conducted for the assessment of water stability of amalgamated cement-bitumen mixture. The observation from the study presented that the stability before and after pouring into water did not change significantly. The stability of the specimen was increased after the filling the voids with grout material. Marshall stability of the specimen mixture had shown saturation of more than 20kN. The test performed here has indicated that the Marshall stability has increased due to the cement mortar material which gains the rigidity.

*Investigation into engineering properties and strength mechanism of grouted macadam composite material. (S Hou et al). (2015).*Wheel tracking test was performed in this study for the evaluation of stability of GMCM. Rectangular slab were manufactured at maintained their temperature at an constant rate of 60°C ± 0.5°C at 6 hours. The rectangular slab were located on steel plate, the rectangular slab were confined from all 4 sides. When the rectangular slab was under the confined area then there was an application of load which was applied by an rubber wheeled vehicle with an force of 0.7Mpa. The distance for travelling of wheel was 230 ± 10 mm at speed of 42 ± 1 cycle/min in 60 min. The deformation which was caused were recorded with the help of LVDT to measure out the vertical displacement. Beam Bending Test, it is been observed in the study that low temperature causes more distress in the pavement of composite material. For the evaluation of low temperature stress in the GMCM beam bending test was performed. The beams was sustained at temperature of 10̊ C for 3 hours, and were evaluated for the beam bending evaluation. The beam been tested with a loading rate of 50 mm/min at 10̊ C. This test method helps to evaluate the flexural strength and tensile stain which occurred due to the load applied in low temperature. Fatigue test was performed in the study on GMCM to observe the fatigue performance, the test consist of four point bending apparatus on MTS-810 at 15̊ C. Test was conducted underneath the environmental control cabinet as the property of the GMCM was hard. A haversine wave loading with no rest period was constantly applied on specimen at 10Hz. The value evaluated from this test had distinct as beam crack to occur. Moisture susceptibility test were performed with the help of Retained Marshall Stability (RMS) and Indirect Tensile Strength (ITS), these test were helpful in study for GMCM susceptible to moisture damage. The specimen used for the evaluation was kept for 28 days curing. The specimen of GMCM was separated into two cluster, where the one group of specimen was controlled at 60̊ C for 30 min and another group of specimen was controlled at 60̊ C for 48 hours. The applied rate of loading was at 50 mm/min. The evaluation of moisture susceptibility showed that the GMCM had better resistance form the moisture when compared with the conventional asphalt mix. Scanning electron microscopy observation is an test which was performed in this study to understand the microstructure change of material under the different load conditions along with the varying environmental condition. The apparatus used for the evaluation was 6390L V, JEOL. The test were performed when the specimen of GMCM were coated with gold so that proper electrical conductivity takes place.

Laboratory and field evaluation of cement grouted bituminous mixes. (G. Bharath et al).(2019). The study carried out on CGBM was evaluated with following test which included the, Indirect Tensile Strength (ITS), the determination of ITS were based on ASTM D6931 (2012) which is been performed on an cylindrical sample of CGBM, where the ,load applied was along the diametrical axis as the rate of loading 51 mm/min. The determination of Marshall stability as well as compressive test were performed, to understand characteristics of CGBM, with the standard guidelines of ASTM D1559 (2012) and ASTM C39 (2015) respectively. Modulus of Resilience (M_R) is an significant factor which is been used to design and analyze the pavements structure. ITS test was performed for conventional BC and CGBM both to carry out the difference among them in this study. Three samples were taken from the BC and CGBM samples to carry out the ITS test. It is been studied in this research that the CGBM used here showed higher value for resilient modulus as measure up to the conventional BC. Analysis showed in the paper presented that the resilient modulus value decreased with an increase in temperature which was quite understood and obvious. The reduction of resilient modulus with increase in temperature was of 82.2% for the BC specimen and 45% for the CGBM specimen. It was hence proved that CGBM mixes were less susceptible when compared with the conventional BC. Dynamic Modulus was evaluated for the specimen by the help of stress-strain relationship under varying load. The factors which were in concern with the dynamic modulus were like temperature, rate for loading age plus the mixture characteristics, these are the influencing criteria. The tests were conducted at 20̊ C, 35̊ C and 50̊ C respectively. Frequencies following temperature were at 25, 20, 10, 5, 2, 1, 0.5 and 0.1 Hz were considered. The research paper also evaluated the experiment to calculate Phase angle (ɸ) characteristics of the conventional bituminous mix. The purpose to evaluate the phase angel was to obtain the dynamic modulus (E*) test. The test was based on the guidelines of AASHTO TP 79 (2013). The temperature at which test were conducted was 35̊ C. The model through which results were generated was sigmoidal modal. The study on the composite material showed that Dynamic modulus (E*) values were decreasing when there was decrease in temperature. The study concluded that the Dynamic modulus values of composite material were superior to the conventional bituminous mix at same temperature and frequencies. It is been observed from the evaluated values of Phase angel (ɸ) that it started increasing when there was decline in the frequency and with improve in temperature.

The performance and analysis of semi-flexible pavement by the volume parameter of matrix asphalt mixture. (Q. Ding et al). (2011). The research paper had conducted the test performance of semi-flexible pavement with the guidelines of JTJ052-2000 i.e. Standard Test Method for Bitumen and Bituminous Mixture for Highway Engineering. The performance for semi-flexible pavement showed and behaved as an excellent surface course as the rutting depth on the specimen was least, over the DS 30000 cycles per mm. The Marshall stability strength was around 16.25 kN and 5.98MPa after 28 days. The water stability results were outstanding with a ratio of gain up to 100%. It is been observed from the study that with ageing the strength of the pavement increases. Compacted strength and the compacted modulus values augmented with improve in the bituminous content inside the matrix of open graded mix. It is been observed from the result that the strength increases with increase in air voids but the property of brittleness also increases. The strength value of the specimen was 5.23 MPa and compacted modulus of 2812.60 MPa. The study explains about the microstructure of a combined material has been helpful to gain the strength because of mechanism performance inside the material.

*Laboratory and field evaluation of a novel cement grout asphalt composite. (S. An et al). (2018).*The specimen which is produced from the cement grout asphalt composite material were tested to evaluate following property i.e. air void content, Marshall stability, flow value, dynamic stability in rutting, low temperature flexural failure, tensile strength ratio and permeability coefficient. The results of the study show that the property of grouted material was remarkably good when compared with the conventional surface course of bituminous material.

Table 2.12. Properties of Cement Grout Asphalt Composite Material (S. An et al.2018)

Property	Value	Specification limit	Standard
Air void (%)	5.1	≤8	T0711
Marshall stability (kN)	30.2	≥28	T0709
Flow (mm)	5	Measured value	T0709
Dynamic stability in rutting test (times/mm)	No deformation	No deformation	T0719
Low-temperature flexural failure strain at −10°C ($\mu\varepsilon$)	3,150	≥2,500	T0715
Tensile strength ratio (TSR) (%)	95.9	≥85	T0729
Permeability coefficient (mL/min)	Impermeable	Impermeable	T0730

The application of semi-flexible pavement on heavy traffic load. (Ling et al).(2009). The test performed to assess the property of semi-flexible pavement were low temperature splitting property, low temperature bending test of semi-flexible pavement mixture with study on the performance based on high temperature and water stability. Low temperature test was done in this study which showed that effect of temperature on failure strength of semi- flexible pavement was significant. It was observed that the specimen made in this study had increased the strength when there was decrease in the temperature. The results show that the specimen had shown that the failure strain of the semi-flexible pavement decreased gradually when there was decrease in the test temperature. The stiffness modulus of the specimen observed that when it decreases the specimen is more prone to cracking. It is been observed that the air voids of bituminous mixture had influence in low temperature resistance property of mix i.e. when the air voids were increased at low temperature properties become poorer.

*Formulation and performance comparison of grouting material for semi-flexible pavement. (J Zhang et al).(2016).*The relative analysis of the cement paste showed that the recommended water cement ratio is from 0.56 to 0.58, with the addition of 10% fly-ash and 10% mineral powder. The experiment was performed in this study to evaluate the fluidity, drying shrinkage and strength parameter of the grout. The observation from the paper presented that the fluidity decrease with decrease in water content and increase with increase in water content with varying strength parameters. The strength was also decreased when the fluidity increased. The strength parameter of the grouting material was proportional to the water content i.e. when the water content increased the strength decreased and vice versa. The 7 day compressive strength of the selected paste showed value of 15MPa which was approaching to 20 MPa. The flexural strength value had increased by 21.5%. It is been observed from the study that the prepared grout material posses minor drying shrinkage, while it posses the better fluidity and higher strength value. The scope of study presented that parameters can be enhanced further with the change in above parameters.

2.5. Concluding Remark

Study on the mechanical performance and application of the composite cement-asphalt mixture. (H. Zhang Et Al). (2016). The study had concluded that the pavement design which was evaluated in laboratory had it feasibility that amalgamated cement-asphalt mix can be poured in to open graded bituminous mix as it is observed that the pouring method is more convenient. The study showed that composite material has superior high temperature stability, and the flexibility of the material is maintained as it acts as better performing pavement. The water stability of the mixture enhanced significantly when compared with the conventional mix.

*Investigation into engineering properties and strength mechanism of grouted macadam composite material. (S Hou et al) (2015).*The conclusion form the evaluation of GMCM showed that it had higher temperature stability, with increase in the resistance of fatigue performance and moisture stability when the GMCM was compared with conventional asphalt mix. The grouting of the bitumen matrix has improved the strength due to adhesion property of harden cement leading to enhancing the engineering property. The harden grout material has generated an crystalline lattice network in the mix. It forms an integral coagulation-crystalloid structure which helps the structure to bear load. GMCM produced had meet better mechanical property and durability characteristics.

*Laboratory and field evaluation of cement grouted bituminous mixes. (G. Bharath et al).(2019).*The study has prepared a suitable volumetric mix to prepare an high void bituminous mix. The selection of appropriate grout mix was prepared considering the property of workability and strength parameter. The evaluation CGBM showed that the composite material have higher stability, indirect tensile strength, resilient modulus, dynamic modulus, compressive strength and performance were compared with conventional bituminous mix. The grouted macadam has TSR value increased by 90%. The ITS value of the CGBM had shown increment of 2.3 times then the conventional bituminous mix, whereas the compressive strength increased by 6.25 to 2.75 times.

The performance and analysis of semi-flexible pavement by the volume parameter of matrix asphalt mixture. (Q. Ding et al.). (2011) Observation from the study presented that volume parameter of matrix bitumen is playing an important role in the performance of semi-flexible pavement. The increase in the air void has increased the performance parameter. The grading of the aggregate had vital role in providing optimum void content which further help in pore structure bonding. The author has figured it out that microstructure has an great influence in mechanism performance and pavement performances due to the bonding interface between the cement and bitumen present on the surface of aggregate.

Laboratory and field evaluation of a novel cement grout asphalt composite. (S. An et al). (2018). The test result exhibited in study has shown that customized asphalt mixture has immense performance criteria and it is meeting all the engineering properties. The porosity in the open graded asphalt mix is not only helpful in permeability but also help in providing the suitable grout application. The semi-flexible material after grouting showed a concerning low porosity and high stability. The evaluation for the filed performance was done which concluded that grouting technology can improve the bearing capacity along with the moisture susceptibility of pavement.

*The application of semi-flexible pavement on heavy traffic load. (Ling et al).(2009).*The observation from the study had concluded that when the temperature decreased properties of composite material decreased gradually as the air voids content increased. The polymer used in the cement mortar helped to increase the low temperature crack resistance phenomenon. For the evaluation of composite material in low temperature brittle point as well as strain energy density were the good parameter to consider. The material produced show advantages in terms of economy, technique and performance when it is been compared with asphalt mix design.

*Formulation and performance comparison of grouting material for semi-flexible pavement. (J Zhang et al).(2016).*The study was based on enhancing property of the grout material prepared for the open graded mix of asphalt, which relates that water-cement ratio posse's largest effect on fluidity, strength and dry shrinkage. The recommended water-cement ratio in paper was 0.61 to 0.63 with fly-ash content of 10% and standard sand content of 15%. Study recommend that cement paste and mortar can meet the technical requirement when the mix recommended range is taken as per the study i.e. 0.58 water-cement ratio with 10% of fly-ash and mineral content.

Design and performance validation of high performance cement paste as a grouting material for semi-flexible pavement. (J Pie et al). (2016). The research has evaluated that when the water-cement ratio, Polycarboxylate superplasticizer, air entering agent along with expansion mixture were kept at an range of 0.55-0.57, 0.5-1.0%, 0.008% and 10% respectively the SPF designed showed better performance of grout to provide strength in semi-flexible pavement. The HPCP designed with different formulation were studied on the parameter of fluidity, strength and drying shrinkage property, where recommended SFP model shoed early strength, better fluidity with lowers drying shrinkage.

3. MATERIALS AND METHODOLOGY

3.1. Materials

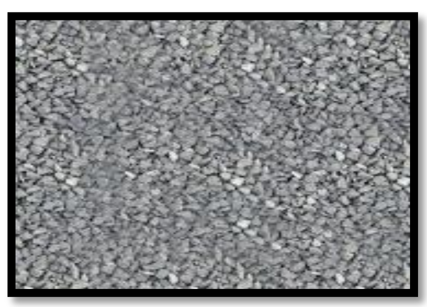
3.1.1 Aggregates

In this dissertation, the source of aggregate which were used to perform and evaluate the CGBM was procured from Larsen & Turbo which were using these aggregate for the development of one of the national highway in India. The obtained aggregate were sieved for different gradations i.e. 19-12.5 mm, 12.5-9.5 mm, 9.5-4.75 mm, 4.75-2.36 mm and 2.36-0.075mm, which is been depicted in the Figure 3.1. The above aggregates were used to manufacture the CGBM based on the Marshall Mix design method to analyze mechanical properties. Aggregate quality influences role in the strength production inside the Marshall specimen and to a great extent in transferring the load within the pavement. The necessity of testing the aggregate becomes essential before using it in construction. The aggregate procured should posses proper shape and size so that the pavement acts monolithically. Strength, hardness, toughness or the water absorption of the aggregate should be tested to choose the appropriateness of the aggregate used in the pavement.

19-12.5 mm

12.5-9.5 mm

9.5-4.75 mm



4.75-2.36 mm

Figure 3.1. Aggregate used for CGBM

The basic test were performed to assess the quality of aggregates to demonstrate the usage of aggregate were under the approved limits by MORTH. The physical properties of selected aggregates is been depicted in the Table 3.1. The temperature while manufacturing the Marshall specimen of aggregate was taken 175˚C-190˚C, as per the guidelines of MS2.

3.1.1.1. Specific Gravity

Specific gravity of aggregate is an important property which is beneficial for the designing the bituminous mixes. The definition of specific gravity is ratio of the mass of aggregate in water which is permeable to voids inside it. As the aggregate contain the voids inside it which is been filled by water this is soaked inside it. Two specific gravity are measured for aggregates, which included apparent specific gravity and bulk specific gravity. The differentiation between the two is water permeable in voids of the aggregate. It can be measured simply by evaluating the dry weight of the aggregate in oven and then weight by the saturated surface where all the voids of aggregate is filled with water.

