# Development of Novel Semi Flexible Surface Pavement Material for Highway Applications

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## ABSTRACT

Several studies have examined the performance of both flexible and rigid pavements. However, the integration of bituminous mix with cement grout represents a novel approach that combines the advantages of both types, resulting in a semi-flexible pavement. Traditionally, it was believed that a new pavement material was required to address the limitations of conventional surfaces while retaining their benefits. The acceptance and implementation of this semi-flexible pavement concept may still be limited in India. This research aims to develop a new semi-flexible surface pavement material for highway applications by utilizing cement grouted bituminous mix (CGBM) and comparing it with Open Graded Premix Carpet (OGPC), a common flexible surfacing material used in high-traffic areas like highways and airports. The study evaluates the strength parameters of OGPC and CGBM by preparing test specimens using Marshall mould in the laboratory. The performance of the grout in CGBM is crucial in determining its overall effectiveness. Results indicate that the newly developed CGBM exhibits superior properties compared to OGPC. Implementing CGBM could potentially address current surface course challenges and allow for quicker traffic flow as the grout can set in just one day.

**Keywords:** Open Graded Premix Carpet, Cement Grouted Bituminous Mix, Marshall mould, semi-flexible pavement, rigid pavements.

## 1.0 Introduction

Cement Grouted Bituminous Mix (CGBM) is a bituminous mix infused with a cementitious grout, containing air voids that allow for grout accumulation to enhance its properties. This high void mix is created by carefully selecting aggregate gradation, binder content, and compaction methods.

In India, flexible pavements are preferred for their cost-effectiveness, ease of maintenance, and construction speed. However, issues such as water seepage, pothole formation, frequent stops, and heavy vehicle traffic can lead to early deterioration. The tropical climate and oil spills further decrease the lifespan of bituminous pavements. Rigid pavements offer a solution but are costly and time-consuming to construct, impacting traffic flow. Construction and maintenance of rigid pavements on urban roads pose challenges, affecting traffic capacity and leading to congestion, especially during peak hours. The use of CGBM can address these challenges by allowing for quicker traffic movement on the pavement, as the grout sets within a day. CGBM originated in France in the 1960s as resin-modified pavement and was first utilized in the USA in 1987. Several countries, including France, USA, Germany, Japan, Spain, Portugal, Sweden, Norway, Saudi Arabia, and Austria, have successfully implemented CGBM. However, its adoption in India has been limited due to a lack of performance studies in laboratory and field settings to provide necessary technical knowledge. Further research is needed to understand the engineering properties of CGBM with different grouts and aggregate gradations.

Grout, defined as cementitious slurry that penetrates air voids in bituminous mixes without segregation, plays a crucial role in the performance of CGBM. Fine aggregate content affects the density and moisture susceptibility of the mix, impacting grout penetration depth. Analyzing the performance of grout constituents is essential to optimize the performance of CGBM.

This research aims to develop and evaluate suitable cementitious grout slurry for use in sample specimens and compare the strength parameters and physical properties of OGPC and CGBM in terms of Marshall Stability, compressive strength, and indirect tensile strength tests to determine the best surface course.

## 2.0 State of the art – review

Setyawan (2013) conducted a thorough investigation into the development of semi-flexible pavement using highly porous, open asphalt framework and specific cementitious grouts. Grouted macadams combine the strength and stiffness of the cementitious element with the flexibility of the bituminous component. Pei, et al., (2016) concentrated on the formulation of grouting material for semi-flexible pavements, utilizing admixtures and superplasticizers to improve performance. Semi-flexible pavement (SFP) has been widely utilized in highway engineering due to its favorable pavement performance. Zhang, et al., (2016) identified optimal compositions for two grouting materials and compared their performance in terms of fluidity, strength, and drying shrinkage. While both cement paste and cement mortar met technical requirements, their properties varied based on composition. The study concluded that cement paste is the superior grouting material. An, et al., (2018) investigated the mechanical performance and engineering properties of the grouted mixture. Bharath, et al., (2019) evaluated the properties of CGBM mix, including Indirect Tensile Strength (ITS), Resilient Modulus, and Dynamic Modulus at different temperatures. Khan et al., (2021) analyzed a semi-flexible mix of various grouts. Gupta, et al., (2021) devised grouting material and established mix design considerations, exploring the potential of CGBM characteristics as an alternative paving material in the Indian context through laboratory and field assessments in comparison to conventional bituminous concrete mix. Khan et al., (2022) discussed the impact of by-products and other additives on the mechanical properties of grouts.

