GUIDELINES FOR CEMENT GROUTED BITUMINOUS MIX SURFACING FOR URBAN ROADS

INDIAN ROADS CONGRESS
2019

GUIDELINES FOR CEMENT GROUTED BITUMINOUS MIX SURFACING FOR URBAN ROADS

Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

DECEMBER, 2019

Price : ₹ 500/-
(Plus Packing & Postage)

First Published : December, 2019

Printed at India Offset Press, Delhi - 110 064
1100 Copies

CONTENTS

PERSONNEL OF THE HIGHWAYS SPECIFICATIONS AND STANDARDS COMMITTEE

(As on 20.07.2019)

1	Pandey, I.K. (Convenor)	Director General (Road Development) & Special Secretary to Govt. of India, Ministry of Road Transport and Highways, New Delhi
2	Balakrishna, Y. (Co-Convenor)	Additional Director General, Ministry of Road Transport and Highways, New Delhi
3	Kumar, Sanjeev (Member Secretary)	Chief Engineer (R) S, R & T, Ministry of Road Transport and Highways, New Delhi

Members

4	Behera, Bijan Kumar	Engineer-in-Chief (Civil) (Retd.), Odisha
5	Bose, Dr. Sunil	Head (Retd.), FPC Division, Central Road Research Institute, New Delhi
6	Chandra, Dr. Satish	Director, Central Road Research Institute, New Delhi
7	Gupta, D.P.	DG(RD) & AS (Retd.), Ministry of Surface Transport, New Delhi
8	Jain, R.K.	Chief Engineer (Retd.), PWD Haryana
9	Kapila, K.K.	Chairman & Managing Director, ICT Pvt. Ltd., New Delhi
10	Kukrety, B.P.	Associate Director, CEG Ltd., New Delhi
11	Kumar, Dr. Mahesh	Engineer-in-Chief (Retd.), PWD (B&R) Haryana
12	Lal, Chaman	Engineer-in-Chief (Retd.), PWD Haryana
13	Meena, H.L.	Secretary (Retd.), PWD Rajasthan
14	Nashikkar, J.T.	Secretary (Retd.), PWD Maharashtra
15	Nirmal, S.K.	Secretary General, Indian Roads Congress, New Delhi
16	Parida, Prof. (Dr.) M.	Deputy Director, Indian Institute of Technology, Roorkee
17	Patel, S.I.	Secretary (Retd.), PWD (Roads and Buildings) Gujarat
18	Prasad, R. Jai	Engineer-in-Chief (Retd.), PWD & Bangalore Mahanagar Palike, Karnataka
19	Rawat, M.S.	Executive Director, AECOM India Pvt. Ltd.
20	Reddy, Dr. K.S. Krishna	Secretary, Public Works, Ports & Inland Water Transport Department, Karnataka
21	Reddy, I.G.	Engineer-in-Chief (NH, CRF & Buildings), PWD Hyderabad
22	Reddy, Prof. (Dr.) K.S.	Professor, Indian Institute of Technology, Kharagpur
23	Sharma, S.C.	DG(RD) & AS (Retd.), Ministry of Road Transport and Highways, New Delhi
24	Shrivastava, A.K.	Additional Director General (Retd.), Ministry of Road Transport and Highways, New Delhi
25	Singh, Nirmaljit	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi
26	Sinha, A.V.	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi

27	The Chief Engineer (Basar, Toli)	PWD Arunachal Pradesh
28	The Addl. DGBR (North-West) (Kumar, Anil)	Border Roads Organisation, New Delhi
29	The Director (Tech.) (Pradhan, B.C.)	National Rural Infrastructure Development Agency, New Delhi
30	The General Manager (Projects) (Retd.) (Kaul, Satish)	National Highways and Infrastructure Development Corporation, New Delhi
31	The JICA Expert (Kitayama, Michiya)	Japan International Cooperation Agency, New Delhi
32	The Member (Projects) (Pandey, R.K.)	National Highways Authority of India, New Delhi
33	The Professor (Chakroborty, Dr. Partha)	Indian Institute of Technology, Kanpur
34	The Secretary (Vasava, S.B.)	Roads and Buildings Department, Gujarat
35	The Secretary (Roads) (Joshi, C.P.)	PWD Maharashtra
36	The Secretary (Tech.) (Tickoo, Bimal) (Retd.)	Roads and Buildings Department, Jammu & Kashmir
37	The Special Director General (Retd.) (Bansal, M.C.)	CPWD, Nirman Bhawan, New Delhi
38	Venkatesha, M.C.	Consultant
39	Wasson, Ashok	Member (Tech.) (Retd.), National Highways Authority of India, New Delhi

Corresponding Members

1	Jaigopal, R.K.	MD, Struct Geotech Research Laboratories (P) Ltd., Bengaluru
2	Justo, Prof. (Dr.) C.E.G.	Professor (Retd.), Emeritus (*Expired in June, 2019*)
3	Veeraragavan, Prof. (Dr.) A.	Professor, Indian Institute of Technology, Madras

Ex-Officio Members

1	President, Indian Roads Congress	(Basar, Toli), Chief Engineer, PWD Arunachal Pradesh
2	Director General (Road Development) & Special Secretary to Govt. of India	(Pandey, I.K.), Ministry of Road Transport and Highways, New Delhi
3	Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

ABBREVIATIONS

All symbols are explained where they occur first. Some of the symbols are:

AAAT	-	Average Annual Air Temperature
AAPT	-	Average Annual Pavement Temperature
AMAT	-	Average Monthly Air Temperature
AMPT	-	Average Monthly Pavement Temperature
AASHTO	-	American Association of State Highway and Transportation Officials
ASTM	-	American Society of Testing and Materials
AUSTROADS	-	Association of Australian and New Zealand Road Transport and Traffic Authorities.
BC	-	Bituminous Concrete
BIS	-	Bureau of Indian Standards
CBR	-	California Bearing Ratio
CGBM	-	Cement Grouted Bituminous Mix
DAAV	-	Dry Aggregates Air Voids
DAVR	-	Dry Aggregate Void Ratio
DBM	-	Dense Bituminous Macadam
E	-	Resilient Modulus of Elasticity
GB	-	Granular Base
GSB	-	Granular Sub-base
IRC	-	Indian Roads Congress
ITS	-	Indirect Tensile Strength
MIST	-	Moisture Induced Sensitivity Test
M_R	-	Modulus of Rupture
MEPDG	-	Mechanistic Empirical Pavement Design Guide
MSA	-	Million Standard Axle
MoRT&H	-	Ministry of Road Transport & Highways
OGFC	-	Open Graded Friction Course
RMC	-	Ready Mix Concrete

SAMI	-	Stress Absorbing Membrane Interlayer
TSR	-	Tensile Strength Ratio
UCS	-	Unconfined Compressive Strength
V_a	-	Volume of Air Voids
V_b	-	Volume of Bitumen
VDF	-	Vehicle Damage Factor
VG	-	Viscosity Grade
VIM	-	Voids in Mix
VMA	-	Voids in Mineral Aggregate
WBM	-	Water Bound Macadam
WMM	-	Wet Mix Macadam
ε_t	-	Horizontal Tensile Strain
E_v	-	Vertical Subgrade Strain
μ	-	Poisson's Ratio
με	-	Micro Strain

GUIDELINES FOR CEMENT GROUTED BITUMINOUS MIX SURFACING FOR URBAN ROADS

The first development of the semi-flexible process was carried out in the 1950's in France, as a protection of asphalt concrete surface course against the attack of waste oils and fuels. Jean Lefebvre, a French construction company as a cost-effective maintenance alternative to concrete roads developed this technology. In India, the CGBM technology was initially developed by a premier laboratory and a few stretches were constructed with this technology. CGBM technology consists of having a high void bituminous mix in which highly flow able high strength grout is poured which occupies all voids and make it water tight. This also leads to substantial improvement in the engineering properties. Performance study on CGBM overlay was carried out by CRRI and noted that compared to conventional bituminous mixes there is substantial improvement in engineering properties of this material. This technology has been adopted by Surat Municipal Corporation and in several other city roads. National laboratory at Chennai was requested to develop the grout and conduct laboratory tests on CGBM samples to ensure that engineering properties recommended for grout and CGBM based on various references are achievable.

The task of preparation of these Guidelines was taken up by H-9 Committee during the tenure 2012-14. The initial guidelines prepared by Dr. Animesh Das, Professor, IIT Kanpur in the year 2012 and discussed in the then H-9 Committee. Based on various references and research work at IIT Kharagpur & CSIR-CRRI, New Delhi, the initial guidelines were modified by late Prof. B.B. Pandey, IIT Kharagpur. The H-9 Committee was reconstituted in the year 2015 and draft document was discussed during various meetings of H-9 Committee and finally approved in its meeting held on 19.11.2016 for placing before HSS Committee. The HSS Committee in its meeting held on 23.06.2017 decided to wait for performance report on CGBM trial sections laid by CSIR-CRRI and referred back the document to H-9 Committee in light of comments made by the HSS.

Thereafter, the H-9 Committee was reconstituted for the tenure 2018-20. The H-9 Committee in its meeting held on 14.04.2018 constituted a subgroup comprising Shri P.L. Bongirwar-Subgroup Leader, Shri Manoj Kumar Shukla, Dr. Ambika Behl, Shri Anil Jadhav, Shri Vikas Thakar, Dr. I.K. Pateriya, Dr. Rajan Choudhary, Dr. Siddhartha Rokade and Dr. G. Bharat to review the comments of HSS and consider outcome of CRRI Study on CGBM Trial in Surat and finalize the document. The modified draft was discussed during various meetings of H-9 Committee and approved in its meeting held on 29.09.2018 for placing before HSS Committee. The HSS Committee in its meeting held on 23.10.2018 decided to refer back these draft guidelines to H-9 Committee in the light of comments made by HSS members. The draft guidelines were again discussed in the H-9 Committee and were finally approved in its meeting held on 08.06.2019 for placing before the HSS Committee. The HSS Committee in its meeting held on 20.07.2019 decided that Convenor, H-9 Committee will modify the document based on written comments and verbal comments offered during the meeting and submit final document to IRC for placing before the forthcoming Mid-Term Council meeting. The Mid-Term Council in its meeting held on 9th and 10th August, 2019 at Goa approved the document for publishing.

The composition of H-9 Committee is given below:

Bose, Dr. Sunil	……..	Convenor
Singh, R.K.	……..	Co-Convenor
Jha, Bidur Kant	……..	Member-Secretary

Members

Behl, Dr. Ambika	Pateriya, Dr. I.K.
Bhargava, Rajeev	Rokade, Dr. Siddhartha
Bongirwar, P.L.	Sahoo, Prof. U.C.
Choudhary, Dr. Rajan	Sinha, A.V.
Das, Dr. Animesh	Srivastava, Ashish
Jadhav, Anil	Subramanian, R.
Kumar, Sanjeev	Swamy, Dr. A.K.
Kumar, Satander	Thakar, Vikas
Mathur, H.C.	HoD, FPD, CRRI (Shukla, Manoj Kumar)
Mathur, Sudhir	HoD, RPD, CRRI (Kumar, Dr. Rakesh)
Nirmal, S.K.	