Apparent Specific Gravity: Weight of aggregate which does not have water permeable voids, using Equation 1.

$$G_{app} = [(M_D / V_N)] / W \tag{1}$$

Where,

M_D = Dry mass of aggregate

V_N = Total volume of aggregate which does not have volume of absorbed water

W = Density of water

Bulk Specific Gravity: Total volume of aggregate with water permeable void, using Equation 2.

$$G_{bulk} = [(M_D / V_B)] / W \tag{2}$$

Where,

V_B = volume of aggregate including absorbed water

3.1.1.2. Water Absorption

The water is been absorbed by the aggregate which increases aggregate soaking value for water which is undesirable for pavement. It can be evaluated by the weight of aggregate in total dry state and weight of aggregate submerged in water and all the voids filled with water. The difference between the weight will give the M_W, as mentioned in Equation 3.

$$\text{Water Absorption} = (M_W / M_D) * 100 \tag{3}$$

3.1.1.3. Los Angeles Abrasion

Test performed for evaluating the toughness, crushing and degradation of an aggregate. The guideline followed for the evaluation of abrasion values for the selected aggregate was ASTM C131. The aggregate used for the pavement construction are subjected wear and tear by the movement of traffic. This makes the aggregate to be rigid enough to oppose the abrasion. The principle used in this test is to produce an abrasive charge on the aggregate by standard steel balls where the balls and aggregate are inside the drum for the specific number of revolution. While the revolution takes place the aggregate are subjected to rubbing with the balls to determine the Los Angeles value. Aggregate are clean and dried in oven at 105°-110°C, as shown in Equation 4.

$$\text{Abrasion Value} = (W_1 - W_2) / W_1 \times 100 \tag{4}$$

Where,

W_1= Original Weight of aggregate, g

W_2= Weight of aggregate retained, g

W_1- W_2 = Aggregate passing 1.7mm IS Sieve, g

3.1.1.4. Angularity Number

Test performance gives an indication about the shape of aggregates. The aggregate can be angular, rounded and cubical in shape. Angularity number test is based on voids present in aggregate after compaction. In this test the aggregate with same gradation is filled inside the metal cylinder which is having capacity of 3 liter. After filling the aggregate inside it, the aggregate are compacted in standard manner and the percentage of voids is been evaluated. For the aggregate having void up to 33% the aggregate angularity considered is zero. For the aggregate having void up to 44% the aggregate angularity considered is 11. The aggregate having angularity zero is considered to be least angular aggregate, while the 11 angularity number indicates most angularity which could be used in pavement.

3.1.1.5. Impact Value

Impact value of aggregate is to determine the aggregate suitability for road construction. It emphasizes the property of aggregate which resist impact on it known as toughness. As the aggregate are subjected to the wheel load of the vehicles which disintegrate the aggregate it is necessary to have stronger toughness property in it. It gives out the resistance when a sudden impact or shock is applied to the pavement aggregate.

Table 3.1. Physical Properties of Aggregates

Physical Properties (IS: 2386)	Aggregate Size (mm)			
	19-12.5	12.5-9.5	9.5-4.75	4.75-2.36
Specific Gravity	2.792	2.864	2.627	2.872
Dry Unit Weight (kg/l)	1.54	1.62	1.67	1.59
Air voids in Dry Aggregates (%)	43.92	44.79	44.50	44.83
Los Angeles Abrasion (%)	16.72	15.88	18.8	20.05
Angularity Number	12	11	11	12
Impact Value (%)	18	15	17	16

3.1.2 Bitumen

Bitumen used in the road construction is distilled product of crude oil used to manufacture the conventional flexible pavement. Bitumen remains in the semi-flexible state in the room temperature and posse's high viscosity high softening point. The bitumen is material which is susceptible to the temperature and rate of loading. It loses its viscosity and behaves like non-viscous fluid. For the mixing purpose the bitumen is heated at a standard temperature range of 130°-175° C or even at the higher temperature which varies with respect to the type of bitumen being used. The basic requirements of the bitumen are, to be capable of turning into fluid by heating or by the mean of adding any volatile solvent. To be able to turn down into complete viscous material when the temperature decreases from the standard heating temperature which up heals the criteria for the pavement stability so that it can able to resist the deformation caused in the pavement due to the traffic loading. Also the bitumen should posses the property to retain the stability of pavement in the highest temperature of the pavement in the hot climatic condition to maintain the service life of pavement. As the property of bitumen is to be flexible it should be able to make the pavement flexible not brittle under the heavy traffic loading condition.

Figure 3.2. Bitumen used for CGBM

Bitumen obtained for the research work has been procured from the Larsen & Toubro, which is been also used for the construction of national highway in India. Bitumen is a by-product of crude oil which the last residue after the fractional distillation. Bitumen is a mixture which consists of several hydrocarbons with different molecular weight. The bitumen used for the CGBM mixture was embraced of VG 30 viscosity graded bitumen. The properties of VG 30 binder content is depicted in Table 3.2. The temperature at which bitumen is to be mixed with aggregate was 120˚C-165˚C, as per the recommendation of MS2 guidelines.

3.1.2.1. Viscosity

Viscosity is a property of bitumen which is opposite of fluidity. It is a property which is a resistance to flow by retarding the flow inside it due to the internal friction. Viscosity can be understood i.e. when any force is applied on liquid the property of viscosity will lead to decide the movement of the fluid at that time, if it poses higher viscosity the movement of the fluid will be least and when the viscosity of the fluid is least which can reach up to water and it tend to show higher movement while applying the load. The application of bitumen is done when the bitumen is in its liquid state therefore it is essential to examine the viscosity properties of the bitumen as there is variation in the type of bitumen procured from the refineries with variability in the viscosity. The guideline adopted for the viscosity values which were evaluated from the ASTM D4402, using the rotational viscometer. This test is to measure the torque requirement for the spindle inside the apparatus to maintain rotational speed of 20 RPM at an constant temperature of 60̊ C and 135̊C where it is been submerged inside the procured bitumen. Using Equation 5,6.and 7.

Input data:

Torque, T;   N-cm

Effective spindle length, L; mm

Spindle radius, R_s; mm

Container radius, R_c; mm

Rotational speed, ω; rad/sec

Radius at location of calc. x; mm

Calculation:

$$\eta = \zeta/\gamma \quad (5)$$

$$\zeta = T/2\pi R_s^2 L \quad (6)$$

$$\gamma = 2\ \omega R_s^2\ R_c^2 / x^2(R_c^2 - R_s^2) \qquad (7)$$

Where,

ζ = shear stress, N/cm²

γ = Shear rate, sec^{-1}

η = Dynamic viscosity, Pa-s

3.1.2.2. Softening Point

Softening point is an experiment which is been conducted to determine the temperature at which the bitumen undergoes phase alter from solid to flow-able phase. Bitumen used for CGBM open graded bituminous mix should be heated such that its applicability could be enhanced in the field at construction. It is been evaluated with the reference of ASTM D6493-11, which is done with the help of ring and ball test. The apparatus consist of two brass ring along with the two steel balls. Softening point is the indicator for the bitumen which has the same viscosity at constant temperature. Bitumen does not have melting point inside it, it changes from the state of solid to liquid in a very gradual manner with a very wide range of temperature. The higher softening point of the bitumen states that bitumen is stiffer and it will induce in longer serviceability at higher temperature giving enhanced life to pavement.

3.1.2.3. Penetration Test

Penetration test on bitumen is performed to determine the consistency of bitumen. The higher penetration values indicate that the bitumen used is of softer consistency. The test for penetration value is done with the ASTM D5 guidelines, the test were performed at 25℃ with 100gm weight of needle and the penetration time for the needle is 5 seconds.

3.1.2.4. Specific Gravity

Specific gravity of bitumen is used to determine the type of bitumen used for the pavement construction. Bitumen used for the open graded bitumen mix isVG30. Specific gravity is ratio of mass of known volume of the bitumen to the equal volume of water at temperature of 27̊ C. The determination of the bitumen for the specific gravity is done with the help of pycnometer method. The bitumen which is in semi-solid state at 27̊ C should be tested with the help of balance method only. To evaluate the specific gravity of the bitumen it is necessary to evaluate the coefficient of expansion or the specific gravity of bitumen at different temperature. It also helps to know the source of bitumen. Specific gravity ranging from 0.97 – 1.02 is considered as pure bitumen, from Equation 8.

Calculation:

$$\text{Specific Gravity} = \frac{e}{(e-f)} \tag{8}$$

Where,

e = weight of the dried specimen, g

f = weigh of the bitumen sample when immersed in water, g

Table.3.2. Physical Properties of Bitumen (VG30)

Property	Value Obtained	Test Method
Viscosity (135˚C) cP	415	ASTM D4402-15
Viscosity (60˚C) cP	2558	BIS 1206 (1978)
Softening Point ˚C	55	BIS 1205 (1978)
Ductility (27˚C) cm	108	BIS 1208 (1978)
Penetration (25˚C)	68	BIS 1203 (1978)
Specific Gravity (27˚C)	1.05	BIS 1202 (1978)

3.1.3 Cementitious Grout Material

The present study on CGBM had very essential contribution on strength and compressibility of CGBM. The grout material is been made of OPC43 grade cement, Polycarboxylate superplasticizer and air entering additives (CeBEX100). OPC43 is most widely used cement in the market which consists of argillaceous of silicate forms of alumina which are in the form of clays and shales. Limestone and chalk in the calcareous or calcium carbonates consisting in clay calcium carbonate. POC43 used in the manufacture of grout had specific gravity of 3.12, normal consistency of 29%, initial setting and final setting time of 65 and 275 respectively. Fineness was around 330 Kg/m^2 with bulk density of 830-1650 Kg/m^3. The OPC cement has property of greater resistance with cracking and shrinkage but more susceptible to chemical attacks. Initial setting point of OPC cement is faster which is beneficial for its early usability and the curing period requirement is also less. Polycarboxylate superplasticizer is used for the strengthening of grout material, and reducing water content in grout. CeBEX100 is an admixture used which is in powder state; this material is a combination of gas producing and plasticizing agent which also helps in reducing water content which makes strength and durability superior of grout.

The accurate proportion of all the grout material was adopted with the help of past studies based on the citation work and was accepted for final grout by applying hit and trial method. The appropriate grout was checked based on criteria like flow ability, workability and full depth penetration of prepared grout. Compressibility of grout is a second criterion which was considered for selecting the grout proportion. The variation with respect to water content showed that the increasing water content will lead to increase in the flow ability while it decreases the compressibility of the grout, while if we decrease the water content it showed resistance in grouting i.e. it had lower flow ability and workability with increase in compressibility. The proportion of superplasticizer was concluded based on the hit and trail technique. The range of superplasticizer used for testing and analysis was from 0.6, 0.8 and 1.0 (%). Admixture used for grout was an air-entering agent named CeBEX whose proportion was 250gm for 50kg of cement.

Figure 3.3. Preparation of Cementitious Grout (DG Mixer)

The flowability and workability of cementitious grout was tested based on the Marsh Flow Cone. For the evaluation of compressive values of grout 50cm² cube were manufactured which was been tested in CTM. Both the criteria were performed on various proportions so as to adopt the suitable grout. The result illustrate the optimum value of water cement was 0.45, been adopted which provides higher compressive strength with respect to workability and fluidity characteristics of prepared grout material. Grout material is been used to fill the voids of the open graded bitumen Marshall sample by simple method of gravitational force. Figure 3.4 show us the result based on compression strength of prepared grout. The displayed results for compressive strength are after 7 days full depth curing process.

3.2 Methodology

3.2.1 Preparation of Open Graded Bituminous Mix

3.2.1.1 Gradation of Aggregates

Open graded bituminous mixes are designed with the help of aggregates with uniformity in their size. The uniformity of aggregate helps the mix to attain the higher air voids in them; mixes are typically consisting of 9.5-12.5 mm size aggregate. The open graded bituminous mixes are also referred for drainage as well as for the semi-flexible pavements. The design methodology is been adopted with the help of MS2 guidelines. Generally open graded mixes are designed with only one aggregate size. The precise level of air voids requirement was achieved by critical factor in aggregate gradation. The trail of aggregate gradation was performed keeping in mind that stone used which were coarse aggregate skeleton should avoid rutting criteria in it. The criterion for rutting subtraction was confirmed by ensuring that (VCA) i.e. voids in coarse aggregate fraction of (VCA_{mix}) i.e. fraction of compacted mix are less than (VCA) of voids in coarse aggregate in dry condition (VCA_{DRC}), using Equation 9 and 10.

Calculation of VCA_{DRC}

$$VCA_{DRC} = \frac{G_{ca}\,\gamma_{w} - \gamma_{s}}{G_{ca}\;\gamma_{w}} \times 100 \qquad (9)$$

Where,

G_{ca} = bulk specific gravity of the coarser gravity

γ_w = unit weight of water

γ_s = unit weight of coarse aggregate fraction in dry condition

Calculation of VCA_{mix}

$$VCA_{mix} = 100 - \left(\frac{G_{mb}}{G_{ca}}\right) \times P_{ca} \qquad (10)$$

Where,

G_{mb} = bulk specific gravity of the compacted mixture

G_{ca} = bulk specific gravity of coarse aggregate

P_{ca} = percentage of coarse aggregate in total mixture

3.2.1.2 Bitumen Content (OBC)

The binder content prescribed by the MS2 guideline is 1.5-3 (%), by total weight of aggregate. The requirement of modified binder is not needed as the neat unmodified binder will be suitable for obtaining the mix. However, the aggregates should not be soft as it will be crushed while construction and may hamper the rise of air void content.

The optimum binder content of open graded bituminous mix was obtained from drain down test for the CGBM. The test procedure is carried out with the help of ASTM D6390 -11 (2017) guideline. The importance of drain down test is more significant for the open graded mix when evaluate with conventional dense graded mixes. Drain down test is performed from the loose mixture of the Marshall sample to check the draining property of mix. The drain down value was observed for the mixture whose value did not exceeded 0.3% by weight of mixture.

Figure 3.4. Drain Down Test of Specimen

3.2.1.3. Marshall Method

Open Graded Bituminous mix was used to obtain and determine the air voids, permeability and pore parameters of mix. The method adopted for preparing the specimen was based on the Marshal method of mix design as per ASTM D6926.

The steps involved in preparing the Marshal specimen consist of following:

a. Number of specimens formulated was three for each mixture of aggregate at different binder content.
b. Aggregates were dried at 105˚-110˚C and then separated with the help of dry sieving.
c. Regulation of mixing and compaction with aggregate of bitumen is at 170±20˚C
d. Hammer used should weight 4.5kg with a free fall of 457mm height and temperature while compaction should be in the range of 95˚-150˚C.
e. Preparation of specimen was done by heating aggregate on pan and mixing it with right proportion of binder content followed by the compaction process on both faces of specimen.
f. Compaction of specimen was done with 50 numbers of blows on each side where the specimen material and base plate were provided with an intermediate layer of filter paper. The number of blows will support the air voids entreaty.
g. Extraction of specimen was performed after 24 hours of cooling time with the help of extrusion jack.