Dhandapani (2023) emphasized the need for alternatives that combine the rigidity of concrete pavement with the flexibility of bituminous pavement to accommodate the increasing traffic volume. Research publications provided insights into different surface courses, particularly rigid and flexible pavements, and introduced CGBM as a potential alternative solution. The studies also covered basic testing methodologies, sample preparation, sample testing, and advantages of implementing CGBM. A comparison of the strength parameters of conventional surface courses and CGBM was also attempted in this research work based on the information from these journals and publications.

## 3.0 Methodology

The analysis and comparison of strength parameters and physical properties of the surface mixes is done by performing tests on Marshall mould samples of CBGM and premix carpet. A summarized flowchart of the works carried out in this study is shown in Figure 1. Preparation of moulds is then done by performing calculations and following guidelines recommended by IRC. The overall procedure for preparing the two different (surface course) moulds remains relatively similar. But the key difference between the two is presence of voids (achieved by changes in compaction/number of blows given) and the use of grout. As in the case of CGBM, additional effort is required to put forward a grout with adequate flowability, strength and ability to attain full-depth penetration.

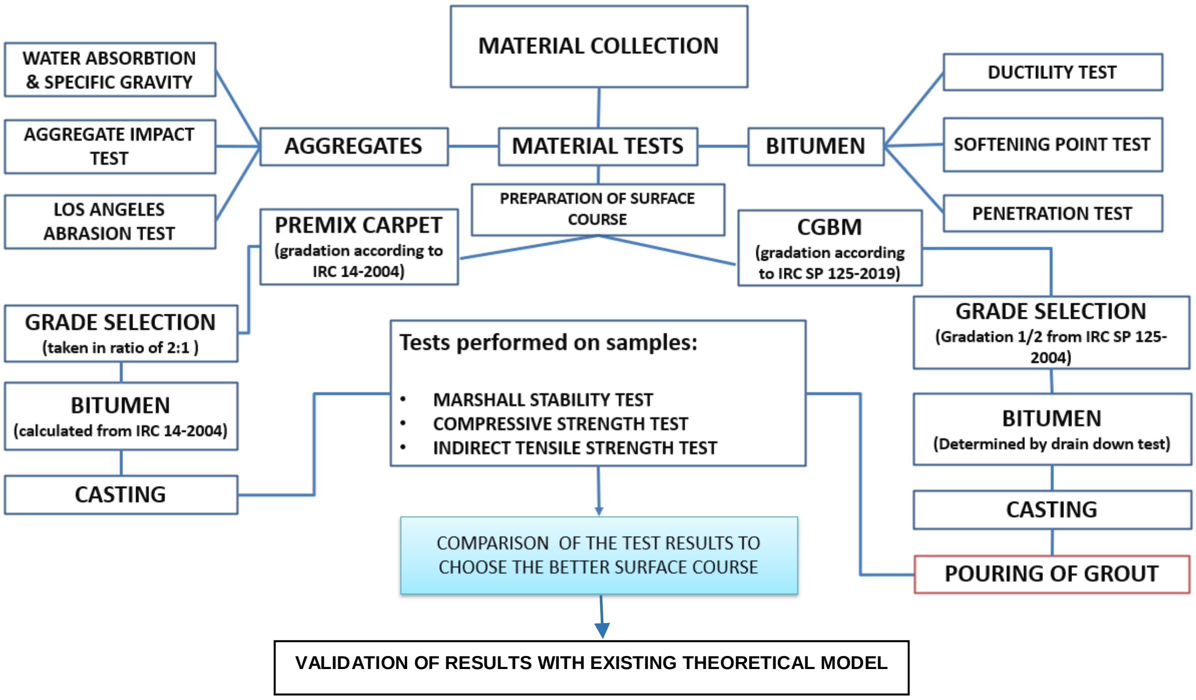


**Figure.1** Flowchart of the works carried out in this study

The aggregate gradation and optimum bitumen content of the samples is different for premix carpet and CGBM, although the (Marshall) mould used to prepare the sample remain same.