Corresponding Members

Ganju, Col. (Retd.) V.K.,	Veeraragavan, Prof. A.
Lal, Chaman	

Ex-Officio Members

President, Indian Roads Congress	(Basar, Toli), Chief Engineer, PWD Arunachal Pradesh
Director General (Road Development) & Special Secretary to Govt. of India	(Pandey, I.K.), Ministry of Road Transport & Highways
Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

1 INTRODUCTION

Flexible pavements are the most common types of pavement used for highways in India and rest of the world. Bituminous wearing course of such pavements often suffer wet weather damage which gets aggravated in cities due to flooding during monsoon. The pavements at traffic intersections, parking places and bus stops are noticeably damaged due to frequent braking action and fuel spillage. So, there arises a need for durable wearing course which is (i) strong enough to resist braking and accelerating effect of traffic (ii) fuel resistant (iii) impervious to water and (iv) moisture resistant. Research at IIT Kharagpur and at CSIR-CRRI has shown that open graded bituminous layer grouted with a cementitious grout can form a durable wearing course. Some other research Institute had developed similar product which has been used at a few locations in Kharagpur, Surat and Amravati. Flexible and Rigid pavements are common in India and now composite pavements are emerging.

The present guidelines deal with the design, preparation and application procedure for CGBM to be laid over bituminous surface. Almost single graded bituminous mix (having voids more than 25% which is more than the voids in traditional dense graded bituminous mixes) is paved and grouted with cement grout as under:

i) Mixed with optimum dose of bituminous binder (sometimes fibers may be added to prevent drain down) (ii) paved over a base (iii) compacted to design density (iv) filled with cementitious grout slurry (sufficiently flowable cement grout is applied on the compacted surface). This cement grout is primarily prepared by mixing suitable proportions of cement, fine sand and water. Other materials like fly ash, micro silica, super plasticizers, fibres etc. may be adequately and suitably added in order to improve the grout flowability and strength of grout.

CGBM is to be generally used as surface layer, but it also has potential to be used as base course.

International Applications of CGBM

The pavement surface made with this kind of technology seemed to have been developed in France during 1960s and was known as 'resin modified pavement'. In USA it was first applied during 1987 (1). Various countries where CGBM has been used include France, USA, Germany, Japan, Spain, Portugal, Sweden, Norway, Finland, Saudi Arabia, Great Britain, China, Denmark, Malaysia, South Africa and Austria etc. CGBM technology had been reportedly used in bus stations, parking areas, warehouses, roads, aprons, etc.

For Road Surface Treatments (RSTA), UK has developed a code of practice for grouted Macadam, approved by ADEPT (Association of Directors of Environment, Economy, Planning and Transport, UK) (2) and the same has also been approved by the Highway Authorities Product Approval Scheme (HAPAS), UK in 2006. CGBM was implemented by an organization called CIP Jointless Surfacing, England, primarily in Harbours, Airports, Warehouse Distributions, Bus-Depot Stations, Manufacturing-Production areas etc. However, in UK, there is no BSEN (British Standards, Europe) specification on CGBM as yet. In other parts of Europe like Denmark, Netherlands, Sweden etc. this technology has been extensively used. The Copenhagen Airport, Denmark already laid approximately 3 lac m^2 of CGBM. M/S BREMAT, Rosmalen, Netherlands carried out the execution and maintenance of this technology in Roundabouts, Intersections and Signals. Stockholm, Sweden implemented CGBM at different Bus stops and Bus-Depot stations, to bear the static loads and to diminish the chances of wearing and tearing.

In USA, primarily CGBM has been incorporated in Army bases, Air force Stations and Airports. McCord Air force Base, Washington and Logan International Airport, MA, has constructed CGBM pavement for having durable surface. To develop a fuel damage resistant surface Malmstrom Air Force base, Montana, has constructed wearing surface incorporating CGBM.

Mississippi Department of Transportation performed a project investigating grouted macadam at two signalized, heavily trafficked intersections.

In the Asia Pacific, CGBM has been widely implemented in Malaysia, China, Australia, Japan, Saudi Arabia etc. Kualalampur City Council has implemented CGBM technology extensively in heavily trafficked surface, Bus Lanes in the city area and maintenance of this is taken care of by Kualampur City Hall, since 2001. In China, Ministry of Construction of Chinese Technologies had executed several projects in late 20th Century.

Considering the widespread application of CGBM around the world, it may prove to be an emerging sustainable technology in road infrastructure development. The advantages of using CGBM surface in comparison to conventional pavement are as follows:

- ✓ Resistance to oil induced damages caused due to fuel spillage
- ✓ Resistance to permanent deformation
- ✓ Resistance to abrasion/wearing
- ✓ Resistance against moisture induced damages
- ✓ Lower thermal susceptibility in comparison to flexible pavements
- ✓ Impermeability and good skid resistance property

These advantages enable CGBM surface to take care of some of the individual limitations linked to cement concrete and bituminous mixes. Past researchers have conducted laboratory studies on stiffness, tensile and compressive strength, Marshall Stability, thermal expansion coefficient, low temperature fracture, fatigue properties of CGBM and found to show satisfactory performance. Recently, CSIR-CRRI has conducted detailed laboratory testing and evaluation of Trial section of CGBM in two roads of Municipal Corporation in Surat, Gujarat. The laboratory study included testing for compressive strength, stability, indirect tensile strength, moisture sensitivity, oil induced damage, wheel tracking test, resilient modulus, modulus of rupture, dynamic creep, flow number, dynamic modulus, etc. The study conducted by CRRI on CGBM trial section included visual inspection for any surface distress, core analysis for verification of full depth grouting, volumetric analysis using micro-CT technique, surface friction measurement and FWD survey. Trial stretches were studied on rural roads in heavy rainfall areas of West Bengal, a bridge deck and Dadar flyover in Mumbai City, roads of Municipal Corporations of Mumbai and Surat, etc. have given good performance. In hot summer, the cement grouted wearing course did not display any bleeding or rutting.

2 SCOPE

These guidelines discuss construction of laying of surface layer for Cement Grouted Bituminous Mix (CGBM), preferably over an existing bituminous pavement. CGBM is based on the concept of preparing a coarse aggregate skeleton structure which is then filled with cementitious grout material. A few trial stretches are also in progress where it is proposed to change the conventional seal coat on bituminous premix carpet with cement grouted seal coat. Minor changes in gradation are made to create more voids. This new type of wearing course is suitable for traffic up to 30 msa, in case of a new flexible pavement or as an overlay/renewal coat over an existing flexible pavement; though it can be used for heavier traffic as well if the base is strong. Such pavements have the benefit of flexibility of the bituminous pavement while possessing advantage of rigid pavement as well. Typically, the open graded aggregates are coated with about 3.25% to 4.0% bitumen. However, CRRI study on CGBM with a specified gradation finds that lower limit of binder content can be decreased up to 3% whilst using good aggregates of specific gravity more than 2.7. Once the paved high voids bituminous surface cools down to ambient temperature, the cementitious grout is poured over the surface which penetrates and fills up the voids and forms an impervious layer. It is ensured that grouting is achieved for full depth of high voids bituminous layer.

Properties of grout, method of construction of cement grouted bituminous layer as well as pavement design principles are included in the guidelines. Users of the guidelines should maintain a record of pavement performance periodically and send their feedback to Indian Roads Congress for the future revision of the guidelines.

3 MATERIALS

3.1 Coarse Aggregate

The coarse aggregate shall consist of crushed rock retained on 2.36 mm sieve. It shall be clean, hard, durable of cubical shape and free from dust and soft organic and other deleterious substances. The aggregate shall satisfy the physical requirements given in **Table 1** and should satisfy the specifications of the surface dressing as per the MoRT&H Specifications. Since open graded aggregates coated with a binder is compacted by a road roller, Los Angeles Abrasion value shall be less than 30% to eliminate or the aggregate Impact value should be less than 24% to prevent crushing during rolling. The sum of flakiness and elongation indices must be less than 35%.

Table 1 Physical Requirements of Coarse Aggregates for Cement Grouted Bituminous Mixes

Property	Test	Method	Specification
Cleanliness	Grain Size Analysis	IS:2386 Part 1	< 2% passing 75 μm
Particle Shape	Combined Flakiness and Elongation Index	IS:2386 Part 1	<35%
Strength	Los Angeles Abrasion Value	IS:2386 Part 4	<30 %
	Aggregate Impact Value	IS:2386 Part 4	<24%
Polishing*	Polished Stone Value	IS:2386 Part 4	> 55%
Durability	Soundness (either Sodium or Magnesium) - 5 cycles		
	Sodium Sulphate	IS:2386 Part 5	< 12%
	Magnesium Sulphate	IS:2386 Part 5	< 18%
Water Absorption	Water Absorption	IS:2386 Part 3	<2%

*i) Polishing requirement does not apply when the coarse aggregate is used in the 19 mm CGBM.

ii) If the minimum retained tensile test strength falls below 80%, use of anti – stripping agent shall be used as per requirement.

3.2 Fine Aggregate

Fine aggregate (passing 2.36 mm sieve and retained on 75 µm sieve) shall consist of 100% crushed, manufactured sand resulting from stone crushing operations. The fine aggregate shall be clean, hard, durable, of fairly cubical shape and free from soft pieces, organic or other deleterious substances. The Sand Equivalent Test (IS:2720, Part 37) value for the fine aggregate shall not be less than 50. The Plasticity Index of the fraction passing the 0.425 mm sieve shall not exceed 4, when tested in accordance with IS:2720 (Part 5).

3.3 Bitumen

The bitumen for CGBM shall be viscosity grade (typically VG-30/VG-40) complying with Indian Standard Specification for paving bitumen i.e. IS: 73 or Polymer Modified Bitumen (PMB) Grade 40 complying with the Indian Roads Congress Specification i.e. IRC:SP:53.

3.4 Grout

Grout consists of the following constituents. The proper proportioning needs to be decided as per the observed results for Grout Flow and Grout Strength.

3.4.1 *Cement*

Ordinary Portland Cement OPC 43 or OPC 53 grade complying with IS 269-2015 shall be used.

3.4.2 *Sand*

The sand should pass 0.6 mm size so that the grout will enter into the air voids easily. Sand content may be minimized to achieve better quality of grout. Fine sand passing 45 µm can also give good results.

3.4.3 *Fly ash and Silica fumes*

Addition of fly ash and silica fumes will increase the grout flowability. The fly ash should conform to IS:3812 with minimum 65% passing 45 µm sieve.

3.4.4 *Super plasticizer/chemical stabilizers*

Super plasticizer (IS: 9103) and other chemical additives help in reducing the water requirement without reduction in strength of the grout, thus improving the flowability and helps in early gain of grout strength.

3.5 Design of Cementitious Grout

The cementitious grout primarily consists of cement, sand and water and may contain other mineral additives such as fly ash, micro-silica, very fine sand and suitable chemical additives in suitable proportion so as to produce a material that can flow easily into the voids of the bituminous mix. At the same time, grout should have enough strength to withstand the traffic load. Though aggregate bears most of the traffic load, the grout should be strong enough to resist the stresses caused by traffic without crushing. Proportion of sand and fly ash may be varied to optimize strength and flowability of grout. Fly ash and silica fume, also known as micro silica are used to improve strength, durability and the performance. Super plasticizer/ chemical additive is used to get the required fluidity at the lower water contents for cement grout without loss of strength. Polymer additive in the powder form or liquid form imparts early strength to the mortar.