Figure 3.5. Open Graded Bituminous Mix

3.2.1.4. Air Voids

The average diameters of specimen were 101 mm and the height gained were around 63.5 mm of Marshall Specimen. The purpose of achieving higher air voids up to the range of 25-35 % was to fill the grout, which was evaluated with ASTM C1754/ C1754-1, test method to obtain density and void content of specimen. Volume of the Marshall specimen was figured out with dimension of specimen. The specimen was dried first such that it attains constant mass and when immersed in water to calculate the volume of specimen. To calculate the air void, difference between total dried volume and volume of submerged specimen were calculated using Equation 11 and 12. This method is applied for the specimen produced in mould.

Calculation of Density:

$$\text{Density} = \frac{K \times A}{D^2 \times L} \tag{11}$$

Where,

A = mass of dry specimen, gram

D = specimen average diameter, mm

L = specimen average length, mm

K = standard density of material

Calculation of Void Content:

$$\text{Void Content} = [1 - (\frac{K \times (A-B)}{\rho_w \times D^2 \times L})] \times 100 \tag{12}$$

Where,

B = specimen mass while submerged, g

ρ_w = water density at temperature of water bath, kg/m³

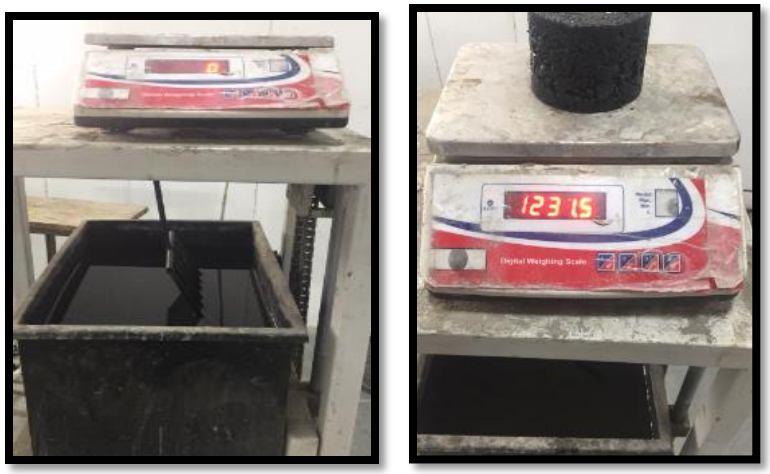


Figure 3.6. Air Void and Density Evaluation

3.2.2. Preparation of Grout

3.2.2.1. Proportion of Grout

It is observed that the earlier study lead their focus on open graded bituminous mix, but the necessity to put emphasis on the composition of grouting material showed very fundamental role in the strength and durability of CGBM. Therefore the present study had put importance on the composition of grout design and performance corroboration of the high performance grout material. The cement paste hence produced consists of following materials:

a. Cement - OPC 43
b. Polycarboxylate Superplasticizer
c. Expansion Admixture CeBEX100
d. Water

As the performance criteria for the cement grout is considered important for the design, two cement additives were used. Polycarboxylate based superplasticizer and expansion admixture were addicted in grout paste in this study. The additives proportion used in the paste were based on the relevant researches of the citation studied and their recommended contents.

The above factor level proportion of cement paste was evaluated for the 7 day and 28 day compression test values. The above table showed that content of water cement ratio and superplasticizer had great effect on the strength of the cement grout and their significance was nearly at the same level. However, the expansion admixture did not have significant effect on the 7 day and 28 day compressive strength. The analysis showed that the water cement ratio and superplasticizer had vital role in the strength of the CGBM mix while the expansion admixture had very less effect on the CGBM as its influence can be ignored as it can be used to replace the cement material usage.

3.2.2.2. Flowability

The open graded bituminous mix produced was subject to cement grouting which should be grouted at full depth of mix. The grouting should be performed such that the paste enters inside the open graded bituminous mix at full depth. This was achieved by filling cement paste, which showed good flow-ability property in it. The paste produced were designed to proportioning such that the paste should be workable and flow able till it gets enter inside the air voids.

Figure 3.7. Marsh Cone Test

To evaluate the grout based on its workability and flow ability, marsh cone flow test as per the guidelines of ASTM D6910 was performed. For the evaluation of workability of cement grout the Marsh cone test is been performed to check the specification and quality of cement grout. The principle of Marsh cone test states that the time required by the cement grout to flow away from the cone which is been recorded and compared with the different proportion of the cement grout. It describes that the more is the time taken by the grout to flow away from the cone lesser is the fluidity or workability of grout. Marsh cone test is an approach to get and understand the behavior of the cement grout with the change in the proportioning with respect to the additives used and variation in the water cement ratio. It helps to define saturation point beyond which the addition of additives will not tend to increase its property of flow-ability and workability of grout. The test is performed by filling the cone with the grout material and closing the nozzle of the cone, the amount or quantity of the grout filled in it is been measured. After filling the grout nozzle is been open and time taken by the grout to flow away from the cone is recorded as Marsh cone time. The saturation point is a point where the dosages of additives in the grout will no further decrease the time in the flow of grout appreciably. Therefore the dosage of additives at which the flow time is lowest is defined as a saturation point of grout.

Cement grout paste produced for the study had comparatively greater workability and fluidity which was necessary to maintain for the certain period of time for the grouting of open graded bituminous mix. The time taken by the cement grout to pass from the cone was noted and the least time taken by the grout was selected for the grouting. Therefore it was noticed that when water cement ratio was kept near the certain value, the performance of the cement grout in terms of its liquidity which gives workability and flow ability enhanced quite significantly as compared to cement mortar, the performance of the cement grout suited to be extra stable when the change in the water cement ratio was performed.

3.2.2.3 Compressive Strength Analysis

Compressive strength of any material is an ability which carries out the load on its surface without showing any cracking or surface deflection in it. When the load is applied on any material it tends to reduce its size and when applied with tension it show elongation in it. The compressive test was performed by manufacturing cement cube of 50×50×50 mm^3 to evaluate and determine compressive strength of hydraulic cement grout using the ASTM C109 guideline, which provides the evaluation of the compressive strength with specification.

The preparation of cube is done by assembling the portion of the mould and the base plate of the mould. The joints present in the mould should be completely water tight, the available mould were not completely water tight in that case the mould were provided with the sealants on the joints to make them water proof. Apply the grease on the inner face of the plates of mould. Fill the cement grout inside the mould as the tampering is not required in grout so to avoid any voids presence. After the duration of 24 hours these cubes after setting were remolded and kept for curing for the duration of 7 days. These specimens were tested inside CTM compression testing machine, where the load applied by the CTM was around 140kg/cm² per minute. The load at which the cubes showed distortion i.e. failure by area of the specimen shoed the compression values of the cubes.

Calculation:

The reading of the total or maximum load which was induced by the CTM on the cubes were noted using Equation 13 and evaluation of compressive strength was produced.

$$Fm = P/A \tag{13}$$

Where,

Fm = compressive strength, MPa

P = total/maximum load, N

A = area of the cube or loaded surface, mm²

Determination of compressive strength after the removal of cubes from the water for 7 days period if done for more than one cube than the other cubes should be kept moist till it is been put inside the CTM, by keeping the cubes under any moist or damp cloth. Specimen while testing should be wiped off from the surface and any loose grain particle should be removed before testing. It is also necessary to check the straightedge of the face of cube, any curvature found should be grinded and make straight before testing. Apply the load on the cube face with the help of any true plane surface like thick metal sheet. The specimen of cube should be placed exactly at the center of the loading machine. After bringing the specimen into uniform contact with the loading area the test should be initiated.

Figure 3.8. Compression Test

Compressive test of any particular cement grout can be achieved with the help of testing of cubes produced. The test considered for any proportion of grout was based on minimum three numbers of cubes, which had same characteristics strength of particular grade of cement grout. The average of compressive strength of any representative sample cubes is taken into account for the grout. The strength produced by the cubes showed variability which was taken as an average for evaluating the value. To, deal with the compression values showing variability it is important to have knowledge of probability and statics. The result showed the compressive strength and the final proportion for the cement grout was selected for the grouting of CGBM which was at 0.50 water cement ratio, 1% of superplasticizer and 0.25 of expansion admixture (CBEX100).

3.2.3 Indirect Tensile Strength

Indirect tensile strength is evaluated by using standard test guideline i.e. ASTM D6931-17. This experiment method is used to determine the IDT strength for the CGBM mixture which is evaluated by applying load on cylindrical specimen across its vertical diameter plane at the pre-defined rate of deformation at standard temperature. The peak failure load is used for calculating the IDT of the CGBM specimen.

Apparatus used in ITS test for CGBM are loading strip of concave surface which consist of radius of curvature which is nominal to the radius of the CGBM specimen. The diameter of the specimen was around 100 mm on an average; loading strip shall be of12.70±0.3 mm wide. The strip used for the load application shall not exceed the height of the specimen and outer edge of the loading strip should be grooved enough to make it smooth to avoid any sharp edges in strip. The bottom strip should be attached to the base of the apparatus or mounted such that it has perpendicular guide rod which are extending toward upwards. The upper loading strip should be free and movable which need to be cleaned and freely sliding in its assembly. The contact of the loading strip should be such that it should allow the strip to be bonded appreciably to avoid any loose contact or motion in the assembly after specimen setup.

CGBM specimen was maintained at temperature of 35° ±1.0 C in water bath to control the specimen temperature as per the guidelines. The temperature maintained was checked by an thermometer with suitable subdivision readable range for accurate and precise readings to maintain temperature within the limits. The preparation of the CGBM specimen was accordance with the following standards D1074, D3387 and D6925. The minimum height of the specimen should be 50 mm with diameter of 100 mm, and on an average the three samples were tested at one proportion. The specimen should have smooth surface with parallel faces on either side.

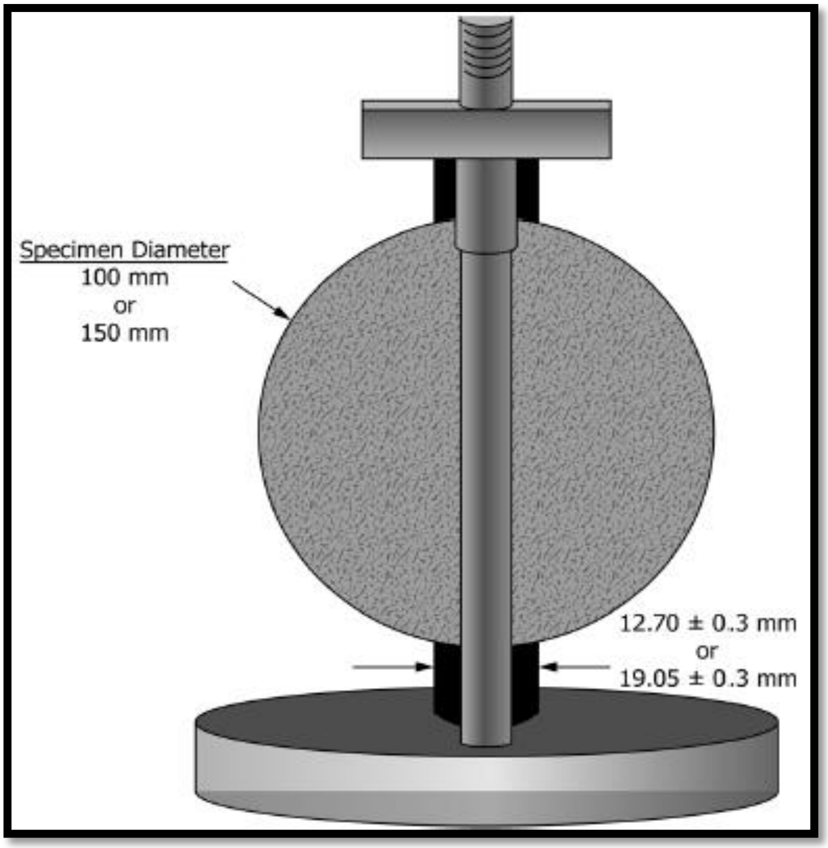


Figure 3.9 Strength Loading Diagram of ITS

For the determination of the CGBM specimen height, test method of D3549/D3549M is followed with minimum adjustment of 1 mm. The specimen was brought to the desired temperature of testing before placing it in the apparatus. The specimen was positioned on the lower loading strip of the assembly, while the upper loading strip was brought into contact with the specimen gently. It was taken due care that the specimen tested were parallel plus centered on the vertical diameter plane of strip. The time difference between the water bath and specimen applying it on assembly was taken not more than 2 minutes. The loading rate applied by the loading strip for evaluating the ITS strength of CGBM specimen were kept at 50 ± 5 mm/min, where the maximum load were recorded for each mix of specimen, using Equation 14.

Calculation:

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \tag{14}$$

Where,

S_t = Indirect tensile strength, MPa

P = Maximum load, N

t = Height of the specimen before testing, mm

D = Diameter of the specimen, mm

The CGBM specimen were laboratory evaluated at a loading rate of 50 mm/min at temperature of 35°C and the obtained values are illustrated in the below table.

3.2.4. Marshall Stability

Marshall Stability is used to measure resistance of the plastic flow of cylindrical specimen which is under the perpendicular loading to the cylindrical axis with the mean of Marshall Apparatus. This test method is used for the dense bituminous mixture and can be used for the semi-flexible specimen to obtain the stability and flow criteria in it. The CGBM mixture which is prepared in the laboratory by weighing the materials and blending the constituent, then compaction is done with the Marshall hammer or any other laboratory devices and later grouting it with the cementitious paste is used for Marshall Stability specimen.

The specimen of CGBM is used for quality control testing. The mixture is not allowed to cool substantially and also it is maintained in the oven to equilibrate the materials to the compaction temperature before molding the Marshall specimen. Marshall stability and flow is used to assess different mix and the effects of condition with water of CGBM mixes along the bitumen difference. The stability and flow of mixture is used characterize and determine from the specimen prepared of specified geometry. The equipment used in Marshall stability could be of two types. (a). using load ring and dial gauge under an loading frame for the evaluation of flow in the specimen. (b). using an LVDT i.e. linear variable differential transducer which is been used for the load and deformation recorder.

Marshall stability is the process where the specimen is under the constant rate of load applied and deformation observation under such loading condition. The deformation will be proportional to the type of mixture used which is a lesser defined failure. The Marshall flow of specimen defines the stability during the failure points. The Marshall stability and flow test are used for the bituminous as well as the semi-flexible crust which consist of different gradation of aggregate and bitumen content along with the grout material. The test is performed for the three sample of same bitumen content used to define the average value among the three specimens. It is important to understand the bitumen content used based on the past experiences as the high bitumen content will decrease the stability and flow value whereas, the optimum bitumen content the values within the permissible standards. The philosophy for the different proportion of material used in the mix can be defined from this test. The requirement of minimum voids in nominal maximum aggregate size in mixture in important. The difference between the laboratory produced sample and field extracted specimen could show different values for the stability and flow due to the variation in material quality and workmanship effort, where the source of variation should be resolved and the problem should be corrected. The Marshall specimen is prepared using the guideline of ASTM D6926 where the procedure for the compaction as well as the material heating is mentioned. It is important that the specimen on which the test is to be performed needs to be smoother on surface.