### 3.1 Preparation of test specimen / mould:

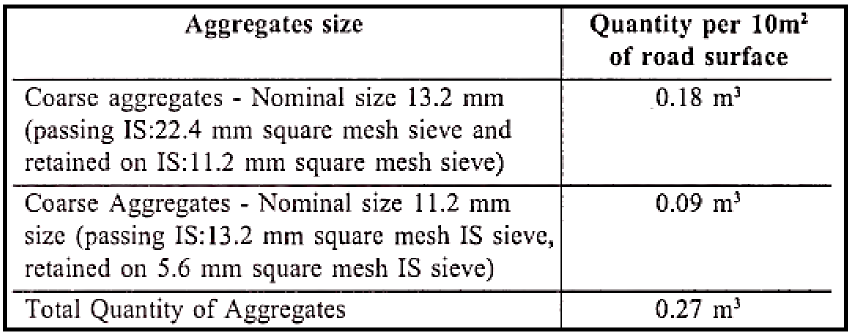
Preparation of mould is the most important and challenging task in this research works. A sample mould is prepared in a Marshall mould, using aggregates of specified proportions and calculated amount of bitumen for a conventional surface course.

- The quantity of bitumen and gradation of premix carpet is done based on the codal recommendations of IRC 14-2004.
- CGBM and its grade selection is done as per codal recommendations of IRC SP125-2019.

#### 3.1.1 Open Graded Premix Carpet (OGPC) or Premix Carpet (PC)

To commence, 1200 grams of aggregates, carefully measured in the prescribed proportions, are heated on a metal bowl to attain the mixing temperature. Should the specified proportions not total 1200g, it is recommended to incorporate filler material. Bitumen is then melted and gradually introduced into the mixture. Subsequently, the bituminous blend undergoes thorough heating, stirring, and mixing until achieving uniform integration. The Marshall mould is meticulously cleaned, dried, and greased in preparation for receiving the mix. The mixture is poured into the Marshall mould, equipped with a collar and base, and distributed evenly around the mould's perimeter. A filter paper is positioned beneath and atop the sample. The mould is then positioned in the Marshall compaction pedestal, and the material is compacted with 50-75 hammer blows, first on one face and then inverted and compacted on the other face with the same number of blows. Following compaction, the mould is inverted, the base removed with the collar still attached, and the sample extracted by pushing it out from the mould. Subsequently, the sample is allowed to cool for several hours. Once cooled, the mass of the sample in both air and submerged conditions is determined to measure specimen density, facilitating the calculation of void properties. The quantity of aggregates necessary for the premix carpet, as stipulated by IRC 14-2004, is presented in Table 1.

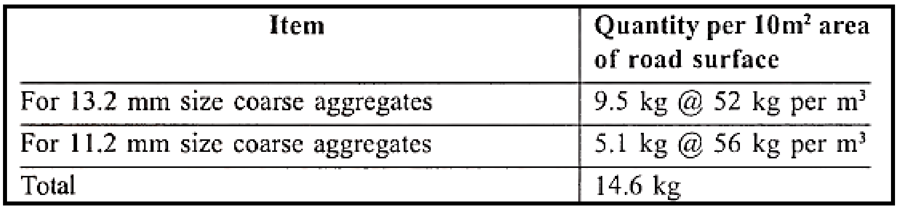
**Table.1 Gradation for OGPC**



| Aggregates size | Quantity per 10m$^2$ of road surface |
|---|---|
| Coarse aggregates - Nominal size 13.2 mm (passing IS:22.4 mm square mesh sieve and retained on IS:11.2 mm square mesh sieve) | 0.18 m$^3$ |
| Coarse Aggregates - Nominal size 11.2 mm size (passing IS:13.2 mm square mesh IS sieve, retained on 5.6 mm square mesh IS sieve) | 0.09 m$^3$ |
| Total Quantity of Aggregates | 0.27 m$^3$ |

Quantity of bitumen for premix carpet as specified by IRC 14-2004 is shown in Table 2.

**Table.2 Bitumen content for OGPC**



| Item | Quantity per 10m$^2$ area of road surface |
|---|---|
| For 13.2 mm size coarse aggregates | 9.5 kg @ 52 kg per m$^3$ |
| For 11.2 mm size coarse aggregates | 5.1 kg @ 56 kg per m$^3$ |
| Total | 14.6 kg |

With the given gradation, a 2:1 mix proportion of aggregates retained on 11.2 mm sieve and 5.6 mm sieve are heated on the metal bowl and preparation was carried out. Procedure is demonstrated in Figure 2 to Figure 8.