For design of cement grout, various proportion of cement, fine sand passing 600 µm sieve, silica fumes, fly ash and ultra-water reducer are to be worked out to obtain desired properties. Extensive study at IIT Kharagpur indicated that the proportions of cement: sand: micro silica: fly ash of 40:40:10:10 and a super plasticizer of 0.5% by weight of the dry powder; all by weight and a water/binder ratio of 0.55 gave satisfactory results. Similarly, laboratory experiments done by other premier laboratory, with proportion of cement: sand: micro silica: fly ash of 38:10:10:42 with super-plasticizer of 0.3% and w/c of 0.25 have given satisfactory results to meet all desired properties as mentioned in **Appendix**. Possibly some other combinations may also be able to achieve the performance parameters as stated in **Appendix**. Since material properties may differ due to different sources, several mix design trials with different proportions are necessary. The grout should satisfy the following criteria:

- ✓ It should be sufficiently flow-able so that it can occupy the voids of the high voids bituminous mix.
- ✓ Sand present in the grout should not pose difficulty for easy flow of grout through the voids in the mix.

Any commercially available ready mixed dry powders (grout) can also be used if they meet the performance parameters, as stated in **Appendix**. The flowability of cement grout is to be measured using Flow Cone as per ASTM C939. The performance properties expected from grout and CGBM composite are given in **Table 3**.

4 BITUMINOUS MIX DESIGN FOR CGBM

4.1 Aggregate Gradation

The combined grading of the coarse and fine aggregates for CGBM is shown in **Table 2**. This Table consists of three gradations namely Gradation I, II & III for preparing bituminous mixes with voids suitable for CGBM, out of which Gradation I & II are as per Table 500-21 of MoRT&H Specifications for Surface Dressing and Gradation III is similar to Open Graded Friction Course as per ASTM. Gradation III has slightly lower air voids as compared to Gradation I and II. Generally, open gradations are preferred for CGBM so that minimum air void content of 25% is available in the bituminous mix skeleton. Selection of any gradation for CGBM can be made with the objective that cementitious grout flows freely into the voids of bituminous mix. Some general principles of selection of gradation for CGBM are discussed in **Appendix**.

Table 2 Gradations of Aggregates for CGBM

Gradation	Gr-I	Gr-II	Gr-III
Nominal Aggregate Size	19 mm	13 mm	13 mm
Nominal Layer Thickness	40-50 mm	30-40 mm	30-40 mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing		
26.5	100	-	-
19.0	85-100	100	100
13.2	0-40	85-100	90-100
9.5	0-7	0-40	25-65
6.3	-	0-7	-
4.75	-	-	10-15
2.36	0-2	0-2	8-15
0.075	0-1.5	0-1.5	2-8

4.2 Determination of Dry Aggregate Air Voids

The air voids in dry compacted (rodded condition) aggregates (having coarse and fine portion) is to be determined as per ASTM C29 (see **Annexure A** for outline of the test) or IS: 2386 Part 3. The formula used for the calculation of air voids in dry aggregates is given below in Equation 1.

$$\%\ Voids = 100\ [(5 \times W) - M]/(5 \times W) \qquad \text{.........} (1)$$

Where,

M = bulk density of the aggregate, kg/m^3

S = bulk specific gravity (dry basis)

W = density of water, 998 kg/m^3

4.3 Selection of Optimum Binder Content by Draindown Test

Draindown of the loose bituminous mix shall be determined according to ASTM D 6390 (see **Annexure B** for outline of the test). The drainage test should be performed at the anticipated plant production temperature and should satisfy the specified maximum drain down of 0.30%. If the mixture fails to meet this requirement, then fibers can be added to a level that reduces drain down to the acceptable limit.

There is a scope for reduction in bitumen dose which improves resistance against water penetration and may increase the ratio of ITS wet/ITS dry, However, as this may make the mix more brittle, reduction of bitumen dose below 3.25% is not recommended. Adequate quantity of bitumen is needed to maintain the nature of the prepared CGBM as flexible layer.

4.4 Determining Compaction Effort

The samples of high voids bituminous mix for CGBM can be prepared in different ways; namely (i) Marshal samples of 100 mm dia., (ii) Extracting cores from compacted slabs and (iii) extracting 100 mm dia. core from 150 mm dia. Marshall sample. Depending on the type of sample being prepared (in terms of mix composition and sample size), the compaction effort may vary from case to case. Compaction effort needs to be worked out by analyzing the lowering rate of air voids in the sample being prepared with respect to increase in the number of blows (compaction effort). Out of three gradations given in **Table 2**, only 40 blows are suggested for Gradation I & II and 60 blows for Gradation III, all applied on one face of the Marshall sample only.

4.5 Sample Preparation and Testing

Four samples for each of the trial gradations at the bitumen content selected as per draindown test are to be prepared. Three samples from each trial gradation shall be prepared with the optimum compaction effort as found out earlier and used to determine the volumetric properties of Marshall samples, and the fourth uncompacted loose mix sample shall be used to determine the theoretical maximum specific gravity (G_{mm}) according to ASTM D 2041 (see **Annexure C** for outline of the test).

4.6 Selection of Job Mix Gradation

Compact the specimens as discussed above and then remove them from the moulds once they cool down to ambient temperature (open graded mixes need to be handled carefully). Determine the bulk specific gravity (G_{mb}) of the specimens (ASTM D3203). The uncompacted mix samples are used to determine the theoretical maximum specific gravity (G_{mm}). Using G_{mb} and G_{mm}, the percent air voids (V_a) and VMA are calculated by the formulas shown in Equations 2 & 3, respectively.

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}} \qquad \text{……..(2)}$$

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 \qquad \text{…….(3)}$$

Where,

VMA = Voids in Mineral Aggregate

V_a = Percent Air Voids

G_{mb} = Bulk specific gravity of compacted mixture

G_{sb} = Bulk specific gravity of total aggregate

P_s = Percent of aggregate in mixture

G_{mm} = Theoretical maximum density of the mixture

5 OPTIMIZATION OF GROUT FOR CGBM

The grout slurry needs to have sufficient fluidity so that it can easily fill the air voids in the compacted mix. The fluidity of grout slurry is measured using Flow Cone as per ASTM C939 (See **Annexure D** for outline of the test). The strength of grout is basically evaluated in terms of its compressive strength measured on casted grout specimens (IS 4031 Part 6 or ASTM C109 or ASTM C579). The commercially available grout powder or own synthesised composition of grout as discussed in Para 4, needs to be optimised for quantity of mixing water such that the prepared grout slurry has optimum balance between its flow value and strength parameter, as acceptable for the considered aggregate gradation. General trend of grout flowability and strength with respect to mixing water content is shown in **Fig. 1**. The quantity of mixing water content should be optimised towards its minimum value while maintaining full depth of grout penetration into the high voids bituminous mix and thus consequently to achieve higher grout strength.

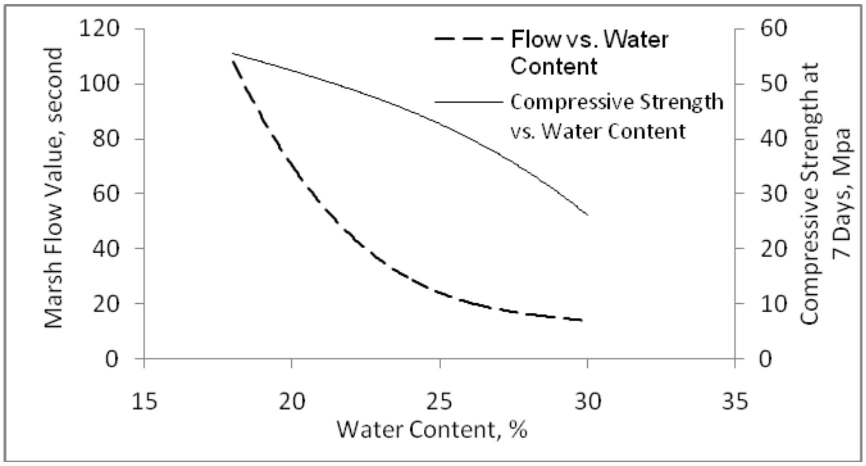

Fig. 1 Variation of Grout Flow and Strength Values with respect to Mixing Water Content

6 RECOMMENDATIONS FOR CGBM

The designed CGBM composite material shall meet the following requirements, as given in **Table 3**.

Table 3 Requirements of Cement Grouted Bituminous Mix

Sr No.	Properties	Units	Test Method	Recommended Values for CGBM
1	**Aggregate Gradation**			
1.1	Aggregate grading	-	-	CGBM Gr-I, Gr-II, Gr-III or Any other grading giving 25-35% voids
1.2	Air Voids	%	ASTMD3203	25-35
1.3	Binder content	%	-	As per drain down test or min. 3.25%*
2	**Grout Material** (Formulated or Commercially available grout)			
2.1	Grade of Cement	-	IS 8112, IS 12269	OPC 43 or OPC 53
2.2	Fly ash specification	-	IS 3812 part 2 (min. 65 % passing 45 micron)	Fly ash for concrete application
2.3	**Properties of Grout**			
2.3.1	Initial Setting Time	Hrs	IS 4031 Part 5	4-5
2.3.2	Final Setting Time	Hrs	IS 4031 Part 5	6-10

Sr No.	Properties	Units	Test Method	Recommended Values for CGBM
2.4	Characteristic Compressive Strength @28 days	N/mm^2	ASTM C109 (size 50*50*50 mm)	40-100
2.5	Flexural strength at 28 days	N/mm^2	IS 4031 Part8 (sample size-160*40*40 mm)	5-7
2.6	Fluidity ASTM C 939	sec	ASTM C 939	20-50
3	**CGBM Composite**			
3.1	Voids in CGBM @ 7 days	%	ASTM D3203	2-3
3.2	Full depth grouting	%	Visual	97-100
3.3	Compressive strength at 28 days	N/mm^2	ASTM C39 (100mm dia. & 200 mm ht.)	>5
3.4	Resilient Modulus @ 28 days,35°C	N/mm^2	ASTM D4123	> 10000**
3.5	Flexural strength @ 28 days	N/mm^2	ASTM C78 (Beam size 180*60*60 mm)	min.2.0
3.6	Marshal Stability @ 28 days, 60°C	kN	ASTM D6927	min. 60 (Pl check this value) (60 kN=6000kg)
3.7	Indirect tensile strength @28 days, 35°C	N/mm^2	ASTM D6931	min.1.0
3.8	Retained ITS strength at 28 days	%	AASHTO T283	97
3.9	CGBM layer thickness	mm	-	30 mm for traffic up to 5 MSA 40-50 mm for traffic > 5 MSA 30 mm for renewal coat if designed traffic is less than 30 MSA till next renewal cycle
3.10	Opening to traffic	-	-	After 24 hrs for light traffic Requirement can be specified by user
3.11	Skid resistance	BPN	ASTM E303	>50 in Wet & >60 in Dry Condition

* Corresponds to specific gravity of aggregates being 2.7. In case, aggregates having high specific gravity of more than 2.7 are used, the minimum bitumen content can be reduced

** For design purpose, Resilient Modulus value can be taken as 5000.

7 CGBM PRODUCTION

7.1 At Laboratory Scale

Brief description for method of preparation of CGBM composite along with the recommended values for different parameters and test results are described in **Appendix**. The recommended and acceptable values would depend on method of preparation of sample. **Appendix** also describes the method for sample preparation which is suggested as per the equipment available at project site laboratory. The various engineering properties of grout and composite CGBM recommended in **Table 3** are based on the methods of sample preparation and test procedure as described in **Appendix**.