The apparatus used for the Marshall testing are, braking head which is having an upper and lower cylindrical segments which is made of an ductile material of steel. The lower segment of braking head is mounted on the base of the apparatus which perpendicularly guided. The upper segment is free to move vertically such that the specimen after keeping fits in it appropriately. Compression loading machine is an instrument used to apply the load on specimen at the adjustable rate of 2.00 ± 0.15 in./min (50 ± 5 mm/min). The power for loading is supplied to the machine electrically. The loading machine can be mechanically and hydraulically controlled also. Loading measuring device is been used to calibrate the reading in the apparatus with an dial indicator which measure the deflection for the particular applied load. The ring is been used to determine the value of minimum sensitivity of (50 N). The dial indicator used shall be graduated with an increment of 0.0001 in. (0.0025) or finer. The proving ring used should be attached with the testing frame which provides the transmitter to load from the breaking head. The dynamometer ring assembly can be replaced with any load cell connection with the load deformation recorder or a computer with an capacity and sensitivity to meet the above requirements. Flwometer is equipment which consists of guide sleeves and a gauge. It is an device which designed to measure as well as record the relative movement between the upper breaking post and guide post.

Water bath is procedure applied to the specimen, such that it is deep enough to maintain the water level at minimum of 30mm above from the top of specimen. The water bath applied to the specimen should be thermostatically controlled so that the standard specified temperature could be maintained. The standard temperature in the water bath should be maintained with ± 1℃ variation. The tank which is been used for the water bath shall consist of perforated bottom base which should be equipped with mechanically water circulator. Oven used should be capable of maintain the test temperature with variation of ± 1℃. the specimen after water bath shall be introduced with air bath which should be thermostatically controlled which is able to maintain the temperature 25 ± 1˚C.

Figure 3.10. Marshall Stability of CGBM

The procedure for the Marshall testing shall be consisting of testing three specimen of an given mixture, the specimen shall be of same mixture of aggregate type, quality and gradation. The entire three samples shall be of same preparation which includes the temperature, cooling, and the compaction standards. The CGBM specimen was cooled at room temperature following compaction. The bulk specific gravity of the specimen was evaluated. The dimension of the specimen was taken as per the guideline of ASTM D3549.

The testing or the evaluation of Marshall stability should be done within 24 hours after sample gets prepared. The specimen was kept in water bath of 60 ± 1˚ C and air bath was maintained at an temperature of 25 ± 1˚ C. It is been noted that then temperature variation will affect the results so it is important to maintain the specimen at pre-defined temperature. It was checked that the segment where the specimen were kept are clean and properly lubricate so that the segment slides freely over them. The specimen after water bath shall be cleaned and water should be removed from the surface of the specimen and placed on the lower segment of the Marshall apparatus. Place the upper segment over it; check that the position of the segment is aligned. The elapsed time between the water bath and keeping the specimen for test should not cross more than 30 seconds. The rate of load applied on the specimen was 50 ± 5 mm/min until the dial gauge released or the load was observed to be decreasing.

The Marshall stability is defined as a load which corresponds to the flow value. The procedure requires the two people so that the test can be performed smoothly and values of the dial gauge could be observed or recorded. Marshall flow was read directly from the load deformation chart or it can also be determined from the conversion chart with an suitable factors.

The Marshall stability record was added with the type of sample used. The nature of bitumen and grout material is discussed above with aggregate gradation plus binder content. The specific gravity of material was recorded for all the material separately. Then height of the specimen was noted in millimeters. The temperature to nearest was kept at 0.2˚ C. Criteria for judging the acceptability of Marshall stability test were obtained and presented in the table for the CGBM and BC, which were compared and analyzed.

3.2.5 Modulus of Elasticity

The CGBM specimen manufactured in laboratory were evaluated on the UTM i.e. Universal testing machine to examine the modulus of elasticity. Modulus of elasticity is the stress upon strain value obtained by applying load on the specimen and recording the deformation values of the specimen. CGBM specimen of different bitumen content from 3, 2.5, 2 and 1.5% were grouted with optimum cementitious material and were evaluated to gain elastic modulus values. The test setup consists of aligning specimen inside the universal testing machine and steel plates were fixed on the either side of the specimen which was connected with the LVDT machines. The load was applied on the specimen at 0.001 N/mm², using Equation 15. The deformation caused by the load in specimen was recorded and graph was plotted to interpolate the elastic modulus value. The modulus values obtained was for the static test on specimen.

Calculation:

$$E = \frac{\varepsilon}{\sigma} = \frac{stress}{strain} \tag{15}$$

Where,

ε = Stress

σ = Strain

E = Modulus of Elasticity

3.2.6 Performance Evaluation Durability – Cantabro Test

The evaluation of Cantabro test is performed under the guidelines of ASTM D7064 (2013). Preparation of specimen at different bitumen content were grouted and cooled at room temperature and weighed. Record and designate the weight as W1. For CGBM mixtures, air dried is done to remove the excess moisture, and then use a vacuum device to dry the specimen to constant weight. Once the weight of specimen is constant W1is been recorded for the specimen, it is done by oven dry to constant weight at a temperature not more than 60̊ C and not lower than 50 C. Inclusion of steel ball is not permitted in the test of abrasion. Rotation of Los

Angeles machine is done at speed of 30-33 rpm for a 300 revolutions. After the 300 revolutions, the test was discarded and the loose material of the broken test specimen is collected and weighed as W2, using Equation 16.

Calculation:

$$CL = \frac{W1-w2}{w1} \times 100 \qquad (16)$$

Where,

CL = Cantabro Loss, %

W1 = Initial weight of test specimen

W2 = Final weight of test specimen

4. RESULT AND ANALYSIS

4.1 Gradation of Open Graded Bituminous Mix

Open graded bituminous mix consist aggregate of12.5 mm nominal size, the aggregate were largely of coarser size as compared to the bituminous mix aggregate size. The aggregate size forms a simple structure like shouldering it with the coarser aggregate. The open graded course is of only one aggregate size with pre-determined binder content. The aggregate size is mainly of coarser aggregate which helps to maintain higher air voids in the mixture. Sometimes, the finer aggregate like sand or cement is used to enhance the durability of mix. The advantages of using open graded mix design also helps to reduce the splash and spray along with the high skidding resistance for the wet pavement condition. The open grade layer provides higher visibility of the marking provided on the pavement. Therefore, the aggregate size used to produce an open graded bituminous mix ranges from 12.5, 9.5, 4.75, 2.36 and 0.075 mm form the MS2 guidelines for the open graded mixes.

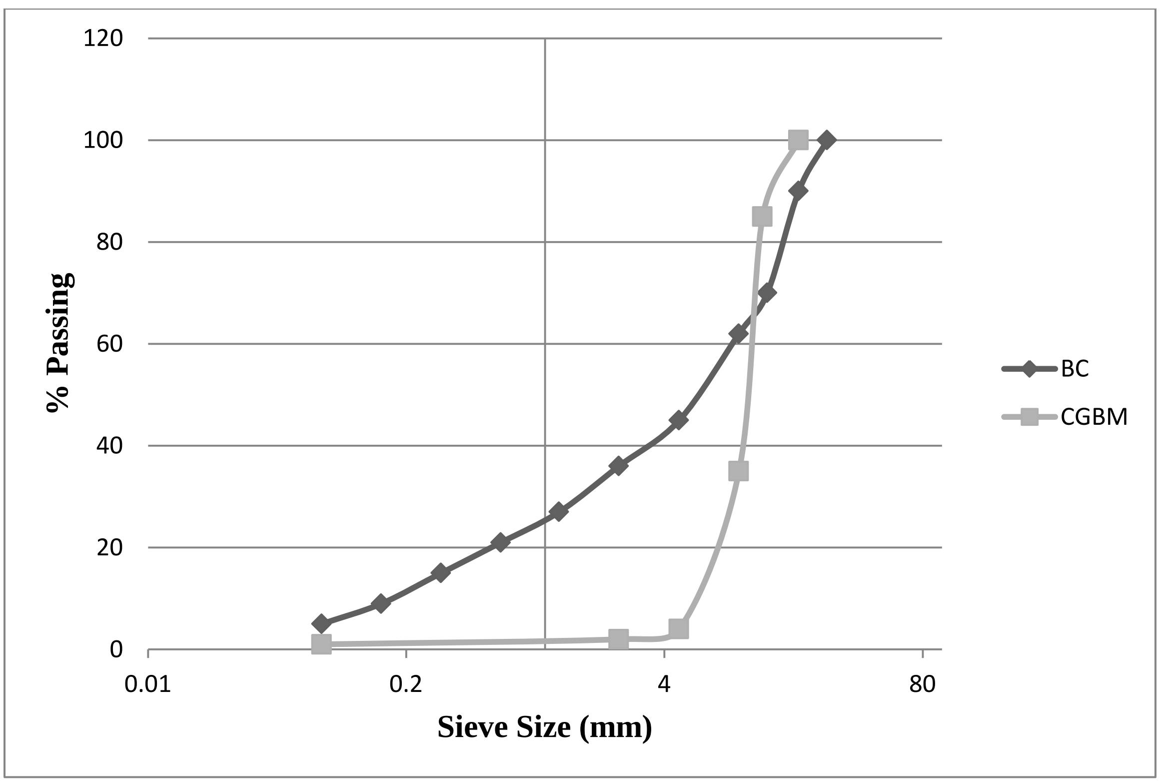


Figure 4.1. Gradation of aggregate for CGBM & BC

As property of open graded bituminous mix in nature, there is a possibility of draining down of the binder content during the construction process. Drain down test is performed to evaluate the optimum binder content required for ready mix. The test is performed as per the ASTM D6390 guidelines, where the test helps to measure the potential in the bitumen which can drain down from the coarser aggregate structure when it is been elevated to the higher temperature. The test is been evaluated for the bitumen content of 1.5, 2, 2.5 and 3 % binder content. The bitumen content at 3 % gives less than 0.3 % binder loss in mix design of open graded mix and evaluating optimum binder content for the mix.

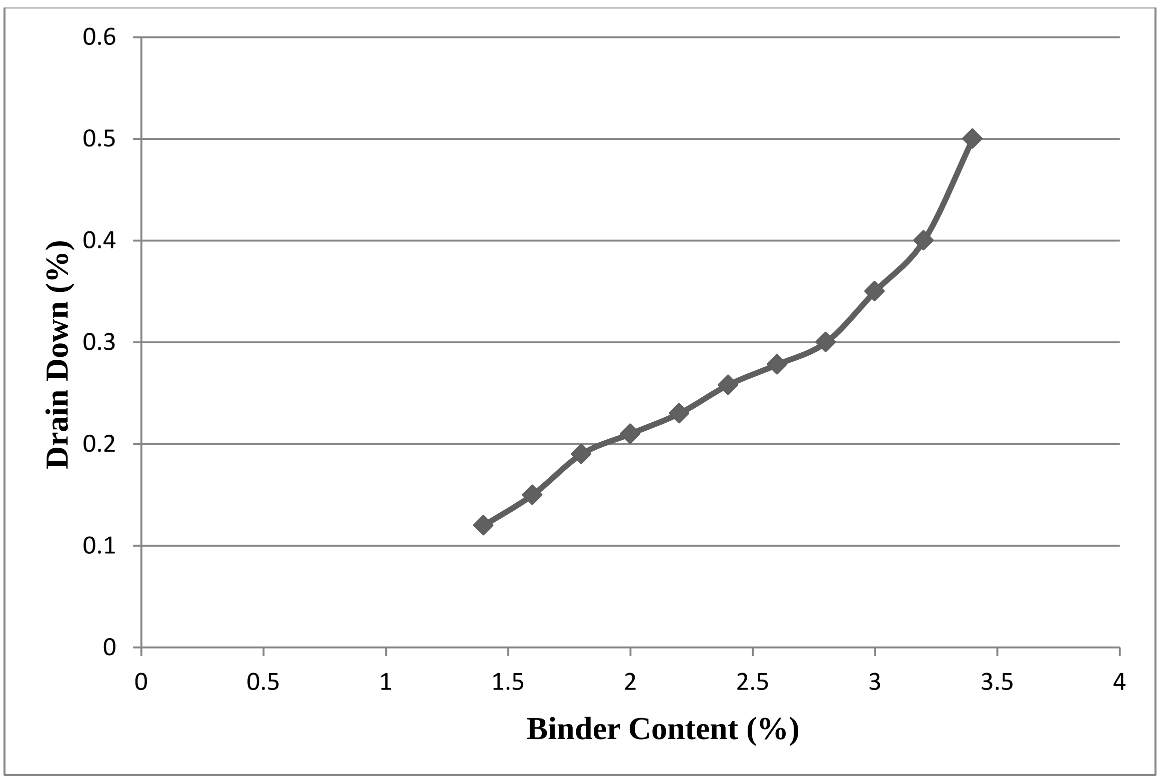


Figure 4.2. Assorting OBC for CGBM

The air void content is directly proportional to the number of Marshall blows applied on the aggregate mixed with bitumen at elevated temperature. Higher values blows through hammer will reduce the air voids content; whereas the less blows will increase the air void in Marshall specimen. It is been observed from the figure that the optimum number of blows required for compaction in open graded bituminous mix is 50 blows for both faces of the specimen. This gives out the air void of 25 – 30 %.