**Figure.2** Aggregates weighed and graded as per its gradation

**Figure.3** Aggregates heated on metal bowl to attain temperature.

**Figure.4** Melted bitumen is then poured into the mix. Trials are performed for different bitumen contents (%).

**Figure.5** The hot bituminous mix is transferred to a Marshall mould (fitted with base plate & collar), fixed using spring tension for compaction.

**Figure.6** Compaction of mould to obtain a test specimen. It can be given 50-75 blows depending on rate of compaction.

**Figure.7** For Premix carpet, compaction is done on both sides, mould is removed and then kept for cooling.

**Figure.8** Extracted test specimen of CGBM (middle) and premix carpet (left and right) to demonstrate results of different compaction rates. OGPC was given 75 blows on both sides, CGBM was given 70 blows on one side.

### 3.1.2 Cement Grouted Bituminous Mix (CGBM)

The procedure has slight variation while preparing CGBM moulds. CGBM is prepared in the same (Marshall) mould but it has additional considerations to be made in its design. The sample must have sufficient air voids for grout material to enter. Therefore, the mould filled with proportioned aggregates and bitumen is compacted only on one side. While the other side is allocated for pouring the grout. CGBM specimen shall not be extracted from the mould until poured grout sets and hardens. If errors occur in its preparation or sufficient air voids are not present, the grout material will not penetrate, making the sample unfit for testing. A CGBM sample requires substantial attempts with varying gradations and study of grout material to be successful and suitable for sample testing. The quantity of aggregates required for CGBM as specified by IRC: SP:125-2019 is presented in Table 3.

**Table.3 Gradation I & II for CGBM as per IRC SP 125**

| **Gradation** | **Gr-I (Gradation I)** | **Gr-II (Gradation II)** |
|---|---|---|
| Nominal Aggregate Size | 19 mm | 13 mm |
| Nominal Layer Thickness | 40-50 mm | 30-40 mm |
| IS Sieve (mm) | Cumulative % by weight of total aggregate passing | |
| 26.5 | 100 | - |
| 19.0 | 85-100 | 100 |
| 13.2 | 0-40 | 85-100 |
| 9.5 | 0-7 | 0-40 |
| 6.3 | - | 0-7 |
| 4.75 | - | - |
| 2.36 | 0-2 | 0-2 |
| 0.075 | 0-1.5 | 0-1.5 |

The grout for CGBM sample is to be prepared parallelly. To ensure the grout's strength, a compressive (cube) strength test is also performed. Compressive strength of the cube depends on factors such as water-cement ratio, cement strength etc.

### 3.1.3 Preparation of cementitious grout

The fluid cementitious grout is more of a slurry and therefore, determination of water-cement ratio that promotes easily flow and penetration through the voids is essential.

Grout trials were performed at increasing water-cement ratios and then poured into trial moulds of CGBM. While doing this, the CGBM specimen remained inside the Marshall mould. The sample is extracted/removed from the mould only a day later, to allow time for grout to set and attain strength. A CGBM sample is obtained only after the grout and bituminous mix binds together and forms a compound mix. The water-cement ratio in this study is fixed at 0.55 as the trials conducted gave full penetration. Moreover, researchers suggest addition of silica fume, fly ash and superplasticizers to reduce water-content and give improved results.

## 3.2 Preparation of cube specimen for cube strength test of grout

To evaluate the strength of grout at various time intervals, cube strength testing is conducted. The compressive strength attained by concrete at 7 days is approximately 65%, and at 14 days, it reaches around 90% of the target strength. Cube moulds are prepared using a mixture of cement, sand, and water, with a fixed water-cement ratio of 0.55 for casting the cubes. The cementitious slurry is poured into the moulds and vibrated using a Cement Mortar Cube Vibrating Machine. Subsequently, the top surface is levelled and smoothed with a trowel, after which it is left undisturbed to reach its full strength, as depicted in Figure 9.

The test specimens are stored in a moist air environment for 24 hours, then removed from the moulds and submerged in clean freshwater until just before testing. Prior to the test, the specimen is taken out of the water and excess water is wiped off from the surface. It is then centrally aligned and positioned in the testing machine so that the load is evenly applied to opposite sides of the cube. The load is gradually applied without sudden impact and continued until the specimen fails. Finally, the maximum load and any peculiar features in the type of failure are noted.

**Figure.9** Grout material poured into cube mould of dimension 7 cm x7cm x7cm

### 3.2.1 Preparation of CGBM sample specimen

Preparation of grout and obtaining CGBM sample is demonstrated in Figure 10 to Figure 15.