7.2 During Pavement Construction

For field application of CGBM surface layer, different stages of work need to be accomplished. The existing bituminous surface is first cleaned and then emulsion (RS1) or low viscosity paving bitumen of VG 10 grade is spread over it as tack coat as per MoRT&H Specifications. A layer of open graded high void bituminous mix is then laid using the paver. Depending upon the grade of bitumen used, the mixed material shall be in the range of 140-170^{0}C. The laying temperature shall be in the range of 130-150^{0}C. The bituminous mix is then compacted with smooth wheeled roller, once its temperature is in the range of 80-100^{0}C. The paved bituminous mix is then compacted with 10 tons static steel wheel roller for 4 to 6 passes to obtain the desired density and the target air voids. Once the compacted bituminous surface cools down to ambient temperature, the requisite quantity of cementitious grout material mixed thoroughly with water can then be poured and spread uniformly over the entire porous surface. Cement grout preferably can be prepared in Pan Mixer so that all ingredients gets fully inter mixed. If patented intimately mixed dry powder is available, then use of Pan Mixer can be avoided and any simple blending equipment to produce liquid grout can be used. Grout can also be produced in the mixer of RMC plant. Grout would automatically flow into voids under the effect of gravity and its flowability. Sweeping or simple such techniques can be adopted to accelerate the process of grout penetration. Any excess grout observed on the surface shall be removed and any unfilled air voids observed are to be again filled with grout. The grout spread over the high voids bituminous mix surface is allowed to set for one day and then the section is cured by sprinkling of water for 7 days. The grouting operation should not be done in rainy or snowy environment. The field procedure to be adopted and the corresponding stages for laying the CGBM surface are outlined in **Annexure E**.

8 RESILIENT MODULUS, FATIGUE LIFE AND STRENGTH OF CGBM

In a typical case the Resilient Modulus (E) measured from Indirect Tensile test (ASTM D4123) for the cement grouted bituminous mix were found to vary from 12000 MPa to 15000 MPa in the laboratory at temperature 35^{0}C. However, a reduced modulus of 5000 MPa may be considered for pavement design considering (i) variability in grading of aggregates (ii) partial penetration of grout in the field and (iii) cracks caused by the construction traffic. The modulus of rupture (M_R, for Flexural strength) was found to be 2.5 MPa. A value of 1.25 MPa may be considered as the M_R value of the grouted macadam for the purpose of checking adequacy of pavement crust. Poisons ratio (μ) may be taken as 0.25. The resilient modulus and the modulus of rupture values can be used to check design adequacy to ensure that the Cement Grouted Bituminous Mix does not crack prematurely.

The fatigue life calculation of CGBM suggested by IIT Kharagpur is given below in Equation 4.

$$N = 10^{17.6019} \times (1/e)^{4.6099} \times (1/E)^{0.6171} \quad (R^2 = 0.77) \qquad \text{........(4)}$$

CSIR-CRRI based on their laboratory evaluations of CGBM samples prepared in the laboratory and cores taken from trial sections have found that Resilient Modulus (E) and Indirect Tensile Strength (ITS) of CGBM varies with temperature and loading. Therefore, CGBM can be concluded as Visco-elastic material.

9 PAVEMENT DESIGN

Elastic layered analysis applied for the analysis of flexible pavements can be used for the design of composite pavement as well. Parameters to be considered for design are CBR of the soil, elastic modulus of the granular layers, elastic modulus of the grouted bituminous layers, Poison's ratio of different layers and design traffic in terms of standard axles.

At present, the structural design (layer thickness) of pavements having CGBM layer can be worked out using the Fatigue Equation as given by IIT Kharagpur and mentioned above in Para 8. Modulus of different types of bases, sub bases and sub grades can be taken from IRC:37-2018.

Based on studies done at Nottingham University, CSIR-CRRI, New Delhi and IIT Kharagpur, the resilient modulus of CGBM can be taken as 5000 MPa (based on laboratory evaluated values ranging from 8000 to 15000 MPa at test temperature of 35°C).

Appendix

MIX DESIGN, METHODOLOGY AND TEST RESULTS FOR CGBM

Mix design for high void bituminous mix is based on the requirement to achieve high volume of interconnecting voids. The morphology of the voids produced should be such that it allows easy flow of the grout through them and then their subsequent filling with the flowing grout itself. The design objective of high voids bituminous mix differs from that of conventional dense graded bituminous mixes. The main design criterion for high void bituminous mixes being: (a) optimum binder content while limiting the drain down and (b) compaction effort needed to achieve optimal density and requisite volume of interconnected air voids. The results shown in this **Appendix** for Gradings I, II & III of CGBM have been obtained from test conducted at CSIR-CRRI, IIT Kharagpur and another premier laboratory. Detailed methodology, test procedure, sample preparation, test results of laboratory prepared samples and field core samples are given in this **Appendix**. The compiled test results for the three considered gradations of CGBM are given in **Table A1** to **A3**.

1. Aggregate Gradation and its Effect on Packing Characteristics

Air voids content in compacted bituminous mix will depend to a greater extent on the gradation of aggregate, binder content, type of binder and compaction method and energy used to compact the same. The packaging characteristics of different gradations can be defined by imparting similar compaction efforts and determining the voids. Different methods for determining air voids in an aggregate gradation are discussed below. These can be used to check the relative suitability of different gradations for preparation of high voids bituminous mixes.

a. Using IS 2386 Part 3

The aggregates selected for the specific gradation should be mixed thoroughly and then, filled into a cylindrical vessel of 250 mm diameter and 15 liters capacity, in three layers. Each layer should be subjected to 25 strokes of round edged tamping rod of 16 mm diameter. Dry Aggregate Air Voids (DAAV) can then be determined by the following equation:

$$Air\ voids\ in\ Dry\ Aggregate = \frac{G_s - \gamma}{G_s} \times 100$$

where

Air voids in Dry Aggregate is in percentage

G_s = specific gravity of the aggregate,

γ = bulk density in kg/litre

b. Using ASTM C29

The air voids in dry compacted (rodded condition) aggregates (having coarse and fine portion) can also be determined as per ASTM C29 (see **Annexure A** for outline of the test). The formula used for the calculation of air voids in dry aggregates is given below:

$$\% \, Voids = 100[(S \times W) - M]/(S \times W)$$

Where,

M = bulk density of the aggregate, kg/m^3

S = bulk specific gravity (dry basis)

W = density of water, 998 kg/m^3

2. Selection of Aggregate Gradation for Grouted Mix

Preparation of acceptable CGBM mix in laboratory depends on two criterions: i) Preparation of high voids bituminous mix, and ii) Proper grouting of the prepared mix. It is also observed that the amount of grout penetration in mix is related to the air void content and vertical permeability of the compacted high voids bituminous mix. The two parameters i.e. vertical permeability (mm/s) and vertical flow rate can be measured as per BS EN 12697 which can indicate the relative performance of different grout mix. There is a good relation between voids in mix and permeability as expected, i.e. higher the VIM, higher will be the vertical permeability. It is also observed that the amount of grout penetrating in mix is related with the air void content and vertical permeability of mix. Voids in Mineral Aggregate (VMA) is an important mix parameter which relates to the volume of binder and air void content that can be incorporated in compacted mix. The threshold values in terms of different dry aggregate and mix parameters required for satisfactory grout penetration have been identified for the three considered CGBM gradations and are listed below in **Table A1**.

Table A1 Threshold Values for Aggregate and Mix Parameters

Parameters	Specified Value	
	Gr-I & Gr-II	Gr-III
DAAV(Dry aggregate air Voids) %	44	38
DAVR (Dry aggregate void ratio)	0.6	0.6
VIM (Voids in mix) %	35	30
VMA (Voids in Mineral aggregate) %	40	35

These values can be helpful in selection of appropriate aggregate gradation for design of high voids bituminous mixes. The series of experiments conducted at IIT Kharagpur has led to following conclusions:

I. Dry Aggregate Air Voids (DAAV) and Dry Aggregate Void Ratio (DAVR) which represent packaging characteristics of dry aggregate are related to each other.

II. Vertical permeability and air voids are related.

III. The aggregate packing parameters DAAV and DAVR have good correlation with air voids in the compacted mix, vertical permeability and voids in mineral aggregate.

IV. The amount of grout penetrating the mix as correlated strongly with air voids content and also with vertical permeability.

V. Threshold values are evolved for different pacing characteristics and mix volumetric parameters for designing bituminous mix for satisfactory grout penetration.

VI. Use of finer sand fraction can improve the flow value and increase the degree of grout penetration. Full depth grout penetration is observed with sand with maximum size of 0.6 mm.

3. Determination of Optimal Bitumen Content

The determination of optimal bitumen content for all three gradations is based on the binder draindown test as per ASTM D6390. For all gradations, bituminous mixtures were prepared at different binder contents in increment of 0.5%. Drain down loss criteria of 0.3% (maximum) for high void bituminous mix is considered for selecting the optimum binder content.

4. Compaction Effort

There are no proper criteria for selection of number of blows/gyrations for the compaction of high voids bituminous mixes. For determining the optimum compaction effort, the bituminous mixes were compacted using Marshal Compactor with incremental variation of compaction effort. Cylindrical specimens of 100 mm diameter were prepared using a 100 mm diameter split mould for all considered aggregate gradations. For each aggregate gradation, cylindrical samples were compacted at various blows (20 to 70) of Marshall Hammer with increment of 10 blows applied on one face of the specimen. Then the volumetric study for each specimen of compacted samples was carried out, which is based on bulk specific gravity of compacted mix (G_{mb}), theoretical maximum specific gravity of mix (G_{mm}) and bulk specific gravity of aggregates (G_{sb}). Three samples were prepared for each specimen. The formula used for calculation of Air Voids (V_a) in the compacted bituminous mix and Voids in Mineral Aggregates (VMA) are given below.

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

Where,

V_a = air voids in compacted mix (percentage)

G_{mm} = theoretical maximum specific gravity of mix

G_{mb} = bulk specific gravity of compacted sample

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

Where,

VMA = voids in mineral aggregate (%)

G_{mb} = bulk specific gravity of compacted sample

P_s = percentage of aggregate by total weight of mix

G_{sb} = bulk specific gravity of the aggregate

Theoretical maximum specific gravity of loose bituminous mix was measured as per ASTM D2041. Since the specimens have high air void content, their bulk density was determined as per ASTM D3203 which mentions the estimation of the specimen bulk volume from dimensions. One of the typical graphs obtained while optimizing the compaction effort i.e. number of Marshall Hammer blows for bituminous mix of Gr. II in shown in **Fig. A1**. The optimum number of Marshal Hammer blows required for Gr.-I & Gr-II are 40 and for Gr.-III it is 60, all Marshal Hammer blows applied on one face only.