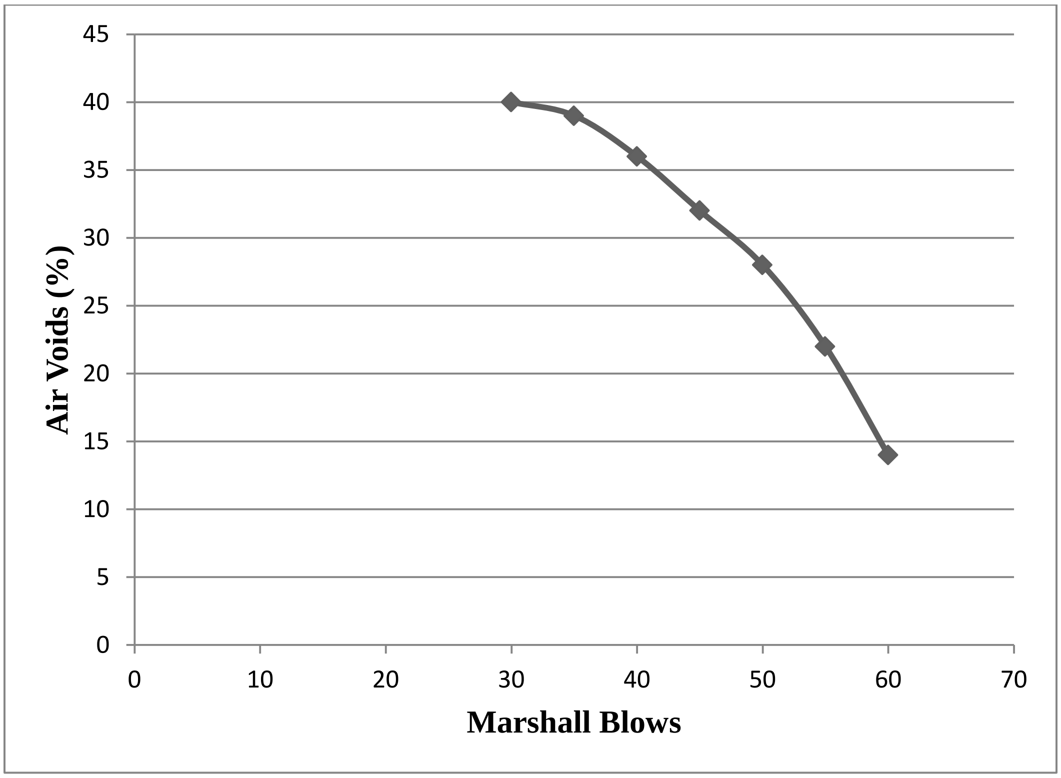


Figure 4.3. Air Voids Deduction from Number of Marshall Blows

4.2. Proportion of Cementitious Grout Material

The cementitious material used as a grout to fill voids content in the open graded bituminous mix was cement of OPC 43 grade, polycarboxylate plasticizer and expansion admixture. The ratio of water content was found out from the citation work performed in the earlier study for formulation of grout performance for better validation by J Pie et al. and J Zhang et at. The water cement ratio adopted for grout mix validation is from 0.40, 0.45 and 0.50. Whereas the amount of superplasticizer used for evaluation was from the range of 0.8 to 1%. Expansion admixture taken for grout material is o.1 and 0.2 %. The proportion of material is been tested for different parameters for validation.

Table 4.1. Proportion of grout material

Factor Level	Water – Cement Ratio	Polycarboxylate Superplasticizer (%)	Expansion Admixture (%)
CG1	0.40	0.8	0.1
CG2	0.40	1	0.2
CG3	0.45	0.8	0.1
CG4	0.45	1	0.2
CG5	0.50	0.8	0.1
CG6	0.50	1	0.2

Flowability is performance criteria taken for the workability of grout material. The test is performed with the help of marsh cone test to evaluate the time taken by the grout material to pass from marsh cone. The water content of 0.45 gives the flow time of 60 second which selects the water ratio with cement to be suitable for workability of grout. The decrease in water cement ratio raised the time of flow for the grout which leads to hamper the full depth penetration of grout inside the open graded bituminous mix.

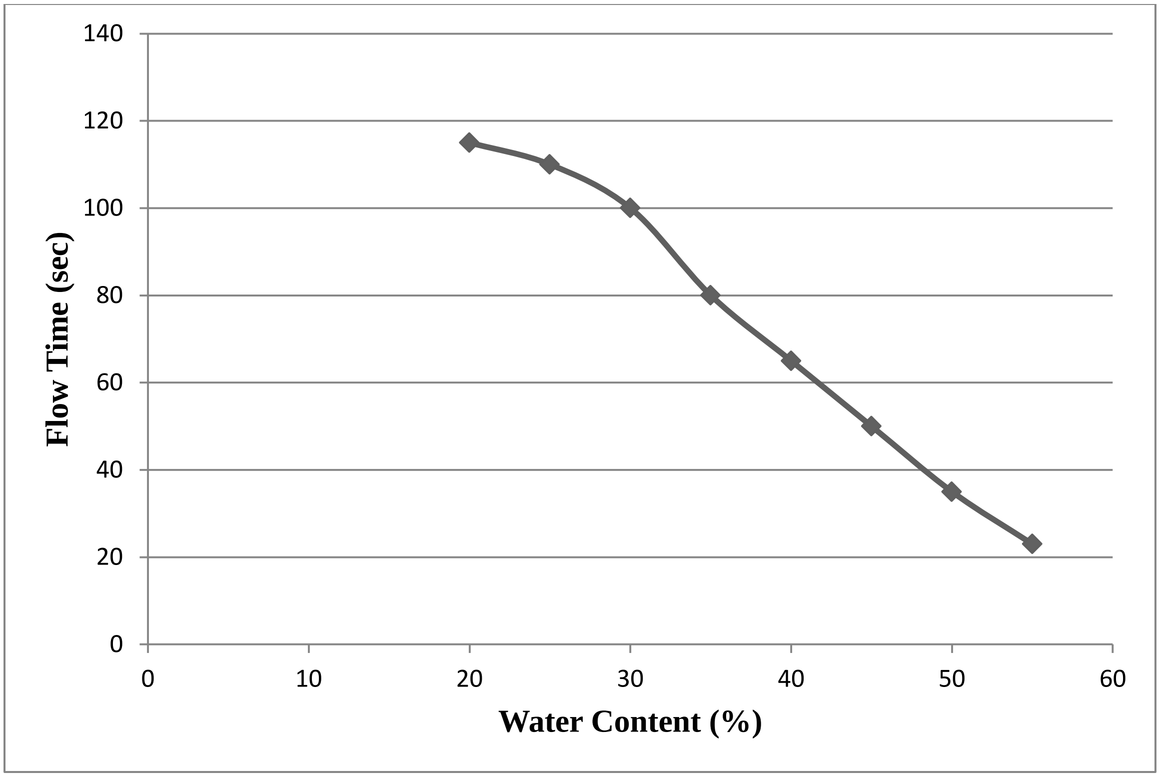


Figure 4.4. Flow ability of Grout

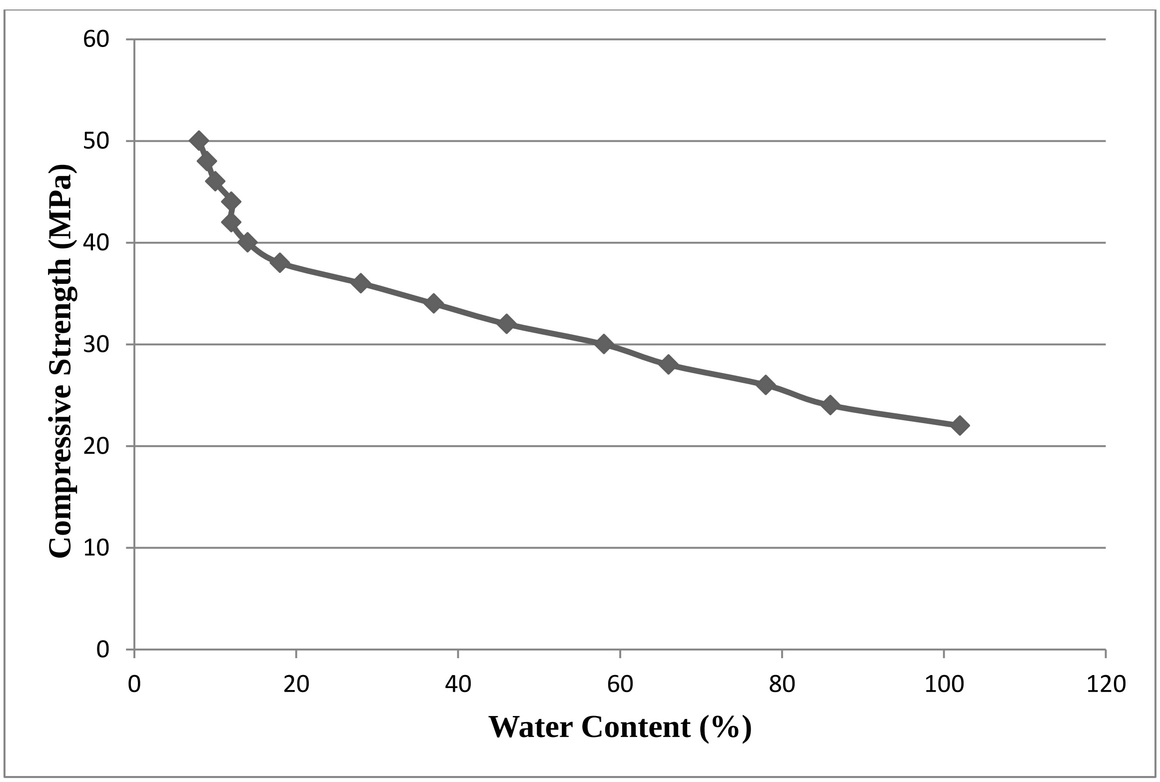


Figure 4.5. Compressive Strength of Grout (7days)

The compressive analysis of grout material showed that the increase in water content will decrease the compression strength inside the grout material and decrease in water content will increase the compressive value of grout. The optimum water cement ratio adopted for the production of CGBM specimen taken is of 0.45. This gives out the compressive value of around 27.46 MPa with 7 days curing time.

Table 4.2. Compressive Value of Cubes

Factor Level	Water – Cement Ratio	Polycarboxylate Superplasticizer (%)	Expansion Admixture (%)	Compressive Strength 7day (MPa)	Mean Compressive Strength (MPa)
CG1	0.40	0.8	0.1	32.02 33.58 35.80	33.8
CG2	0.40	1	0.2	34.28 31.86 33.49	33.21
CG3	0.45	0.8	0.1	26.78 28.56 27.05	27.46
CG4	0.45	1	0.2	29.00 25.78 27.63	27.47
CG5	0.50	0.8	0.1	21.81 20.58 22.74	21.71
CG6	0.50	1	0.2	23.04 21.79 22.02	22.28

4.3. Indirect Tensile Strength

The pavement layer either of the flexible or rigid pavement faces problem relating to cracking which makes it necessary to evaluate the tensile strength of the crust used. It is essential to find out the tensile strength of the CGBM and compare the values with the conventional mix of BC. Indirect tensile strength is performed to obtain the property of tension in the crust or the Marshall sample produced, the property of tension is used to further correlate with cracking property of CGBM. The pavement crust is under the distress due to the fatigue, rutting and cracking of the pavement in low temperature. If the evaluation of the tensile strength of crust to be used gives out higher values then it will correspond that the crust is strong in resisting the cracking distress. It can be further understood that if the crust is able to sustain higher strain in it then it is more likely that it will resist cracking than the one which are not able to tolerate such higher strain.

Many citations were studied based on the performance of conventional BC mix which showed that pavement needed to be evaluated with the tensile property. Zhang et al. (2001), Anderson et al. (2004) have presented that the tensile strength of the crust will correlate to the stronger resistance in the pavement due to the low temperature cracking. Huang et al. (2004), states that the evaluation of tensile strength, fatigue analysis and deformation characteristics of pavement is important to understand the distress criteria applied on crust.

The resistance of CGBM mixture towards the fatigue distress or cracking is directly related to tensile property of the mix. It can also be termed as a characteristic of the CGBM mix which posses tensile strength and property for extensibility when applied under the repeated or fluctuated load due to the traffic movement. When continuous or fluctuating load is applied on the crust it will lead to stress and strain inside the structure of CGBM. The amount or the magnitude of the strain upheld by the mix is totally dependent on the stiffness of the CGBM mix which it posses. The evaluation of CGBM with the help of indirect tensile strength will provide indication of the strength it posses and the adherence which it have against the fatigue distress.

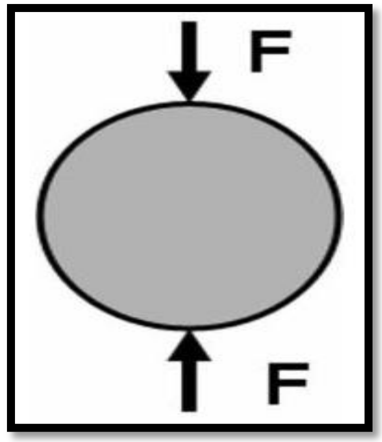


Figure 4.6. Loading Location of ITS Test

The evaluation of CGBM mix can also provide the analysis based on the temperature at which it posses to crack or show rutting in it, it was been examined by the testing it on different temperature range on CGBM specimen. Tensile strength is used measure the performance criteria of the pavement by stimulating tensile stress at the bottom of specimen under the loading condition. The stress applied are specifically the controller of structural design under stress, tensile stress measures indirectly by applying load such that it split while testing.

Result & Analysis (ITS)

A series of ITS test were performed on the CGBM specimen with varying bitumen content. The test was repeated three times for the strength evaluation for single bitumen content of CGBM to evaluate and verify the experimental work. The evaluation of Indirect Tensile Strength (ITS) performed on CGBM specimen showed that the optimum value or the highest value of ITS was been gained for CGBM1 specimen when compared with CGBM2, CGBM3 and CGBM4. It showed that when the optimum binder content of open graded bituminous mix was kept at 3% which had air voids ranging from 28 – 32 % had significantly higher value of ITS. The value of ITS decreased with decrease in bitumen content which is been later grouted. CGBM4 specimen showed the least value of indirect tensile strength of about 0.949 MPa. The value represented by the CGBM1 sample was around 1.735 MPa after 7 day curing at 35̊ C. Indirect tensile strength was also evaluated for difference finding with conventional BC mix which had an average value of ITS around 0.659 MPa. Comparison of CGBM and BC was done, where CGBM showed exceptional strength than the conventional BC.

Indirect tensile strength performances determine the tensile property of CGBM and BC which was further related with the cracking behavior of pavements. It was quite obvious that the ITS value decreased when there was increase in the temperature. Observation showed that CGBM looses less strength with the increment of temperature, whereas the conventional BC lost greater percentage of strength when temperature rises. The susceptibility of tensile property looses largely in BC mix as compared to the cement grouted bituminous mix. CGBM had proved to be less susceptible and overcome as a stronger crack resisting material as the higher value of ITS signify that it tolerates higher strain prior to cracking.

It is been observed from the ITS test after evaluation that the CGBM specimen failure due to tensile crack started from the bottom center of the specimen. Moreover the crack path in CGBM is along the boundary of aggregate and the hardened grout material. The property of brittleness was observed in CGBM specimen due to the hardened gout material which is been filled inside the voids of open graded bituminous mix. The evaluation of ITS showed that increased grout material inside in the bitumen graded mixture leads to decrease the compressive strength of specimen as it posse's higher brittle property, leading to early failure.