**Figure.10** Mixing of materials in a metal bowl.

**Figure.11** Gradual addition of water to obtain slurry

**Figure.12** Mould is inverted (after removing base plate) and grout is poured.

**Figure.13** The grout is allowed to penetrate and bind with the bituminous mix for 24hours.

**Figure.14** Sample specimen is extracted from themouldafter 24 hours. Top view of the obtained CGBM sample is shown.

**Figure.15** Side view of the CGBM sample obtained. The grout exhibited positive results along with good penetration.

### 3.3 Testing of sample specimen:

To compare the strength parameters and physical properties of the sample specimens, three tests were conducted viz., Marshall Stability Test, Indirect Tensile Strength test and Compressive strength test. Marshall mould samples are used to perform the tests on stability and strength.

## 4.0 Result and Discussion

### 4.1 Material Properties

The outcomes from the initial assessment of cement are displayed in Table 4. While those from the preliminary assessment of coarse aggregate can be found in Table 5. Additionally, the findings from the preliminary assessments of the fine aggregate are outlined in Table 6, and the results from the fundamental bitumen tests are detailed in Table 7.

**Table.4 Properties of 53 grade OPC cement**

| SlNo. | OPC specification as per IS 12269 | Properties | Test results |
|---|---|---|---|
| 1 | - | Specific gravity | 3.1 |
| 2 | >30 mins | Initial setting time (min) | 35 mins |
| 3 | <600 mins | Final setting time (min) | 185 mins |
| 4 | - | Fineness % | 4.5% |

**Table.5 Properties of coarse aggregate**

| Sl No. | Test Particulars | Test Results | Requirements as per MoRTH (Vth Revision) |
|---|---|---|---|
| 1 | Aggregate Impact Value | 20% | Max. 30% |
| 2 | Abrasion Value | 5.8% | Max. 40% |
| 3 | Water absorption | 0.45% | Max. 2% |
| 4 | Specific gravity | 2.69 | 2.5 to 3 as per IS 2386 |

**Table.6 Properties of fine aggregate**

| Sl.No | Property | Result |
|---|---|---|
| 1 | Specific Gravity | 2.6 |

**Table.7 Results of tests performed on bitumen**

| Sl. No | Test Particulars | Test Results | Requirement as per IS 73:2013 |
|---|---|---|---|
| 1 | Ductility | 82mm | Min. 75 |
| 2 | Penetration | 66mm | 50-70 |
| 3 | Softening point | 47°C | 45-57 |

All the preliminary test results of the materials used in this satisfied the codal requirements.

### 4.2 Optimum bitumen content

The optimum bitumen content for OGPC samples are taken as per IRC 14-2004. The optimum bitumen content is fixed at 3.75% for OGPC. A slight increase or decrease in the binder content resulted in poor stability or even deformation. Similarly, bitumen content for CGBM Gr-1 and CGBM Gr-2 is fixed at 3.5% and 3.25% respectively based on trial and error, while also considering the guidelines and recommendation as per IRC SP 125 (min. 3.25%). Low bitumen content can create pavement problems including ravelling and cracking, whereas high bitumen content can cause bleeding, slipping, and decreased skid resistance. Figure 16 demonstrates the stability of the sample specimen at various bitumen content.

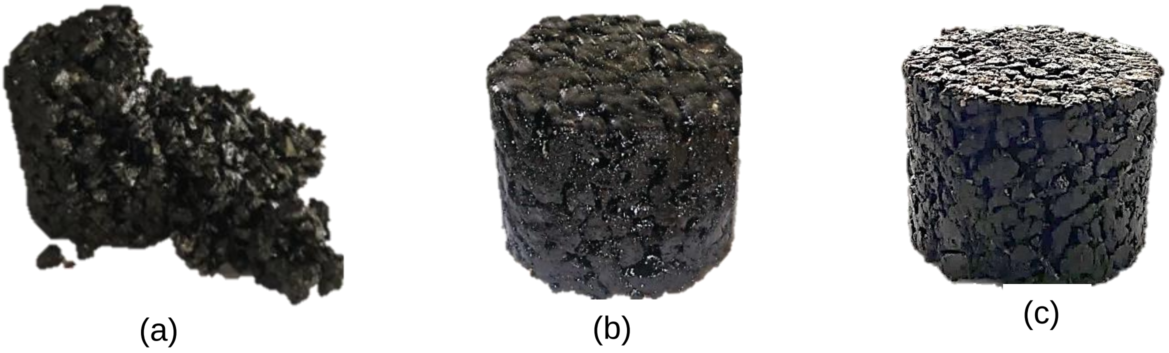


**Figure.16** (a) Sample slipped and collapsed due to high binder content (b) The sample is stable and firm at optimum binder content (c) Sample is dry, hard and easily breaks due to low binder content.