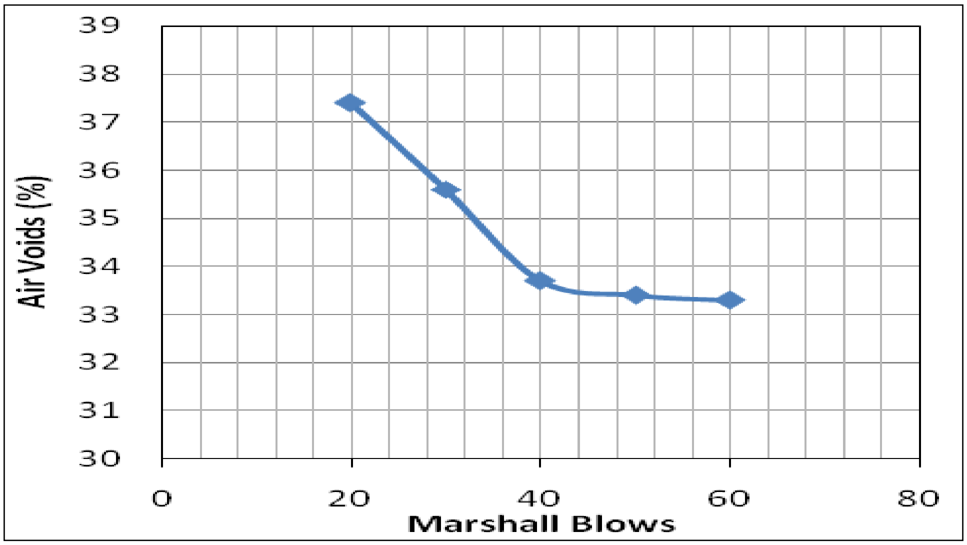

Fig. A1 Compaction Effort vs. Air Voids

5. Optimization of Grout Slurry

The cementitious grout consists of cement, water and super plasticizer in suitable proportion so as to produce a material that can flow easily into the voids of the bituminous mix. Additional mineral additives, like fly ash, slag, micro silica etc. can also be used to develop suitable grout material. It is generally noted that maximum size of sand should not be more than 0.6 mm for improved penetration.

It is very clear that flow of grout material increases with increase in water content with simultaneous decrease in its compressive strength. The flow characteristic of the grout should be evaluated using a Flow Cone as per ASTM C939 guidelines. Minimum three trials for measuring the grout flowability should be performed and average value should be reported. Inappropriate flow value or lower flowability of prepared grout slurry can result in failure of full depth grout penetration. When talking particularly about Gr.-II, different extent of grout penetration achieved with gradual increase in mixing water content is shown in **Photo A1**. The setting time of the grout should be determined as per IS 4031 Part 5 guidelines. It is preferable to have initial setting time of 4-5 hours and final setting time of 6-8 hours. Minimum two trials should be carried out in arriving at the initial and final setting time. The variation of grout compressive strength with respect to mixing water content should also be studied. The compressive strength of the grout should be determined as per IS 4031 Part-6 or ASTM C109 or ASTM C579. The average value of compressive strength of 3 cubes of 50x50x50 mm size should be reported. The flexural strength of the cementitious grout can be determined as per IS 4031 Part 8 using beams of size 160x40x40 mm size.

	
Shallow depth of grout penetration	**Partial depth of grout penetration**
	
Full depth of grout penetration	**Stack of full depth grouted Marshall samples**

Photo A1 Extent of Grout Penetration into the samples of High Voids Bituminous Mixes

6. Preparation of CGBM Samples

The evaluation of the CGBM for different parameters was performed on laboratory prepared samples of different sizes and shapes. As such, varying shape and sizes required for CGBM samples were 100 mm diameter & 63 mm height cylindrical samples for ITS, stability, resilient modulus, Moisture Induced Sensitivity Test (MIST); 100 mm diameter & 180 mm height cylindrical samples for compressive strength test; 100 mm diameter & 150 mm height cylindrical samples for dynamic modulus and flow number tests; rectangular slab for rutting test; rectangular beams for flexural strength or modulus of rupture test. Various types of grouted bituminous mix samples are shown in **Photo A2**. For preparation of these samples, the following steps can be followed:

a) Fill the moulds (Marshall or Gyratory or Slab) with freshly prepared hot high voids bituminous mix prepared as per design mix requirements and spread it uniformly.

b) Compact the mix using proper compaction method as per the type of sample being prepared (Marshall or Gyratory or Slab) up to the optimal density of mix, as discussed in Para 4. Preferably the weight of the hammer should be 4.5 Kg and above. Complete the compaction within 3 minutes, before the mix temperature drops below the specified requirements.

c) Once the temperature of the compacted mix drops down to ambient temperature (near about 50-60°C), the cementitious grout can then be poured slowly on the surface and if needed, the grout can be spread uniformly using a small scrapper/

brush. The corners and edges of the moulds may be sealed from outside to prevent any possible leakage of grout from it.

d) The grouted mix can then be de-moulded after 24 hours and should be cured with moistened jute bags for at least 3 days. Direct water curing is not recommended.

e) Marshall Core samples of size 100 mm dia. and rectangular beam samples can be extracted from slabs using core drilling machine and saw cutter respectively.

Photo A2 Different Types of CGBM Samples prepared in Laboratory

7. Laboratory Based Evaluation of CGBM Samples

All laboratory prepared samples of CGBM were first checked for their basic physical parameters like dimensions, bulk density, bulk specific gravity, etc. The extracted samples are then ready to be used for different tests.

a) Mechanical Strength Parameters of CGBM

Various laboratory tests were performed in order to determine different strength parameters of CGBM samples are described below with their test results mentioned in **Table A3**.

I. Indirect Tensile Strength (ITS)

The Indirect Tensile Strength (ITS) test should be performed as per ASTM D 6931 on Marshall Samples of 100 mm diameter. ITS test method consists of applying a load along the diametrical axis of the cylindrical sample at constant deformation rate of 51 mm/minute and determining the maximum vertical load taken by the sample at time of failure. Failure point is defined as the point after which there is no further increase in load. Before testing, the specimens should be temperature conditioned for different test temperatures like 25, 35 or 45°C. The maximum load P, taken by the sample is then used to calculate the Indirect Tensile Strength as per the equation given below.

$$ITS = \frac{2P}{\pi D t}$$

Where,

ITS = Indirect Tensile Strength (MPa)

P = load at failure (N)

t = height/thickness of specimen (mm)

D = diameter of specimen (mm)

II. Stability and Compressive Strength

Marshall Stability test determines the shear strength of the material. Marshall stability and compressive strength for CGBM were tested as per ASTM D6927 and ASTM C39 respectively. The formula used for the calculation of compressive strength is given below.

$$f_{cm} = \frac{4000\,P_{max}}{\pi D^2}$$

Where,

f_{cm} = compressive strength, MPa

P_{max} = maximum load, kN

D = average measured diameter, mm

III. Modulus of Rupture

The developed composite material (CGBM) was tested for its flexural strength as per ASTM C78. The beam sample being tested for its flexural strength under third-point loading condition is shown in **Photo A3**. The equation used for the calculation of flexural strength is given below.

$$R = \frac{PL}{bd^2}$$

Where,

R modulus of rupture, MPa

P maximum applied load, N

L span length, mm

b average width of specimen, mm

d average depth of specimen, mm

Photo A3 Flexural Strength Test under Third Point Loading Condition

IV. Resilient Modulus

Resilient modulus is used as an input parameter for pavement design and evaluation. This test should be performed using the repeated indirect tensile test method as per ASTM D4123. The test setup for the testing of resilient modulus of elasticity value under indirect tensile loading condition is shown in **Photo A4**. CGBM samples cured for period of 7/28 days were used for determination of the resilient modulus. The equation used for the calculation of resilient modulus is given below.

$$E_R = \frac{P\left(v_R + 0.27\right)}{t\Delta H}$$

Where,

E_R = resilient modulus of elasticity, MPa

v_R = resilient Poisson's ratio

P = repeated load, N

t = thickness of specimen, mm

ΔH = recoverable horizontal deformation, mm

Photo A4 Resilient Modulus Test Setup

b) Performance Evaluation

In order to have an assessment of the expected field performance of the CGBM, different performance related laboratory tests were performed on the CGBM samples. The actual field performance can only be checked by regular monitoring and evaluation of the laid sections. The laboratory-based performance studies done on CGBM are given as follows:

I. Rutting

Rutting performance of the CGBM mixes were studied at 60°C temperature using wheel tracking device. The rectangular slab of requisite size can be saw-cut out of a larger slab. Grouted CGBM slab being tested for 'rutting' using Wheel Tracking Device is shown in **Photo A5**. The test slabs are subjected to vertical pressure of 620 kPa applied through 50 mm wide wheels having diameter of 200 mm and running at speed of 60 passes per minute. Each sample is subjected to 20,000 passes (10,000 to and fro repetitions) of the wheel load. The rutting test results for CGBM is negligible (< 2 mm after 20000 passes) indicating good performance of CGBM against rutting.

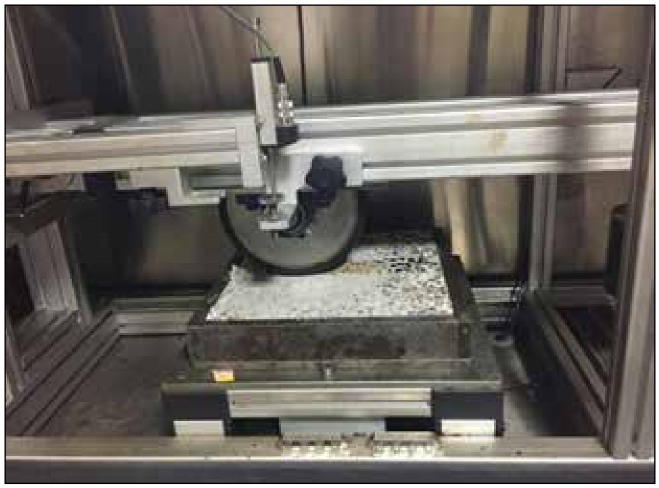

Photo A5 Wheel Tracking Test on CGBM sample

II. Moisture Resistance Measurement using MIST

Moisture induced damage is related to the loss in strength due to reduced adhesion between aggregate and bitumen along with reduction in cohesive property of binder material. Moisture Induced Sensitivity Test (MIST), as per ASTM D7870 can be followed in which an accelerated moisture conditioning method with cyclic loading is used. The MIST equipment and Marshall Samples being kept inside the MIST chamber are shown in **Photo A6**. After completion of moisture conditioning cycles on the CGBM samples, the Tensile Strength Ratio (TSR) can be evaluated to quantify the performance of CGBM mixes.

Photo A6 MIST Equipment with Test Sample being placed inside the Chamber

Alternate methods of sample preparation and testing as done by leading laboratories are presented in following section. The stages of sample preparation and corresponding photos are shown in **Photo A7**.

SAMPLE PREPARATION AND TEST PROCEDURE

1.1. Open Graded Friction Course (OGFC)

The Open Graded Friction Course, OGFC should be designed for air voids in the range of 25-30%. The mix gradation given in **Table 2** can be used to obtain the specified air voids. VG-30 or above grade of bitumen should be used for the OGFC mixes. Bitumen content of 3.0-3.5% is adequate for uniform coating of aggregates and compaction of the mix. MoRTH Section 500 should be used for preparation of bituminous mix.