Table 4.3. Indirect Tensile Test value for CGBM

Sr. No.	Bitumen Content (%)	Factor Level	Thickness of Specimen	Indirect Tensile Strength (MPa) 35̊ C	Mean ITS (MPa)
1	3	CGBM1B3	81.6	1.745	1.735
		CGBM1B3	82	1.661	
		CGBM1B3	81.4	1.800	
2	2.5	CGBM2B2.5	82.3	1.607	1.498
		CGBM2B2.5	80.9	1.482	
		CGBM2B2.5	81.7	1.405	
3	2	CGBM3B2	81.3	0.928	1.199
		CGBM3B2	82.5	1.352	
		CGBM3B2	80.4	1.317	
4	1.5	CGBM4B1.5	81.8	0.882	0.949
		CGBM4B1.5	82.2	0.957	
		CGBM4B1.5	81.4	1.008	

Table 4.4. Indirect Tensile Test value for BC

Sr. No.	Bitumen Content (%)	Factor Level	Thickness of Specimen	Indirect Tensile Strength (MPa) 35̊ C	Mean ITS (MPa)
1	**4.5**	BC1	63.5	0.516	0.568
		BC1	62.8	0.623	
		BC1	63.9	0.567	

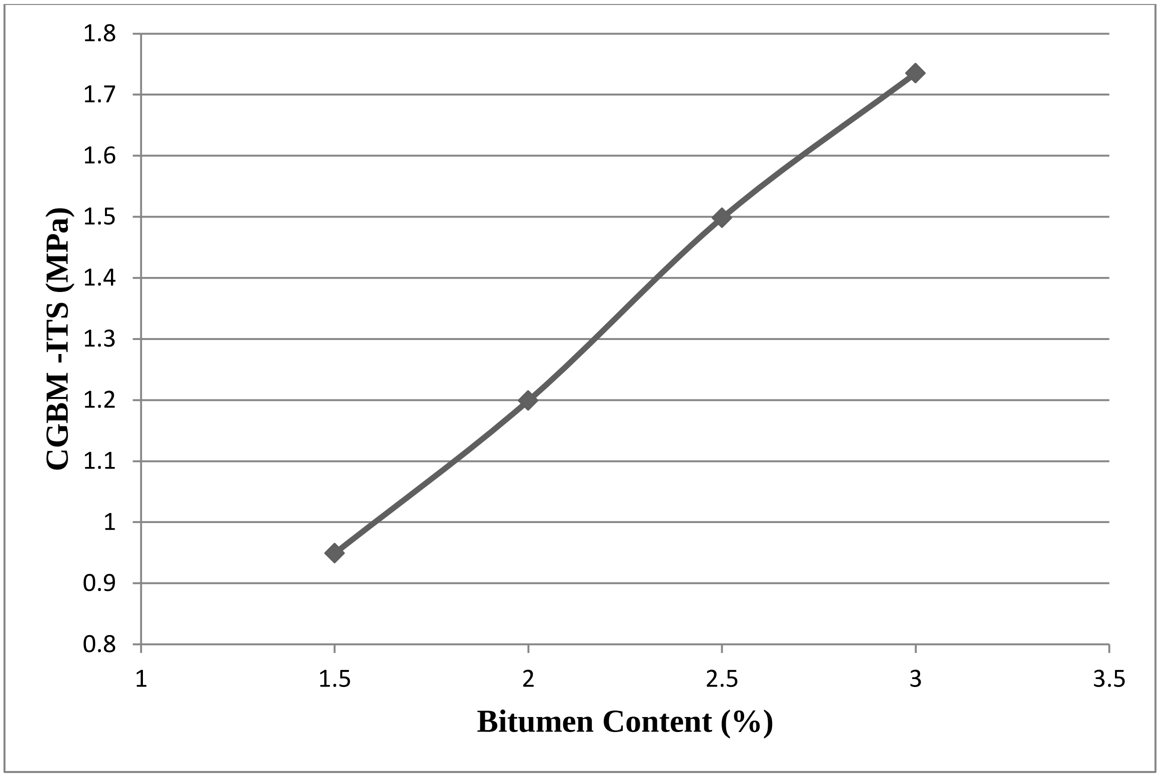


Figure 4.7. ITS Variation with Bitumen Content

The increase in air voids due to less bitumen content leads to extra grouting material to harden as compared to CGBM1B3 specimen. It can be seen in the table that due to extra cementitious content, the tensile strength property decreases and brittleness increases. The tensile strength of CGBM1B3 specimen can be easily noted that it gives optimum ITS value then other proportion of CGBM specimen.

Figure 4.8. Specimen after ITS Test

The reason behind the higher tensile strength is the hydrated grout which brings toughening and bridge effect due to the connection among the bituminous material and cementitious material, when crack starts to initiate in the CGBM structure preventing from getting cracked. The fresh cementitious grout material when introduced with the bituminous material on the faces of aggregate which are coarser provides increase in viscosity and rigidity of CGBM specimen. This action helps the bitumen to stop getting strip away from the aggregate when applied under loading. These are favorable condition characteristic of improving the adhesion interface between the aggregate and harden grout material, which helps in resisting cracks formation due to the applied load. The improvement in adhesion property will also smooth up the progress of enhancing the moisture stability and fatigue recital in CGBM structure.

4.4. Stability

The top most layers in the pavement are prone to be under high stress and wear-tear due to the traffic loading. The top pavement layers are also exposed to the adverse climatic condition due to the high temperature fluctuation, water, etc. The importance and requirement of high quality pavement is necessary to prevent the pavement from the fatigue and rutting from the heavy traffic loading. It is also vital to design a pavement which inhibits skid resistance character in it during the monsoon period. The high quality pavement requires well graded aggregate with suitable amount of bitumen content in it and in the case of CGBM required property of grout material in to be filled in the voids. The CGBM layer used as an surface layer have provided good skid resistance property and the gradation used for aggregate are of same size excluding the finer aggregate in the mix design which helps to gain high air voids it the specimen. The large amount of air voids presence is grouted with the help of cementitious material with slurry filling in the voids. After the grout hardens the voids present inside are filled and intact with the fiber hydrated product, which makes bonding among the bitumen present on aggregate surface with cementitious material. It provides strength inside the CGBM specimen leading it to make more durable top surface layer.

The stability of the CGBM is an important criterion to obtain its property for the effective top surface layer. As it is necessary to design a CGBM in such proportion that it produces as pavement which withstand the continuous stresses induce on it, and able to resist the deformation along the resultant fatigue. The mix should be able to resist the cracks induced due to the low temperature, able to resist the moisture damage during the worst condition. The property in the pavement should posses to provide resistance to deformation during the high temperature which leads to permanent deformation in pavement. Therefore it is very vital requirement from the pavement to sustain above condition by proper mix design which is able to fulfill the requirements.

There are multiple procedures to analyze the pavement stability with help of different test analysis in the laboratory for the design mix of pavement, which includes Marshall Stability method, Hubbard field test, and Hveem stabilometer test with pavement design mix and unconfined strength test.

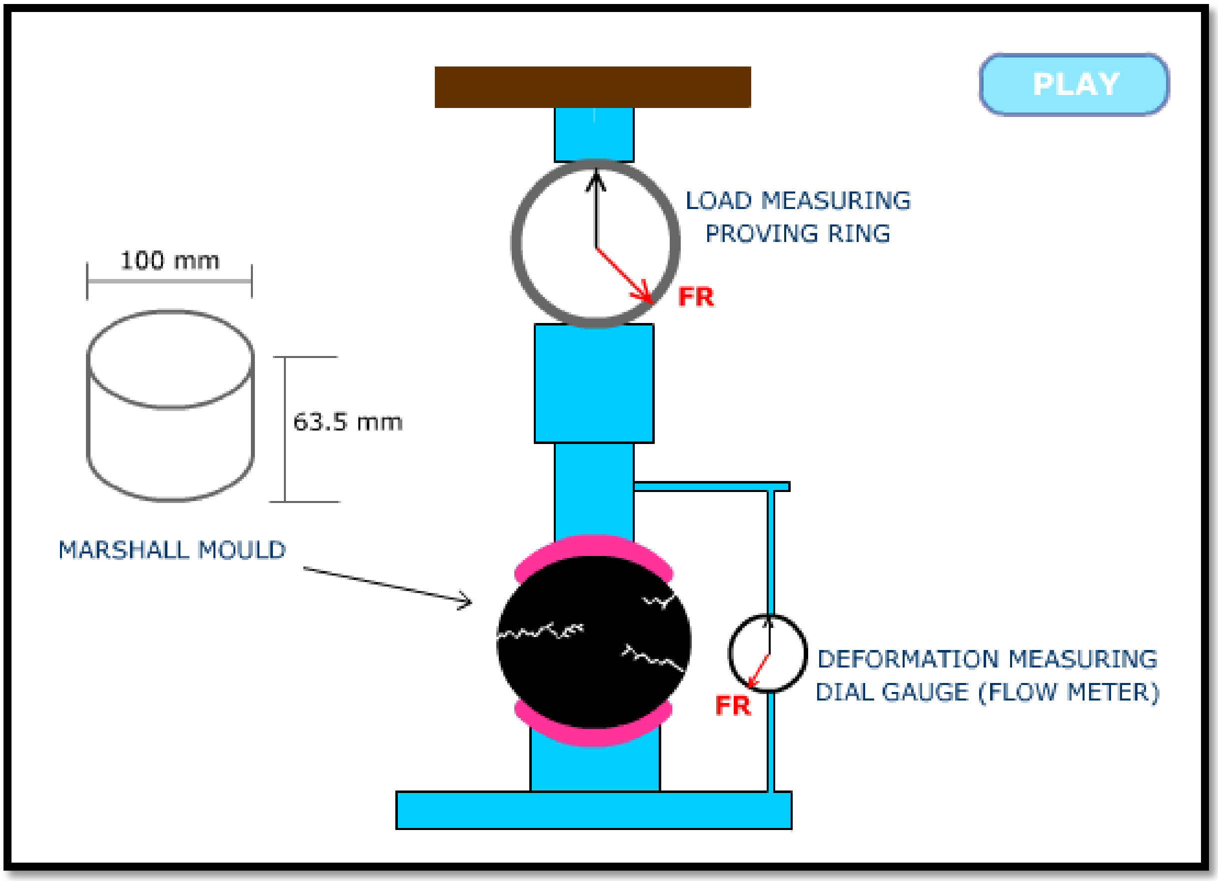


Figure 4.9. Marshall Apparatus

Marshall Stability is an evaluation which is related with resistance of material when under distortion, displacement, shear stresses and rutting criteria. The stability of the material can be derived from the internal friction of material and cohesion which posses by the material tested. Cohesion is a property which helps in the binding of the material with the help of bituminous material, whereas internal friction is the interlocking of the material to increase the frictional resistance of aggregates. As the pavement top layer is under continuous loading due to the traffic movement it is necessary to provide material which differ from the property of conventional mix and able to sustain the above mentioned stress criteria.

Result & Analysis (Stability)

It is been seen that CGBM when compared with the conventional BC it was observed that the values of stability were higher and posses greater stability. The values of CGBM were doubled as compared to BC which has a stability of 32 kN and the conventional BC has value around 15 kN. The test result further confirms that the grouted material used to fill the voids provided substantial increase in the rutting resistance. The reason behind the higher resistance in the CGBM specimen was due to the harden slurry grouted inside the bituminous skeleton, which causes adhesion property between the bitumen and grouted slurry. It is seen that the CGBM had less bitumen content than the conventional BC mix which had higher content of bitumen, and the gradation of CGBM were coarser with less bitumen causing higher voids presence which were filled with grout. The stability of the CGBM specimen increased due to the increment in the contact point with the coarser aggregate. The stress which was caused in the specimen was seen to be transferred to the aggregate which were coarser in the skeleton of CGBM. The high contact pressure between the aggregate caused to increase the internal friction of mix, which was observed that it was beneficial to bear the load induced in it. The rise in temperature causing the conventional mix to fail earlier was decreased in CGBM samples due to this phenomenon.

Figure 4.10. Stability Test of CGBM

Table 4.5. Stability Value of CGBM Specimen

Sr. No.	Mix Type	Sample No.	Stability (kN)	
			Individual	Average
1.	CGBM	CGBM1	33.45	32
2.		CGBM1	28.38	
3.		CGBM1	34.17	

Table 4.6. Stability Value of BC Specimen

Sr. No.	Mix Type	Sample No.	Stability (kN)	
			Individual	Average
1.	BC	BC1	16.8	15.66
2.		BC1	14.9	
3.		BC1	15.3	

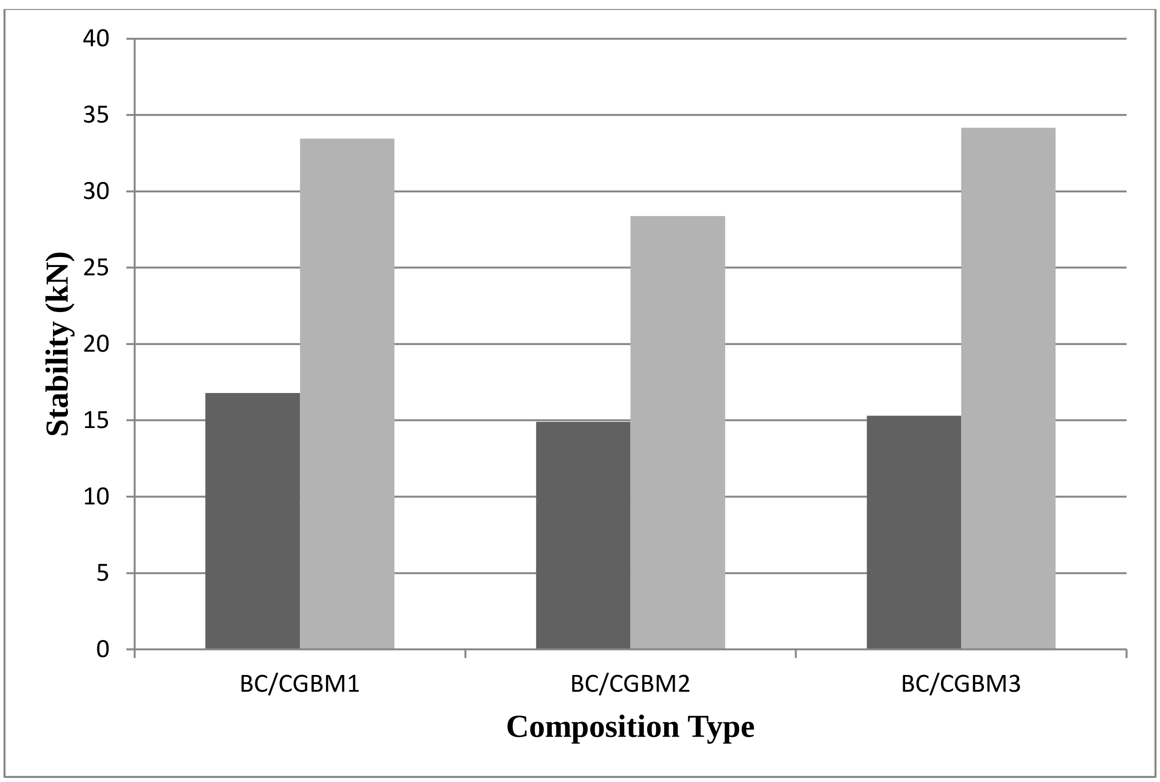


Figure 4.11. Stability comparisons of BC & CGBM

The available result of stability shows that the contribution from the internal friction leads to increment of stability up to 100% when compared with the conventional mix. The mix skeleton plays vital role to bear the loading caused by the traffic.