### 4.3 Proportion of grout

The cementitious grout is prepared using cement and water at w/c ratio of 0.55. i.e., roughly 342 g of cement and 188 ml of water for each CGBM sample. To fix the water-cement ratio, trials were performed with varying quantity of cement and water to ensure adequate flowability and penetration of grout through voids present in the mould. Results of grout trials done at different proportions are shown in Figure 17 and 18. Various grout trials performed at 0.4 to 0.5 w/c ratio resulted in partial or no penetration at all, through the bituminous mix. Clogging of grout was also observed due to insufficient water. A considerable increase in water content resulted in improved flowability and grout penetration, but lacked consistency. After grout hardened, lesser stability and irregular settlement of grout was observed, likely due to excess amount of water. Therefore, w/c ratio is finally fixed at 0.55 and test to assess its strength is performed.

**Figure.17** Grout with higher water content (w/c ratio = 0.6) showed good penetration but lacked strength.

**Figure.18** Grout with desirable proportion of water and cement (w/c ratio = 0.55) showed full depth penetration and adequate strength.

### 4.4 Test result of cube strength test

To evaluate the compressive strength and to assess convenience of the grout, cube strength test is performed. Cement cube consisting of cement and water at 0.55 w/c ratio is prepared and tested at intervals. The results obtained is calculated and shown in Table 8. Testing and observation is shown in Figure 19.

**Table.8 Results of cube strength test**

| **Time** | **7 Days** | **14 Days** | **28 Days** |
|---|---|---|---|
| **Strength**(N/mm$^2$) | 11.98 N/mm$^2$ | 16.59 N/mm$^2$ | 18.4 N/mm$^2$ |

The prepared cube mould exhibited good stability and strength. It withstood load up to 93KN. Cracks and breaks were observed at the edges of the cube before it was removed from the UTM.

**Figure.19** Compressive load is gradually applied until the cube fails.

### 4.5 Test results of surface courses

To carry out the tests, 27 Marshall mould samples were prepared in the laboratory. This includes 9 samples of each type i.e., OGPC, CGBM (Gr-1) and CGBM (Gr-2). The obtained test results are noted, calculated and discussed below. To compare the strength parameters of the surface courses, the average value of three test results was taken.

4.5.1 Results of Marshall Stability test

The Marshall stability of a sample specimen refers to the maximum load necessary to induce failure when the specimen is preheated to a specified temperature, positioned, and subjected to a constant strain, as depicted in Figure 4.4. During the stability test, a dial gauge is utilized to measure the vertical deformation of the specimen. Load is incrementally applied until the specimen fails, and the maximum load reading in Newton is recorded. Additionally, the resulting value observed on the stability gauge after the deformation of the samples is noted. The outcomes are presented in Table 9 and Figure 20.

**Table.9 Marshall Stability test results**

| | Sample No. | Marshall Stability (kN) | Average Value (kN) |
|---|---|---|---|
| OGPC | 1 | 59 | 47.67 |
| | 2 | 45 | |
| | 3 | 39 | |
| CGBM-1 | 1 | 131.5 | 125.83 |
| | 2 | 117.5 | |
| | 3 | 128.5 | |
| CGBM-2 | 1 | 173 | 163 |
| | 2 | 155 | |
| | 3 | 161 | |

(a) (b)

**Figure.20** (a) Sample submerged in controlled temperature for 40 minutes.
(b) Deformed mould after Marshall stability test

The results showed that the bearing capacity for CGBM is higher than that of OGPC. CGBM Gr-I showed a 20% increase in bearing capacity over Gr-II. The ingredients in CGBM exhibited good binding property and which in turn enhances the load carrying capacity and durability.

### 4.5.2 Compressive strength test

Test was performed using UTM machine. A sample specimen is centrally positioned vertically on the machine and load is applied gradually until the specimen deforms. The value obtained is noted and further calculated. Results are shown in Table 10 and Figure 21.