Care should be taken in selection of the bitumen content, as excess bitumen may lead to bleeding and drain down condition. It is preferred to make first the OGFC slabs which represent similar to field condition. OGFC slab specimen of size 700×150×63 mm (See **Photo A7**) can be prepared as described below:

a) Fill the moulds with bituminous mix having the temperature around 130°C and spread uniformly.
b) Compact the mix with vibration compaction hammer. Preferably the weight of the hammer should be 4.5 Kg and above. Complete the compaction within 3 minutes, before the mix temperature drops to 110°C.
c) Extract Marshall Specimen of size 100×63 mm by using core drilling machine. Minimum three cores per slab shall be extracted.
d) The voids in the Marshall specimen can be calculated as per ASTM D 3203 guidelines.

1.2. Cementitious Grout

The cementitious grout consists of cement, water and super plasticizer in suitable proportion so as to produce a material that can flow easily into the voids of the bituminous mix. Additional mineral additives, like fly-ash, slag, micro-silica etc., are also useful in developing the suitable grout. Care should be taken to improve the flowability of grout by suitable additives and time required to discharge from the transit mixer within its workable period.

The flow characteristic of the grout should be evaluated using a Marsh cone as per ASTM C939 guidelines. The Marsh cone should conform to the specification. Initially the Marsh cone should be calibrated using water as per the ASTM guidelines. The flow tests with water should be 8.0±1.0 second conforming to the ASTM requirements. Minimum three trials with water and grout should be performed and average value should be recorded.

The setting time of the grout should be determined as per IS 4031, Part 5 guidelines. It is preferable to have initial setting time of 4-5 hours and final setting time of 6-8 hours. Minimum two trials to be performed in arriving at the initial and final setting time.

The compressive strength of the grout should be determined as per ASTM C 109 by casting three cubes of size using 50×50×50 mm. The average value of compressive strength of 3 cubes shall be recorded. The flexural strength of the cementitious grout can be determined as per IS 4031 Part 8 on 160×40×40 mm beam specimens. The average flexural strength of minimum 3 beam specimen shall be recorded.

1.3. Cement Grouted Bituminous Macadam (CGBM)

Based on the voids, calculate the quantity of grout required for filling of the OGFC slab. The slabs of OGFC mix should be filled with grout when the temperature comes down to ambient temperature or bituminous mix temperature falls to 50-60°C. The corners and all edges of the beam molds should be sealed from outside to prevent the leakage of grout. The cementitious grout can then be poured slowly on the OGFC slab and spread uniformly using a small scrapper. After a few minutes, a vibration compaction hammer should be used on the sides of the steel mold for 30 seconds to provide mild vibration and to ensure complete percolation of the grout to the bottom of the slab. Grouting should be continued until the entire calculated grout quantity is consumed by the OGFC slab. The slab can be de-molded after 24 hours and shall be cured with wet jute bags for 3 days. Direct water curing is not recommended. From slabs, standard Marshall Core samples and 189×63×63 mm beam samples shall be extracted. The Marshall Core samples shall be tested for their compressive strength, Marshall Stability and retained Marshall Stability tests. The failure pattern of Marshall Specimens under compression can be seen in **Photo A7 (d)**. The compression tests should be performed at a rate of loading of 1.8kN/sec. The beam specimens should be tested for their flexural strength as per ASTM C 78 guidelines. Minimum of three specimens should be tested in each case and the average results shall be recorded.

(a) High voids Bituminous Slab specimen

(b) Flow Cone used for Flow Value Measurement

(c) Grouted Beam sample

	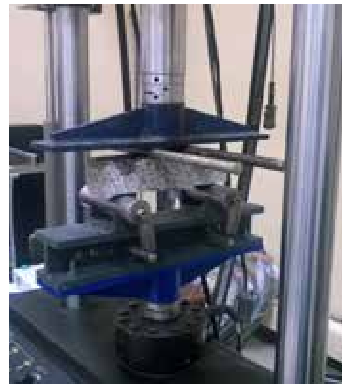
(d) CGBM Marshall Specimen after Compressive Strength Test	**(e) Flexural Test set up for CGBM Beams**

Photo A7 of Preparation and Testing of CGBM Samples

For having the actual field performance study of CGBM, two trial sections were laid in Surat city, Gujarat. The CGBM layer was laid as resurfacing course over existing bituminous surface on which approximately 650 CVPD traffic is plying. Further, the laboratory test results of field core samples (shown in **Photo A8 (a)** & **(b)**) were found to be close to the values determined on the laboratory prepared samples. The test results of field core samples are given in **Table A2**. The CGBM surface was also checked for their skid resistance using British Pendulum Tester (BPN instrument) as per ASTM E303.

(a)

(b)

Photo A8 Field core samples extracted from the test sections

Table A2 Mechanical Strength Values of Field Core Samples (CGBM Gr-II)

Sample No.	**ITS, MPa**	**Resilient Modulus, MPa**		
	@ 25°C	**@ 25°C**	**@ 35°C**	**@ 45°C**
Field Cores	1.80	17936	13089	9963

Table A3 Test Results for the Three Gradations considered for CGBM (Gr-I, II, III)

Sr No.	Properties	Units	Test Method	Test Results & Findings	
				Gr I & II (study by CSIR-CRRI)	**Gr III (study by other premier laboratory)**
1	**High Voids Bituminous Mix**				
1.1	Aggregate Grading	-	-	SD 19 & SD 13 (As per MoRTH)	OGFC (As per South African OGFC)
1.2	Binder content (VG30)	%	-	3-3.5 (ASTM D6390)	3.5
1.3	Air Voids in Mix	%	ASTM D3203	30-35	30
2	**Grout Material**			Jointly developed by CRRI & Industry Partner	Cementitious Flowable Grout
2.1	Grade of Cement	-	IS 12269	-	OPC 53
2.2	Fly ash	-	IS 3812 Part 2	-	Passing
2.3	**Properties of Grout**				
2.3.1	Initial Setting Time	hrs	IS 4031 Part 5	4	5.3
2.3.2	Final Setting Time	hrs	IS 4031 Part 5	7	7.5
2.4	Compressive Strength @28 Days	N/mm^2	-	60 (IS 4031 Part 6, 50 cm^2 Face Area)	40-100 (ASTM C109, 50*50*50 mm)
2.5	Flexural Strength @ 28 Days	N/mm^2	-	5.4	10 (IS 4031 Part 8, 160*40*40 mm)
2.6	Fluidity	sec	-	45 - 50 (Marsh Flow Cone)	23 (ASTM C 939)
3	**CGBM Composite**			Gr-II & Grout	Gr-III & Grout
3.1	Voids in CGBM @ 7 Days	%	ASTM D 3203	2.2 (using Micro-CT Imaging Technique)	2.86
3.2	Full Depth Grouting	%	Visual Inspection	>98	>95

Sr No.	Properties	Units	Test Method	Test Results & Findings	
				Gr I & II (study by CSIR-CRRI)	**Gr III (study by other premier laboratory)**
3.3	Compressive Strength @ 28 Days	N/mm^2	-	5.5 (ASTM C39, Gyratory Samples of 100 mm dia. & 180 mm height)	10.5 (Marshal Samples of 100mm dia. & 60mm height)
3.4	Resilient Modulus @ 28 days at 35°C	N/mm^2	ASTM D4123/ ASTM D7369	15000 (ASTM D4123)	12000 (ASTM D7369)
3.5	Flexural strength @ 28 days	N/mm^2	ASTM C78	2.2 (Sample Size 150*50*50 mm)	2.85 (Sample Size 180*60*60 mm)
3.6	Marshal Stability @ 28 days	kN	ASTM D6927	114	45
3.7	ITS @28 Days at 35°C	N/mm^2	ASTM D6931	1.53	1.03
3.8	Retained Stability@28 Days at 60°C	%	MoRTH specification	96	94
3.9	Retained ITS at 28 Days	%	AASHTO T283/ASTM D7870	98 ASTM D7870	-
3.10	CGBM layer thickness for trial section	mm	-	40	-
3.11	Opening to traffic	-	-	After 24 hours	-
3.12	Skid resistance	BPN	ASTM E303	60 in wet & 70 in dry condition	55 in wet condition

Annexure A

OUTLINE OF ASTM C29 FOR DETERMINATION OF DRY AGGREGATE AIR VOIDS

A. Scope and Summary of Test

This method covers the determination of bulk density (unit weight) of aggregate in a specified compacted condition and calculation of voids between aggregate particles based on this determination. The amounts of calculated voids are used in the mix design of CGBM. Only the dry rodded compaction is covered in this outline of the test method.

B. Testing Equipment

1. Balance or scale accurate up to 0.1 percent of the test load.
2. Tamping rod: a round, straight steel rod, 16 mm (5/8 inch) in diameter and approximately 600 mm in length. Tamping end shall be rounded to a hemispherical tip with a diameter of 16 mm.
3. A sturdy, cylindrical metal measure with a capacity of 10 liters. The height and diameter of the measure should be approximately equal.
4. Shovel or scoop for filling the measure with aggregate.
5. Piece of glass plate of 6 mm thickness and at least 25 mm larger than the diameter of the measure.

C. Testing Procedure

1. Calibrate the measure and determine its capacity in mm^3 by filling it with water and covering with glass plate to eliminate air bubbles and excess water. Determine the mass of water in the measure. Calculate the volume of the measure (V), by dividing the mass of water by its density.
2. Use the dry rodding procedure to place and compact the oven-dry aggregates in the measure. Fill the measure 1/3 full with aggregate and level the surface with fingers. Rod the layer of the aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure 2/3 full, level with fingers and rod as above again. Finally, fill the measure slightly overflowing the measure and rod again as before. Level the surface of aggregate with fingers in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.
3. Determine the mass of the measure plus its contents and the mass of the measure alone and record the values to the nearest 0.05 kg.

4. Calculate the unit weight of the aggregate by the dry rodding procedure as follows:

$$M = (G - T) / V$$

Where,

M = bulk density of the aggregate in dry rodded condition, kg/m^3

G = mass of the measure plus aggregate, kg

T = mass of the measure, kg

V = volume of the measure, m^3

D. Calculation

Calculate the void content in the aggregate using the bulk density determined above, as follows:

$$\% \, Voids = 100\,[(S \times W) - M]/(S \times W)$$

Where,

M = bulk density of the aggregate, kg/m^3

S = bulk specific gravity (dry basis)

W = density of water, 998 kg/m^3

Annexure B

OUTLINE OF ASTM D 6390 FOR DETERMINATION OF DRAINDOWN CHARACTERISTICS IN UNCOMPACTED ASPHALT MIXTURES

A. Scope and Summary of Test

This method determines the amount of drain down in an uncompacted asphalt mixture sample when the sample is held at elevated temperatures, which are encountered during the production, transportation, and placement of the mixture. This test is especially applicable to open-graded asphalt mixtures (such as open-graded friction course) and gap-graded mixtures such as Stone Matrix Asphalt (SMA). A fresh sample of the asphalt mixture (either made in the laboratory or from an asphalt plant) is placed in wire basket. The wire basket is hung in a forced draft oven for one hour at pre-selected temperature. A catch plate of known mass is placed below the basket to collect material drained from the sample. The mass of the drained material is determined to calculate the amount of draindown as a percentage of the mass of the total asphalt mix sample.