The grouted material when filled inside the skeleton of open graded bituminous mix it forms a spatial crystalline network this network acts as a reinforcement which helps in crosslink. This lattice network helps in generating three-dimensional crystallite network. When the wheel load is applied the CGBM act as an integral structure which posses the property to bear such loads. The CGBM specimen also showed that it was not susceptible to temperature change. All the above parameter helps the CGBM specimen to increase the stability and strength. It is been observed that the conventional BC specimen had went under permanent deformation when applied under the load.

The hydration starts in the grout material when it is be permeated inside the open graded bituminous skeleton. The fiber type hydrated material is generated between the grout slurry and bitumen present on surface of aggregate. There is a formation of film which takes place between them helping it to attain a strong structure. This whole phenomenon helps in creating interfacial strength making stronger adhesion between the bitumen and aggregates; it also helps in improving the stability in high temperature.

4.5. Modulus of Elasticity

Elastic modulus is a property of material which is used to measure the material resistance to being deformed elastically when it is applied under the stress, using equation 17. The elastic modulus of a material is defined by an stress strain curve in the elastic deformation region. If the material is stiffer the elastic modulus of that material will be higher.

$$\lambda^{def} = \text{stress / strain} \tag{17}$$

Where, stress is the force which is been applied causing deformation and the strain is the ratio of change in some parameter caused by the deformation to the original value of that parameter. Stress can be measured in Pascal and strain is an dimensionless quantity, therefore the unit for λ will be in Pascal. The elastic modulus measures the resistance of an material to elastic deformation under the load. The stiffer material posses higher modulus of elasticity as under the load application of load its shapes changes slightly, whereas the flexible material will posses lesser modulus of elasticity, and its shapes changes considerably under the load application. If the material is stiff it will require high load to deform elastically. The stiffness of a component means how much it deflects under a given load. This will depend on the modulus of elasticity of a material, and also on how the material is been loaded and also the shape and size of material.

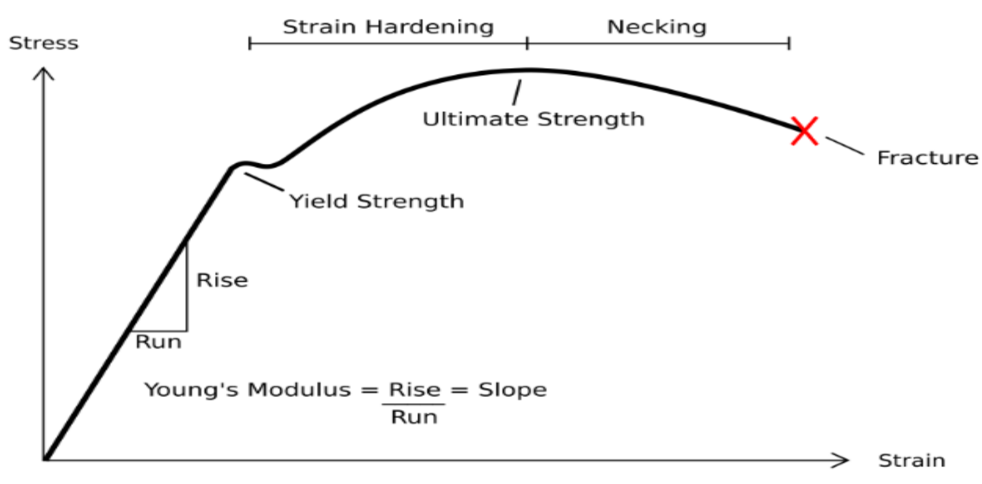


Figure 4.12. Stress-Strain Curve

Figure 4.13. Elastic Modulus Test for CGBM

The CGBM material is a semi flexible material which posses property of flexible as well as rigid component both. It is necessary to evaluate the property of CGBM; therefore tests were done to find out the elastic modulus characteristics of material. The material consists of composite property as the mixture is made up of two different materials consisting of different property. The cement posse's higher modulus of elasticity and bitumen has lesser elastic modulus values, which makes it necessary to examine the elastic modulus property of CGBM

Result & Analysis (Modulus of Elasticity)

The results evaluated by the test for elastic modulus observed that the CGBM1B3 had an elastic modulus of 14330 MPa with an maximum compressive strength as compared to other proportion CGBM. The decrease in binder content had decreased the compressive strength of specimen as the specimen failed at lesser load. The grout material filled inside the voids of open graded mix had lead that the more grout material had made specimen more prone to brittle property due to decrease in the bitumen quantity. The optimum value of bitumen when taken at 3% the grout material showed more compressive strength as compared to decrease in binder content with increase in grout material inside the mix. The graph plotted for elastic modulus evaluation showed that optimum elastic modulus of CGBM1B3 had better resistance to compressive load with other specimen of CGBM.

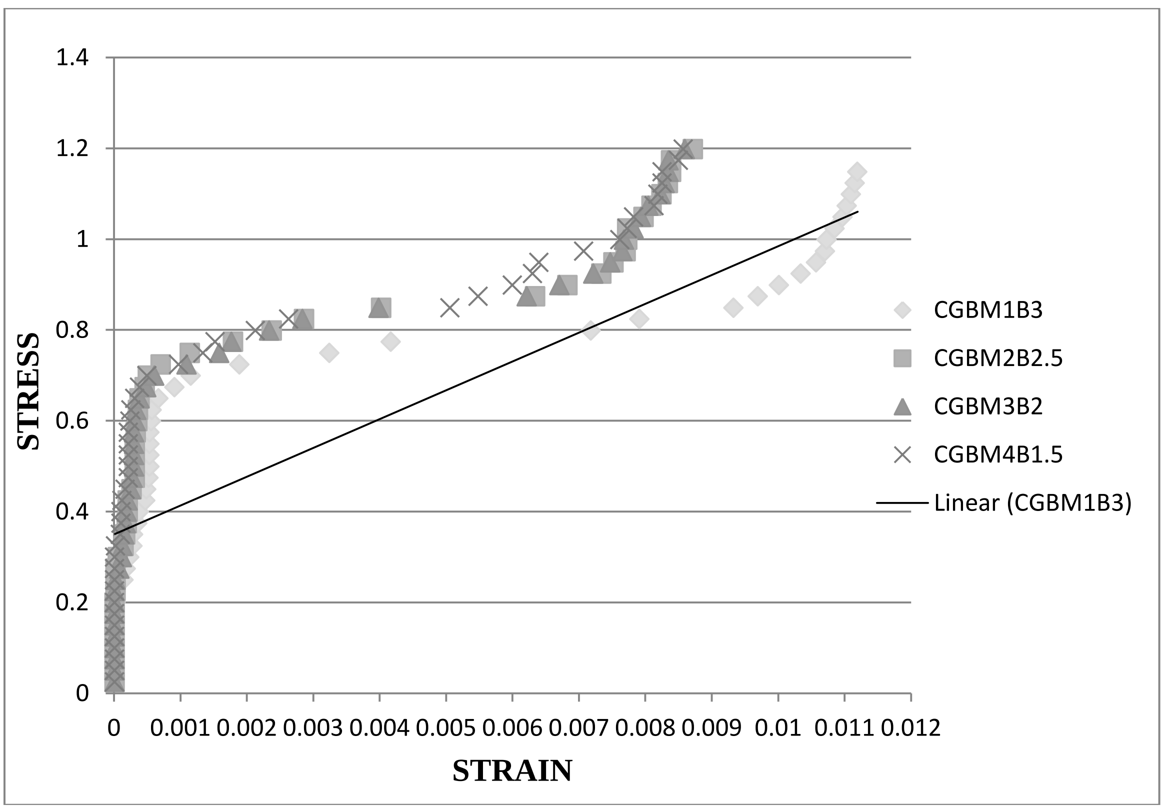


Figure 4.14. Elastic Modulus Stress-Strain Curve of CGBM Specimen

4.6. Performance Evaluation-Durability Cantabro Test

The Cantabro test is performed successfully to evaluate the abrasion resistance of the open graded friction course in the world for past many years. The open graded friction course is an porous mixture which have air voids around 15%, it is very similar to the cement grouted bituminous mix which have the void content of up to 30%, and later been grouted. Cantabro test can potentially be used to obtain the abrasion resistance of CGBM under moving traffic loads. In 2011 Wu et al. evaluated the pervious pavement of concrete with Cantabro test with 300 cycles for the evaluation of abrasion test.

The Cantabro test is evaluated with the help of Los Angeles (LA) abrasion machine without using the steel balls charges. The loss in the weight occurred during the test is been used characterize the abrasion resistance of CGBM. This test procedure is used to measure the breakdown of grouted specimen utilizing the Los Angeles Abrasion machine. The percentage of weight loss is an indication of CGBM durability and relates to the quantity of grout material.

Figure 4.15. Los Angeles Equipment

Result and Analysis (Cantabro Test)

The CGBM specimen evaluation through abrasion test showed the specimen were prone to abrasion loss when compared with bituminous mix specimen. The maximum value allowed for the abrasion loss in a sample is up to 20%. The experiment of specimen had shown that the CGBM material is a composite material and consist of brittle behavior. The durability test performance shows that CGBM specimen has a loss of around 17.5 % of total weight of specimen, whereas the bituminous mix has abrasion loss of 2.08 %. Therefore the cement grouted bituminous material is less durable as brittleness property leads to surface course failure due to the traffic movement. The brittle property of CGBM can be reduced by varying the composition of cementitious grout material.

Table 4.7. Cantabro Test of BC Mix

Mix Type	Sample No.	Initial Weight (gm) W1	Final Weight (gm) W2	Weight Loss %	Mean Weight Loss (%)
BC	1	1248.3	1222.3	2.08	2.08
	2	1257.6	1229.7	2.21	
	3	1242.0	1218.0	1.97	

Table 4.8. Cantabro Test of CGBM

Mix Type	Sample No.	Initial Weight (gm) W1	Final Weight (gm) W2	Weight Loss %	Mean Weight Loss (%)
CGBM	1	1384	1122	18.9	17.50
	2	1362	1131	17.03	
	3	1446	1207	16.59	

Figure 4.16. CGBM Specimen after Cantabro Test

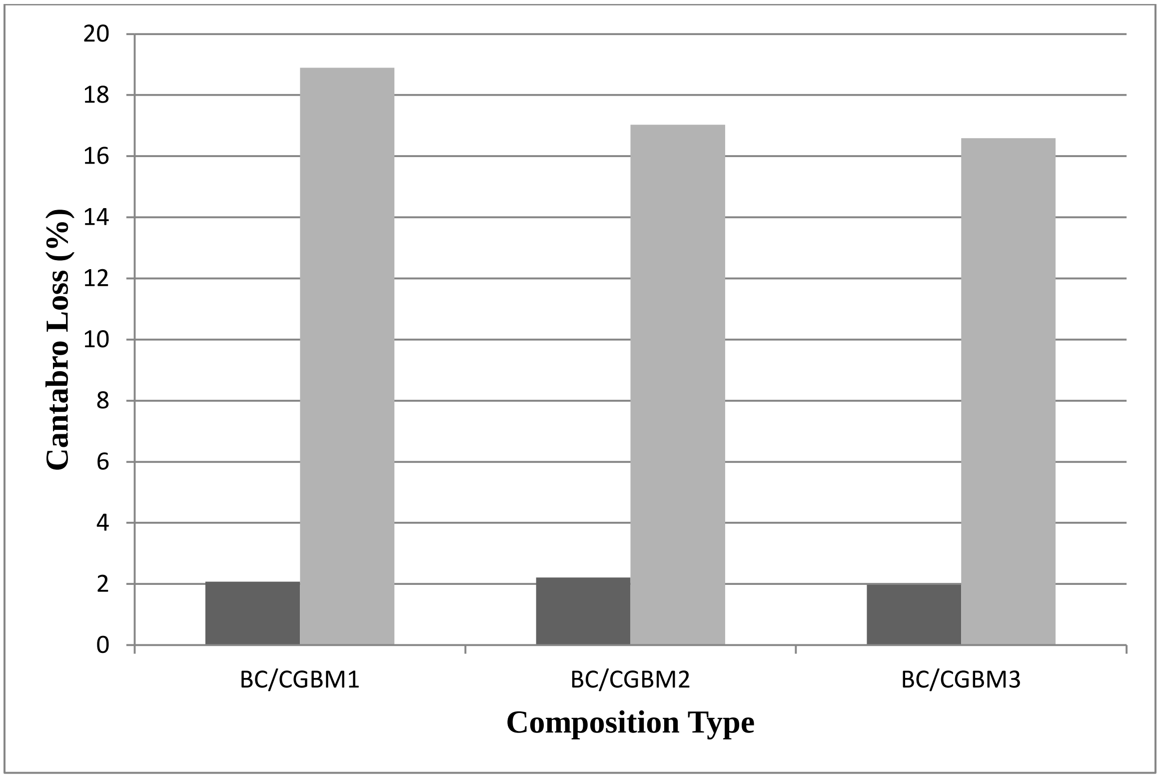


Figure 4.17. Cantabro Test Result comparison of BC & CGBM

5. DESIGN

5.1 General

The viewpoint for pavement design consists of designing pavements for their acceptable functional and structural performance for the design period. The performance of the pavement is explained by performance models which is either empirical i.e. past based experiences or mechanistic-empirical, where the distresses/performance are explained in mechanistic parameters which are stress, strains and the deflection which are been calculated using the specific theory and procedure. In the design method selected structural distresses, critical mechanistic parameter is identified and controlled to acceptable or limiting values in the design procedure. These limiting values of these critical mechanistic parameters are obtained from the performance models.

Linear elastic theory is selected for the analysis of the pavement which is been treated as multi-layer system. The bottom layer is considered as semi-infinite and the above layers are assumed to be infinite for horizontal extent and finite for thickness. The pavement inputs required for the pavement design in this approach requires elastic modulus, poisson's ratio and the thickness of for each layer in the pavement surface. The design of the pavement is done for the different pavement sections consisting of different modulus values and poisson's ratio. The pavement design requires subgrade CBR (%) value and traffic count in million standard axel (msa).The vertical compressive strains at the top of the subgrade layer is considered in the guidelines as a critical mechanistic parameter for controlling subgrade rutting using Equation 18. The horizontal tensile strain at bottom of the bituminous layer is taken as the causative mechanistic parameter which needs to be limiting to control bottom-up cracking for the bituminous layer, using Equation 19.

Performance Criteria:

1. Subgrade Rutting

$$N_R = 1.4100 \times 10^{-08} \, [\frac{1}{E_v}]^{4.5337} \quad (18)$$

Where,

N_R = subgrade rutting life (cumulative equivalent number of 80 kN standard axel loads that can be served by the pavement before the critical rut depth of 20 mm or more)

E_v = vertical compressive strain at the top of the subgrade calculated using linear elastic layered theory by applying standard axel load at the surface of the selected pavement system.