**Table.10 Compressive strength test results**

| Mix Type | Sample No. | Compressive Strength (N/mm$^2$) | Average Value(N/mm$^2$) |
|---|---|---|---|
| OGPC | 1<br>2<br>3 | 2.08<br>2.16<br>2.20 | 2.14 |
| CGBM-1 | 1<br>2<br>3 | 5.85<br>5.6<br>5.38 | 5.61 |

| | | | |
|---|---|---|---|
| CGBM-2 | 1 | 5.35 | 5.23 |
| | 2 | 5.22 | |
| | 3 | 5.14 | |

(a) (b) (c)

**Figure.21** (a) Before testing samples for compressive strength (b) During the test (c) After the compressive strength test.

CGBM showed superior compressive test results over OGPC. Hence, it can resist more compression due to the pressure of cement and bitumen. Compressive strength of both gradations of CGBM was 50% greater than OGPC.

### 4.5.3 Indirect Tensile Strength

Test was performed using UTM machine. A sample specimen is centrally positioned horizontally on the machine and load is applied gradually until the specimen fails. Steel bars are used to support the specimen parallelly at the top and bottom. The value obtained is noted and further calculated. Results are showed in Table 11 and Figure 22.

**Table.11 Indirect tensile strength test results**

| Mix Type | Sample No. | Indirect tensile strength (N/mm$^2$) | Average Value (N/mm$^2$) |
|---|---|---|---|
| OGPC | 1 | 0.808 | 0.802 |
| | 2 | 0.79 | |
| | 3 | 0.808 | |
| CGBM-1 | 1 | 2.24 | 2.24 |
| | 2 | 2.34 | |
| | 3 | 2.15 | |
| CGBM-2 | 1 | 2.09 | 2.03 |
| | 2 | 1.91 | |
| | 3 | 2.09 | |

**Figure.22** (a) Samples placed horizontally for testing (b) Failure of specimen observed as a split in the middle (c) Samples deformation after indirect tensile strength test.

The results show that the tensile strength is significantly greater for CGBM than OGPC. CGBM Gr-1 showed higher strength than CGBM Gr-2 and OGPC. Hence, it has more strength and adherence against fatigue, temperature cracking and rutting.

### 4.6 Suggestions

Cement grout in the CGBM can be customized with varying proportions of cement, fly ash, and silica fume to enhance strength, durability, reduce permeability, improve workability, and lower heat of hydration. To determine the optimal bitumen content, a drain down test can be conducted. Additionally, tests like Cantabro, rutting, and resilient modulus tests can be performed to assess the effectiveness of surface courses.

For effective drainage and prevention of water damage, roads and pavements should be crowned or sloped slightly in the middle, with the edges slanting downwards. This design directs water and fuel towards designated drainage systems, minimizing the formation of puddles. The recommended drainage system is mole drainage, which involves installing subsurface channels to improve water drainage from the roadbed. This system promotes road longevity, surface stability, prevents sub-surface swelling, and is a cost-effective option.

## 5.0 Conclusion

The current study involves preparing sample specimens with a fixed optimal binder content, creating grout material with desired strength and flow characteristics, and testing the specimens for strength. The study also includes analyzing the strength parameters of surface courses, CGBM, and OGPC, and comparing the results to determine the best surface course. All tests were conducted in accordance with Indian Standard/Indian Road Congress/ASTM guidelines provided by research institutions.

Based on the findings and analysis of the study, the following conclusions can be drawn regarding CGBM and OGPC:

- CGBM mix can be effectively prepared using the specified gradation (Gr-1 and Gr-2), binder content (3.75% for OGPC & 3.5% and 3.25% for Gr-1 and Gr-2 respectively), and grouting material composed of water and cement with a water-cement ratio of 0.55.
- The compressive strength of CGBM Gr-1 and Gr-2 is 50% higher than that of OGPC. CGBM Gr-1 has higher tensile strength than Gr-2, while OGPC has 40% lower tensile strength compared to CGBM. Additionally, the stability of Gr-2 CGBM is 20% greater than that of Gr-1.
- CGBM exhibits greater resistance to moisture damage due to the penetration of grout material, which reduces direct contact between moisture and the aggregate-binder interface, as well as moisture accumulation within the mix.
- While rigid pavements take longer to implement, CGBM allows for early traffic flow as the grout material poured into voids in the bituminous mix sets within one day, facilitating faster pavement construction.

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