B. Testing Equipment

1. Forced draft oven, capable of maintaining temperatures in a range of 120 to 175ºC with +/- 2ºC of the set temperature.
2. Plates to collect the drained material.
3. Standard wire basket meeting the dimensions is shown in **Photo 1**. A standard 6.3 mm sieve cloth shall be used to make the basket. The dimensions shown can vary by +/- 10 percent.
4. Balance readable to 0.1 gram.

C. Testing Procedure

1. For each mixture to be tested, the draindown characteristics shall be determined at two temperatures: at the anticipated plant production temperature and at a temperature 10ºC higher than the anticipated production temperature. Duplicate samples shall be tested at each temperature. Therefore, a minimum of 4 samples shall be tested.
2. Weigh the empty wire basket (Mass A).
3. Place in the wire basket 1200 +/- 200 grams of fresh, hot asphalt mixture (either prepared in the laboratory or from an asphalt plant) as soon as possible without losing its temperature. Place the mix loosely in the basket without consolidating it. Determine the mass of the wire basket plus sample to the nearest 0.1 gram (Mass B).
4. Determine the mass of the empty plate to be placed under the basket to nearest 0.1 gram (Mass C).
5. Hang the basket with the mix in the oven preheated to a selected temperature. Place the catch plate beneath the wire basket. Keep the basket in the oven for 1 hour +/- 5 minutes.

6. Remove the basket and catch plate from the oven. Let cool to ambient temperature. Determine the mass of the catch plate plus the drained material to the nearest 0.1 gram (Mass D).

D. Calculation

Calculate the percentage of mixture which drained to the nearest 0.1% as follows:

Draindown (%) = [(D - C) / (B - A)] x 100

Where,

A = mass of the empty wire basket, g

D = mass of the wire basket plus sample, g

C = mass of the empty catch plate, g

D = mass of the catch plate plus drained material, g

Average the two draindown results at each temperature and report it to nearest 0.1 percent.

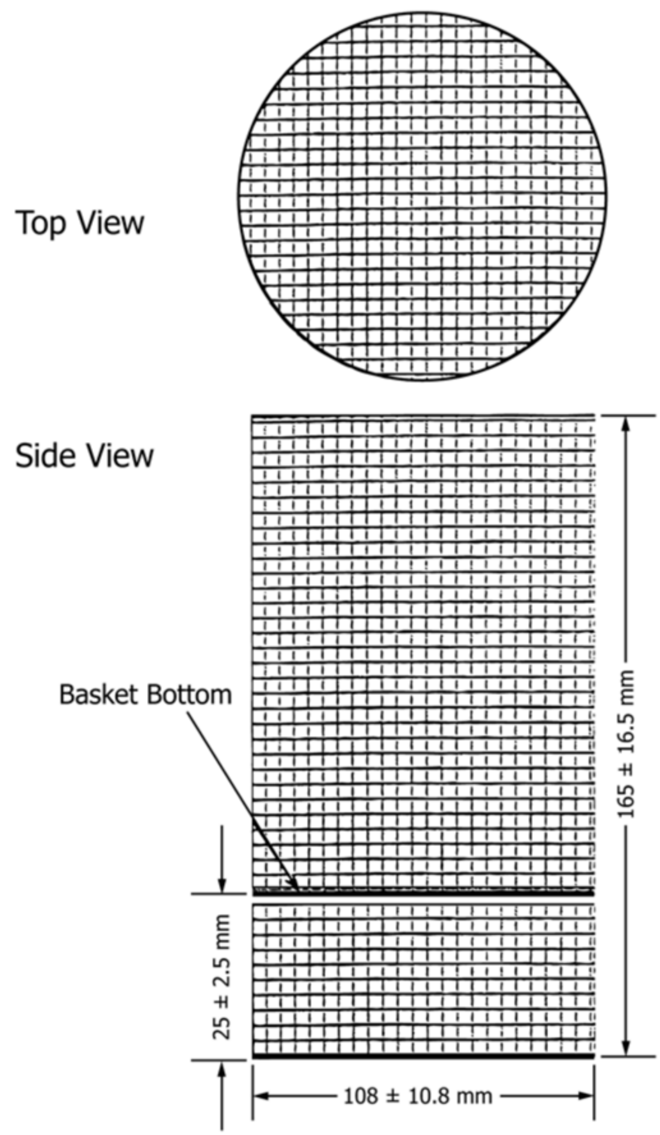

Photo 1 Wire Basket Assembly for Draindown Test

Annexure C

OUTLINE OF ASTM D 2041 FOR THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF BITUMINOUS PAVING MIXTURES

A. Scope and Summary of the Test Method

This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25ºC. The theoretical maximum specific gravity (G_{mm}) is used: (a) to calculate air voids in compacted bituminous mixtures, (b) to calculate the amount of bitumen absorbed by the aggregate, and (c) to provide target value for the compaction of paving mixtures in the field. A sample of loose paving mixture is placed in a tared vacuum vessel. Water is added to completely submerge the sample. A specified amount of vacuum is gradually applied to remove the air bubbles entrapped between asphalt mix particles. After the vacuum is released, the volume of the sample of the void less paving mixture is obtained by either immersing the vacuum container with the sample in a water bath or weighing or by filling the calibrated vacuum container level full of water and weighing in air.

B. Testing Equipment

1. Container (either a or b below)
    a. Vacuum bowls - Either a metal or plastic bowl with a diameter ranging from 180 to 260 mm and a bowl height of at least 160 mm. The bowl shall be equipped with a stiff, transparent cover fitted with a rubber gasket and a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.
    b. Vacuum flask - To be used for weighing in air only: A thick-walled volumetric glass flask with a capacity of approx. 4000 ml, fitted with a rubber stopper with a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.
2. Balance capable of being read to the nearest 0.1 gram. If weighing is to be done under water, a suitable suspension arrangement shall be provided for weighing the sample while suspended from the centre of the balance.
3. Vacuum pump, capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less. Provide a suitable trap between the pump and container to minimize water vapour entering the vacuum pump.
4. Residual pressure manometer or calibrated absolute pressure gauge with a bleed valve to adjust the vacuum level.
5. Water bath capable of maintaining a constant temperature of 25 +/- 1ºC and suitable for immersion of the suspended container.

C. Calibration of Containers

1. Bowls: Determine the mass (B) of the container immersed in water at 25+/- 1ºC. If the bowl is used for weighing in air, place the volumetric lid on the bowl while under water. Remove the water-filled bowl with the lid in place and dry prior to determining the combined mass of the bowl, lid and water. Repeat 3 times and average the 3 masses. Designate the average mass as D.
2. Flasks: Calibrate the volumetric flask by accurately determining the mass of the flask filled with water at 25+/- 1ºC. Use a glass cover plate to ensure the flask is completely full.

D. Testing Procedure

1. Separate the particles of the loose paving mixture (while it is warm) by hand so that the particles are not larger than about 6 mm and don't fracture the aggregates. Place the mix sample directly into the tarred bowl or flask. Weigh the container with the sample and designate the net mass of the sample only as A. (Note: The minimum sample size shall be 1500g for mixes with nominal maximum aggregate sizes of 12.5 mm or smaller; and shall be 2500g for mixes with nominal maximum aggregate sizes from 19 to 25 mm).
2. Add sufficient water at 25ºC to cover the sample completely. Place the cover (bowl) or stopper (flasks) on the containers.
3. Place the container with the sample and water on a mechanical agitation device or agitate manually at frequent intervals (2 to 3 minutes). Begin removing entrapped air by gradually applying vacuum and increasing the vacuum pressure until the residual manometer reads 3.7+/-0.3 kPa (27.5 +/- 2.5 mm of Hg). After achieving this level within 2 minutes, continue the vacuum and agitation for 15+/-2 minutes. Gradually release the vacuum with the bleed valve.
4. Weighing in water- Suspend the bowl (without lid) and contents in water for 10+/-1 minutes and then determine mass. Designate the mass under water of the bowl and sample as C.
5. Weighing in air
    a. Bowl – Submerge the bowl and sample slowly in the 25 +/- 1ºC water bath. Keep it there for 10 +/- 1 minute. Immerse the lid in water and slide it onto the bowl without removing water from the bowl so that no air is trapped inside the bowl. Remove the bowl with the lid in place from the water bath. Dry the bowl and lid with a dry cloth. Determine the mass of the bowl, sample and lid and designate it as E.
    b. Flask – Fill the flask slowly with water ensuring not to introduce any air into the sample. Place the flask in water bath for 10+/- 1 minute to stabilize the temperature at 25ºC without submerging the top of the flask. Completely fill the flask with water using a cover plate without entrapping air beneath the cover plate. Wipe the exterior of the flask and cover plate. Determine the mass of the flask, plate and its contents completely filled with water. Designate this mass as E.

6. Calculations: Calculate the maximum specific gravity of the sample of loose paving mixture as follows:

a. Bowls Used Under Water Determination

$$G_{mm} = A / [A - (C - B)]$$

Where,

G_{mm} = max specific gravity of the mixture

A = mass of dry sample in air, g

B = mass of bowl under water, g

C = mass of bowl and sample under water, g

b. Bowls in Air Determination

$$G_{mm} = A / [A + D - E]$$

Where,

G_{mm} = max specific gravity of the mixture

A = mass of dry sample in air, g

D = mass of lid and bowl under water at 25ºC, g

E = mass of lid, bowl and sample and water at 25ºC, g

c. Flask Determination

$$G_{mm} = A / [A + D - E]$$

Where,

G_{mm} = max specific gravity of the mixture

A = mass of dry sample in air, g

D = mass of cover plate and flask filled with water at 25ºC, g

E = mass of flask, cover plate, sample and water at 25ºC, g

Annexure D

OUTLINE OF ASTM C939 FOR MEASURING THE FLOW VALUE OF GROUT USING FLOW CONE

A. Scope and Summary of Test

This test method covers a procedure, used both in the laboratory and in the field, for determining the time of efflux of a specified volume of fluid grout through a standardized flow cone. The measured time of efflux of a specified volume of grout from a standardized flow cone is termed as Flow Value of grout, which directly relates to the Flow-ability of the grout.

B. Apparatus

1. Flow Cone, with dimensions as shown in **Fig. 1**.
2. Receiving Container of minimum 2000 mL capacity.
3. Ring Stand or other device, capable of supporting the flow cone in a vertical, steady position over the receiving container.
4. Level
5. Stop Watch, least reading of not more than 0.2 s.
6. Grout Mixer, conforming to Practice C 938.

C. Procedure

1. Moisten the inside of the flow cone by filling the cone with water and, 1 min before introducing the grout sample, allow the water to drain from the cone. Close the outlet of the discharge tube with a finger or a stopper.
2. Introduce the grout into the cone until the grout surface rises to contact the point gauge, start the stop watch, and simultaneously remove the finger or stopper. Stop the watch at the first break in the continuous flow of grout from the discharge tube.
3. The test for time of efflux shall be made within 1 min of drawing of the grout from the mixer or transmission line.