2. Fatigue Cracking

$$N_f = 0.5161 \times C \times 10^{-4} \left[\frac{1}{E_t}\right]^{3.89} \times \left[\frac{1}{M_{Rm}}\right]^{0.854} \quad (19)$$

Where,

C $=10^M$, and M = 4.84 $\left[\frac{V_{be}}{V_a + V_{be}} - 0.69\right]$

V_a = per cent volume of air void in the mix used in the bituminous layer

V_{be} = per cent volume of effective bitumen in the mix used in the bottom bituminous layer

N_f = fatigue life of bituminous layer (cumulative equivalent number of 80 kN standard axel load that can be served by the pavement before the critical cracked area by 20%or more of surface paved area)

E_t = maximum horizontal tensile strain at the bottom of the bituminous layer calculated using elastic layered theory by applying standard axel load at the surface of the selected pavement surface

M_{Rm} = resilient modulus (MPa) of the bituminous mix

5.2 Design Evaluation

Table 5.1. Standard Condition for Pavement Analysis using IITPAVE

Analysis Condition	
Material response model	Linear elastic model
Layer interface condition	Fully bonded (all layer)
No. of wheels	Dual wheel
Wheel loads	20 kN on each single wheel
Contact stress for critical parameter analysis	0.56 MPa for tensile strain and vertical compressive strain on subgrade
Critical mechanistic parameters	
Bituminous layer	Tensile strain at the bottom
Subgrade	Compressive strain at the top

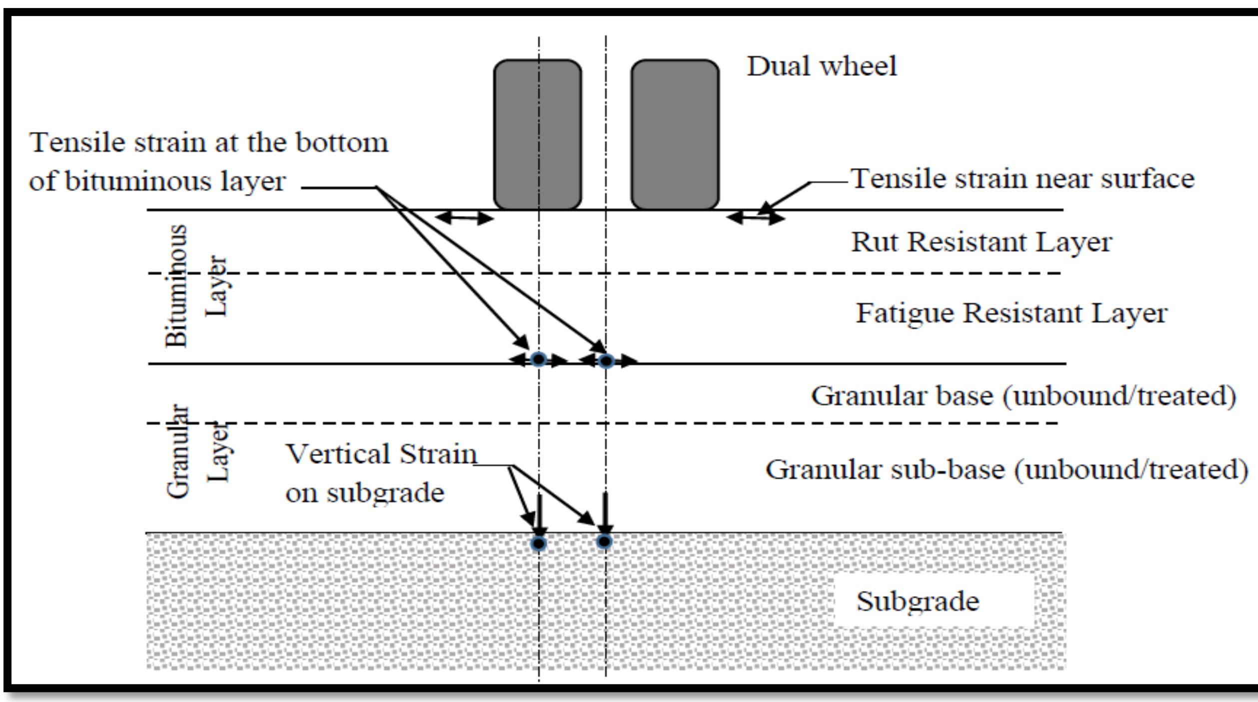


Figure 5.1. Pavement Section with Bituminous Layer, Granular Layer and GSB showing Critical Strain Location (IRC: 37-2018, Figure 3.1)

Problem -

CBR = 10%

CVPD = 50 msa

Allowable Vertical Strain = 371.696 micron

Allowable Horizontal Strain = 178.51 micron

Pavement Structural Design Catalogue (IRC: 37-2018, Figure 12.6)

Bituminous Course = 40 mm

Dense Bituminous Macadam = 105 mm

Granular Base = 250 mm

Granular Sub Base = 200mm

5.3. IITPAVE Analysis -CGBM

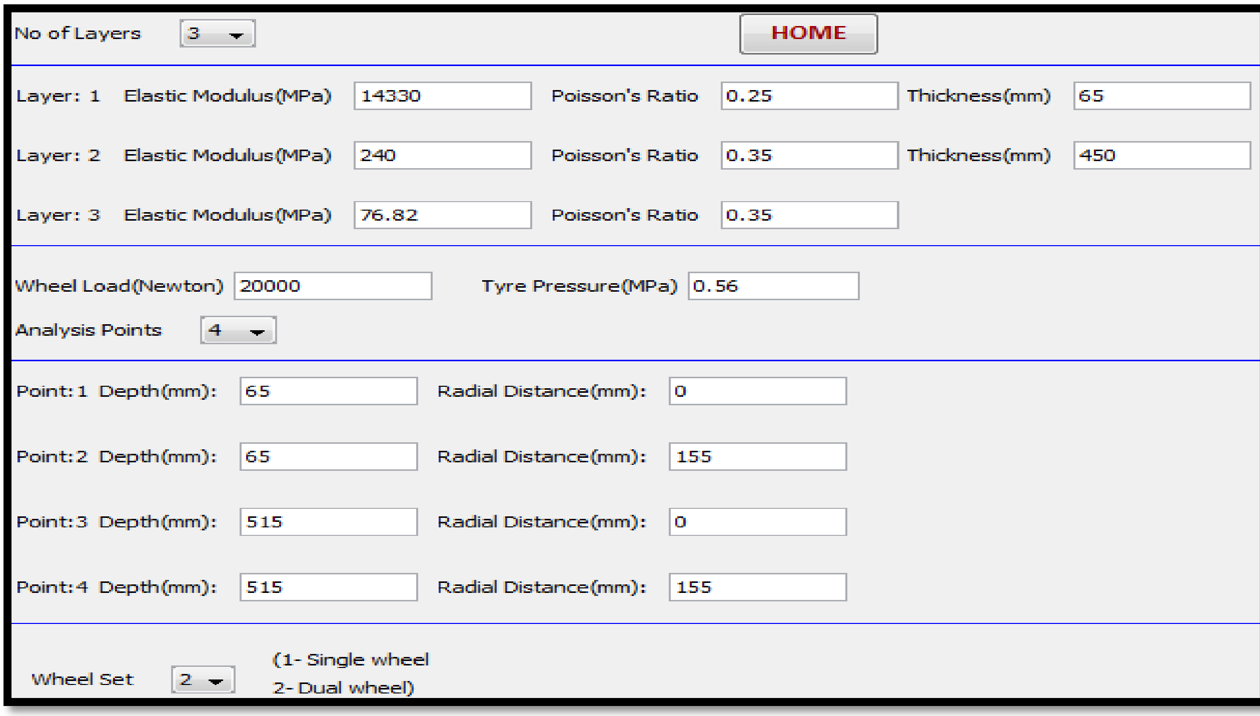
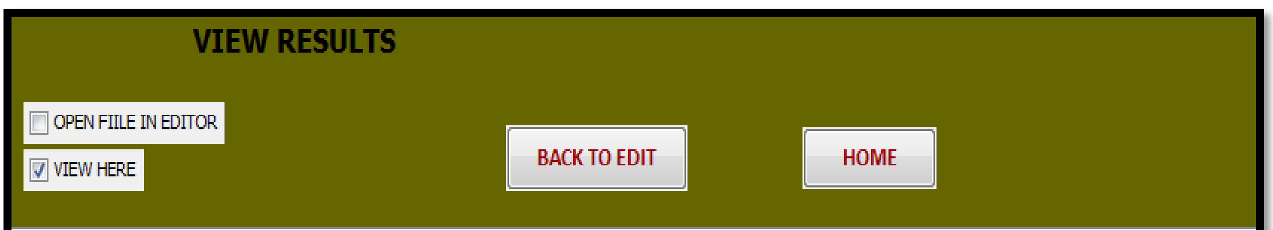


Figure 5.2. Input Parameters for CGBM



No. of layers 3
E values (MPa) 14330.00 240.00 76.82
Mu values 0.250.350.35
thicknesses (mm) 65.00 450.00
single wheel load (N) 20000.00
tyre pressure (MPa) 0.56
Dual Wheel

Z	R	SigmaZ	SigmaT	SigmaR	TaoRZ	DispZ	epZ	epT	epR
65.00	0.00	-0.1611E+00	0.2672E+01	0.2062E+01	-0.1682E-01	0.4146E+00	-0.9383E-04	0.1533E-03	0.1001E-03
65.00L	0.00	-0.1611E+00	-0.3522E-01	-0.4467E-01	-0.1682E-01	0.4146E+00	-0.5546E-03	0.1533E-03	0.1001E-03
65.00	155.00	-0.1370E+00	0.2199E+01	0.4160E+00	-0.5966E-01	0.4261E+00	-0.5519E-04	0.1486E-03	-0.6949E-05
65.00L	155.00	-0.1370E+00	-0.3380E-01	-0.6146E-01	-0.5966E-01	0.4261E+00	-0.4320E-03	0.1486E-03	-0.6948E-05
515.00	0.00	-0.2430E-01	0.3561E-01	0.3035E-01	-0.4216E-02	0.2792E+00	-0.1975E-03	0.1396E-03	0.1100E-03
515.00L	0.00	-0.2431E-01	0.2507E-02	0.8341E-03	-0.4214E-02	0.2792E+00	-0.3317E-03	0.1396E-03	0.1102E-03
515.00	155.00	-0.2623E-01	0.3826E-01	0.3464E-01	-0.5758E-02	0.2878E+00	-0.2156E-03	0.1472E-03	0.1268E-03
515.00L	155.00	-0.2623E-01	0.2643E-02	0.1486E-02	-0.5780E-02	0.2878E+00	-0.3603E-03	0.1471E-03	0.1268E-03

Figure 5.3. Calculated Vertical Strain (epZ) & Calculated Horizontal Strain (epT)

5.4. Comparison for Composition Thickness and Strain Values

Table 5.2. Strain Values Comparison

Vertical Strain-epZ (micron)	Horizontal Strain-epT (micron)	Vertical Strain-epZ (micron)	Horizontal Strain-epT (micron)
Conventional (Allowable Strain)		CGBM1B3 (Calculated Strain)	
371.696	178.51	360.3	153.3

Table 5.3. Composition Thickness Comparison

Conventional		CGBM	
Composition Type	Thickness (mm)	Composition Type	Thickness (mm)
BC	40	CGBM	65
DBM	105		
GB	250	GB	250
GSB	200	GSB	200
Total	595	Total	515

The composition analysis through IITPAVE evaluated that the calculated value for the CGBM composition for vertical and horizontal strain were lesser than the allowable strains for the conventional pavement section with Bituminous Layer, Granular Layer and GSB. The strain values of CGBM were 360.3 of epZ and 153.3 of epT, which were lesser than the strains of conventional mix of 371.696 of epZ and 178.51 of epT strain respectively. It is been concluded that the use of CGBM as a surface course will help to optimize the composition thickness and thus reduces the material and cost requirements.

6. CONCLUSION AND RECOMMEDATION

6.1 Conclusion

The major conclusion drawn from the study carried out on the CGBM pavement, which is a composite structure, possessing flexible and rigid pavements properties were based on the mechanistic properties and performance parameters are as follow:

- Composition of aggregate gradation for the CGBM is selected from the MS2 guidelines of open graded bituminous mix design. The Georgia gradation of aggregate having nominal size of 12.5 mm is selected which ranges from 12.5, 9.5, 4.75, 2.36 and 0.075 mm size aggregate.
- The optimum binder content for the open graded bituminous mix adopted as per the drain down test is 3%.
- Variation in number of Marshall Blows has significant effect on the air voids of open graded bituminous mix. The adopted numbers of blows for compaction of loose specimen were 50 blows in each face.
- The volume parameters to obtain the higher air voids in the Marshall specimen of open graded bituminous mix is been achieved by selecting coarser aggregate and suitable number of blows for compaction. The specimen evaluation for density and void content ranges air voids from 25 -30% in specimen.
- Compositions of cementitious grout material has significant role in strength parameter and durability of CGBM. Grout material consists of OPC43 grade cement, polycarboxylate superplasticizer, expansion admixture for air entering purpose. The water-cement ratio of 0.45, superplasticizer 1% and expansion admixture of 0.1% is selected for grout.
- Parameters adopted to evaluate grout material were flowability and compressive strength. Flowability of 60 seconds is achieved for 0.45 water-cement ratio of grout with compressive strength of 30 MPa in (7 day) curing.
- Full depth grouting is observed in CGBM specimen after the destructive test performance, which is gained by the categorization of suitable grout material. Full depth grouting had enhanced the compressive strength in CGBM specimen.

- Performance evaluation of CGBM and BC through indirect tensile strength (ITS) were measured. CGBM1B3 had the optimum value of ITS with 1.75 MPa with comparison of 0.568 MPa of BC mix.
- In terms of stability of CGBM, the results concluded that CGBM had a stability of 32 kN whereas the BC mix had stability of around 15.66 kN. Observations show that CGBM increases the stability value twice to that of BC.
- The static modulus of CGBM specimen evaluated that CGBM1B3 had elastic modulus of 14330 MPa, which decreased by decrease in bitumen content of other CGBM specimen. Increase in grout material inside the skeleton of open graded bituminous mix leads specimen to early distress failure due to the brittle property of grout material.
- Performance test of CGBM were evaluated with Cantabro test, concluded that CGBM are more susceptible to abrasion loss, with a cantabro loss value of 17.50%.
- Design of CGBM is analyzed with IITPAVE software in comparison with the conventional BC mix, which had lesser strain values and composition thickness.

6.2 Recommendation

The optimization of grout with different material type and at different proportion can be experimented, which will provide CGBM to gain strength and durability as per the requirement. The cementitious material used as a grout has significant role in CGBM design. A trial section of a pavement, with CGBM1B3 proportion of material can be prepared and be used to investigate the field performance of CGBM pavement. The trail section can be used to evaluate the performance characteristic both in terms of structural evaluation as well as functional evaluation of the pavement.

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