D. Result

Average time of efflux to nearest 0.2 seconds is reported as the Flow Value of grout along with time interval from completion of mixing at which the test was made.

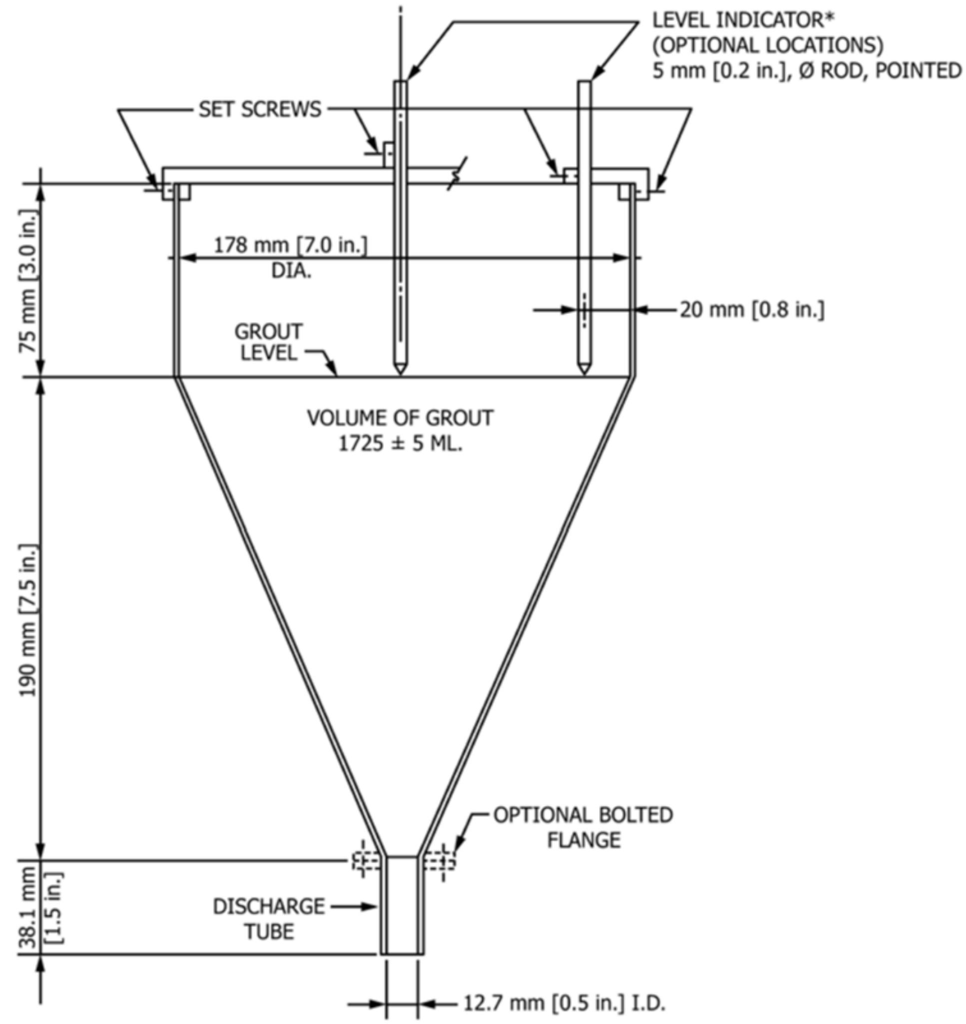

Fig. 1 Cross section of Flow Cone

Annexure E

CONSTRUCTION OF CGBM PAVEMENTS

Different stages for construction of CGBM are described below. The summarized stages of CGBM construction at field are also depicted in **Photo 2(a)** to **Photo 2(e)**.

1. A tack coat of bitumen or bitumen emulsion should be applied as per the MoRTH specifications, before the construction of High Voids Bituminous Mix. If only aggregate layer such as WMM or WMM is the base, prime coat shall be applied.
2. Aggregates and bitumen should be heated and mixed in a hot mix plant.
3. The hot High Voids Bituminous Mix is then laid with Paver and then lightly compacted with smooth wheel Static Roller. Normally 4 to 6 passes are given.
4. When the temperature of the paved high voids bituminous mix drops down to ambient temperature (say near about 50 to 60ºC), then the compacted bituminous surface is ready to be grouted.
5. The cement grout should preferably be prepared in Pan Mixer so that all ingredients gets get fully intermixed. If patented intimately mixed commercial dry powder is available in market, the pan mixer may be replaced with any simple blending equipment to produce liquid grout slurry.
6. Once the grout slurry is thoroughly mixed and has achieved the desired Flow Value, then the cementitious grout slurry can be applied on the prepared high voids bituminous surface. Application of cementitious grout can be done manually or by mechanical means over the high voids bituminous surface. Sweeping/Squeezing or other such simple techniques can be adopted for this purpose. The applied grout should be able to automatically flow into the voids of the bituminous surface under the effect of gravity alone. The edges of the bituminous layer should necessarily be covered with any suitable material like fly ash in order to restrict the outflow of the grout slurry. Grout application work should not be executed in rainy or snowy environment.
7. To improve the surface roughness, the grouted surface can be mechanically/ manually broomed to create texture on the surface.
8. Moist curing needs to be done in accordance with IRC:44. Curing by water spray can also be carried out for seven days, even with traffic in operation. If polymer based grout is used, curing for at least twenty four hours must be done.

No construction joints are required in CGBM pavements. Looking to needs of urban area the CGBM roads can be opened to light traffic within 24 hrs, provided that compressive strength of at least 3MPa for the composite CGBM layer is achieved. Cores should be taken at random places and be examined to check the full depth penetration of grout into the high voids bituminous layer. The skid resistance should be evaluated using British Pendulum Tester and the minimum skid resistance value should be 60 BPN for dry condition and 55 BPN for wet condition.

There is availability of readymade commercial products for grouting with strength of up to 90 MPa at 7-8 days. These grouts can be used in CGBM works, if they are found suitable and satisfying the strength and flowability requirements. Leachability test may also be done to check whether the chemicals contain any harmful components.

(a) Cleaning of existing Bituminous Surface

(b) Paving of Hot High Voids Bituminous Mix

(c) Compaction of Laid High Voids Bituminous Mix

(d) Spreading of Grout on High Voids Bituminous

(e) Squeezing and Spreading of Grout

(f) View of Finished CGBM Surface

Photo 2 (a) to (f) Stages of CGBM Construction at Site

REFERENCES

1. Specification on Construction and Evaluation of Resin Modified Pavement (RMP), 1996, Randy C. Alrich and Gary L. Anderton, Dept. of Army, Waterways Experiment Station, Corps of Engineers, Mississippi, USA.
2. Code of Practice for Grouted Macadam Surfacing, RSTA, ADEPT, UK, March 2017.
3. G. Bharath, Manoj Shukla, M. N. Nagabushana, Satish Chandra & Amit Shaw, “Laboratory and field evaluation of cement grouted bituminous mixes”, Journal of Road Material and Pavement Design, (2019).
4. Design & Performance Evaluation of Cement Grouted Bituminous Mix for Urban Roads. Research Report submitted by CRRI under CSIR - Fast Track Translation (FTT) Project, July 2018.
5. Manoj Shukla, M.N. Nagabhushana, Sagar Verma “Cement Treated Grouted Macadam-A New Concept of Long-Lasting Pavement” Conference on Sustainable Asphalt Pavement for Developing Countries, CRRI, March 11-12, 2016.
6. Al-Qadi, I., Gouru, H., and Weyers, R. E., Asphalt Portland Cement Concrete Composite: Laboratory Evaluation, Journal of Transportation Engineering, 120(1), 1994, pp.94-108.
7. Anderton, G. L., 2000, Engineering Properties of Resin Modified Pavement (RMP) for Mechanistic Design, Geotechnical Laboratory, U. S. Army Engineering Research and Development Center, ERDC/GL TR-00-2. <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA376263>, July 12, 2013.
8. ASTM C109, Standard Test Method for Compressive Strength Hydraulics Cement Mortar 50 mm Cube, ASTM International, West Conshohocken, 2010.
9. ASTM C 476-10, Standard Specification for Grout for Masonry, ASTM International, West Conshohocken, 2010.
10. ASTM C937-10, Standard Specification for Grout Fluidifier for Preplaced Aggregate Concrete, ASTM International, West Conshohocken, 2010.
11. CRRI, Evaluation of ACC Marg Overlaid Road Sections, report submitted by Central Road Research Institute, sponsored by Associated Cement Companies India Pvt. Ltd., Research and Consultancy Directorate, Thane, 2002.
12. IS:73, Specifications for Paving Bitumen, Bureau of Indian Standards, New Delhi, 2006.
13. IS:12269, Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi, 2008.
14. IS:9284, Method of Test for Abrasion Resistance of Concrete, Bureau of Indian Standards, New Delhi 2007.
15. IS:2386, (Part IV), Friction tester, Bureau of Indian Standards, New Delhi, 1963.
16. IRC:SP:53, "Guidelines on Use of Modified Bitumen in Road Construction", Indian Roads Congress, New Delhi.

17. Gawedziniki, M., (2008) Evaluation of Semi-Flexible (Resin Modified) Pavement 12008-1, Illinois Department of Transportation Bureau of Materials and Physical Research.

18. Specifications for Roads and Bridge Works, 2013, Fifth Revision, Ministry of Road Transport and Highways, Government of India, published by IRC.

19. Oliveira, J. R., Zoorob, S. E., Thom, N. H., and Pereira, P. A., (2007) A simple approach to the Design of Pavements incorporating Grouted Macadams, 4th International Conference Bituminous Mixtures and Pavements, Thessaloniki, Greece.

20. Oliveira, J. R., Thom, N. H., and Zoorob, S. E., (2006) Fracture and Fatigue Strength of Grouted Macadams, 10th International Conference on Asphalt Pavements, Quebec City, Canada, vol. 1, pp. 225-34.

21. Oliveira J. R., Sangiorgi C., Fattorini G., and Zoorob S. E., (2009) Investigating the fatigue performance of grouted macadams, Transport, 162(TR2), pp. 115-123.

22. Oliveira, J. R., Thom, N. H., and Zoorob, S. E., (2008) Design of Pavements Incorporating Grouted Macadams, Journal of Transportation Engineering, ASCE, 134(1), pp. 7-14.

23. Suresha, S. N., Ravi Shankar, A. U., George, V., Investigation of Porous Friction Courses and Mixes: a brief over review, Indian Highways, July 2007.

24. Wu, D. Q., The Semi-Rigid Pavement with Higher Performances for Roads and Parking Aprons, CAFEO 29, Sustainable Urbanization – Engineering Challenges and Opportunities, November 27-30, 2011, Brunei Darussalam, pp.1-7.

25. Mani anta Raju (2013), 'Evaluation of Performance of Cement Grouted Bituminous Mixes' M.Tech Thesis, IIT Kharagpur.

26. Grouted Macadam: Successful Technology for Rehabilitation of Bituminous Roads by V.V. Deshmukh, A.K. Chatterjee.

27. The Semi-Rigid Pavement with Higher Performances for Roads and Parking Aprons Dong Qing Wu, Daud, Yanli Zhang Chemilink Technologies Group, Singapore hq@chemilink.com.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)