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Laboratory Characterization of a Cement Grouted Bituminous Macadam made with Portland Slag Cement

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Abstract

Cement grouted bituminous macadam (CGBM) consists of porous asphalt skeleton with a void content of 25% to 35%, which is filled with a cementitious grout. It is usually considered as a semi-flexible layer as it incorporates both the flexibility of bituminous layer and the stiffness of the grout content. In this study, a porous asphalt skeleton with 28% voids was filled with a cement grout made with Portland slag cement (PSC). To achieve high fluidity of the grout at low water to cement ratio, a poly carboxylic ether based superplasticizer was added and the minimum dosage of superplasticizer required to fill all the voids of the porous mix under gravity was determined. Strength and stiffness properties of the CGBM were evaluated by carrying out various tests in the laboratory such as Marshall stability, indirect tensile strength, moisture susceptibility, flexural strength, rut resistance, shrinkage strain and flexural modulus. This paper presents results of all these tests and analysis of the same, which will help the engineers in rational analysis and design of pavements with CGBM layer.

Keywords: CGBM; Marshall stability; indirect tensile strength; flexural strength; flexural modulus; drying shrinkage

1. Introduction

Conventional asphalt pavements appear to be a popular choice worldwide for pavement construction because of their low initial cost as well as easy construction and maintenance procedures. However, they are unable to bear the increased stresses at the surface of heavy duty pavements as a result of which rutting occurs. Especially in tropical

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countries, high pavement temperature along with heavy truck loads and frequent start-stop conditions cause significant rutting in bituminous roads. Moreover, stripping of bitumen film may occur in presence of moisture and ultimately ingress of water into the lower layers of the pavement takes place leading to pavement deterioration. Flexible pavements also undergo rapid degradation when subjected to oil and fuel spillage. On the other hand, cement concrete pavements with their high modulus of elasticity, low porosity and high resistance against chemical attacks can easily overcome all the limitations of flexible pavements. But the excessive construction cost and long curing period are major disadvantages of rigid pavements. Moreover, they exhibit poor riding quality because of the presence of joints. Therefore as an alternative cost effective solution, CGBM has been gaining popularity worldwide over the last few decades. The presence of the cementitious slurry in CGBM provides a rut resistant, impermeable surface with protection against oil and fuel spillage. At the same time it eliminates the necessity of joint construction. In addition to these it requires much less curing period as compared to rigid pavements. Therefore such pavements allow quick commissioning of road for opening to traffic. Further its increased stiffness compared to flexible pavements makes it an ideal choice for areas subjected to high tyre pressure and heavy static load like parking aprons, airports, bus terminals and similar heavily stressed areas.

CGBM primarily consists of two parts; the porous asphalt mix and the cementitious slurry. To achieve high porosity value, the asphalt mix is produced using large proportions of uniformly graded coarse aggregates. Setyawan (2005), Oliveira et al. (2007) and Husain et al. (2010) studied the effects of varying aggregate gradation and concluded that a coarser gradation increases the porosity of the asphalt mix with easy penetration of grout. Setyawan (2005) recommended that hydraulic conductivity of the porous mix is the most important property that indicates the ease with which grout would flow through the voids. Ding et al. (2011) showed that even with the same air void percentage, a uniformly graded mix exhibited better strength than a continuous graded one because of the difference in their pore structure. Further, the binder content selected for the porous mix should be such that all aggregates get uniformly coated without the occurrence of draindown of the binder. Setyawan (2005) and Oliveira (2006) also used cellulose fibres in the bituminous mix to prevent draindown. However, Setyawan (2005) reported that addition of fibres decreased the hydraulic conductivity of the asphalt skeleton slightly. Studies showed that the main criterion for grout preparation is the fluidity that helps to occupy all the voids of the bituminous mix under the effect of gravity and without segregation of its components (Fang et al. 2016; Pei et al., 2016 etc.). Such high fluidity can be achieved by using different types of superplasticisers. Studies were also carried out on different types of grout compositions. The main component of the grout is usually ordinary Portland cement (OPC). However to improve the grout properties and make it more economical, many researchers (Hasan et al., 2002, Koting et al., 2014, Zhang et al., 2016) partly replaced OPC with fly ash, sand, resins and silica fume etc..

Properties of grouted macadam having different porosity values, bitumen content, aggregate gradation and grout compositions were studied by different researchers. However, behaviour of grouted macadam using Portland slag cement (PSC) as a component of the slurry was not in available in the literature. PSC is a mixture of OPC, ground granulated blast furnace slag (GGBS) and gypsum. GGBS is a pozzolanic material that reacts with calcium hydroxide to form compounds possessing cementitious properties. Production of PSC results in lower carbon dioxide emissions and lesser consumption of raw materials as compared to OPC. Therefore, compared to OPC, PSC would make the pavement more sustainable. Again, use of PSC results in increase of strength at a later stage and reduction of shrinkage due to the refined pore structure of the hardened grout. Hence there was a need to study the effect of Portland slag cement on properties of CGBM. Keeping this in mind, the present study was carried out with the objective of evaluating the mechanical properties of CGBM made with a grout prepared from PSC and studying the performance of this composite material against rutting.

2. Materials and methods

2.1. Materials

The raw materials used in this study are as follows:

a) Coarse and fine crushed stone aggregates from a local quarry with apparent specific gravity of 2.81 and 2.59 respectively, determined as per IS 2386- Part III (1963).
b) VG-30 grade bitumen conforming to IS 73-2006.

c) Portland slag cement (PSC), manufactured by Dalmia Bharat Cement, conforming to BIS 455-1989. As mentioned in the manufacturer's official website the addition of slag content varies from 40% to 70%.
d) Poly carboxylic ether (PCE) based superplasticiser (SP) conforming to IS 9103:1999.

2.2. Methodology

In order to carry out the present study, compacted porous asphalt skeletons with desirable voids content were prepared. This was followed by preparation of cement slurry with PSC as the major component. A PCE based high range water reducing admixture was added to achieve greater fluidity of the slurry at low water-cement ratio. Through trial and error the optimum fluidity of the slurry was achieved so that all the voids of the open graded asphalt mix get filled under the effect of gravity without causing bleeding or segregation. The engineering properties of grouted composite were obtained in terms of Marshall stability, indirect tensile strength, moisture susceptibility, drying shrinkage, flexural strength, and flexural modulus under cyclic load. Performance of the CGBM against rutting was assessed using the wheel tracking device.

3. Experimental investigations

3.1. Sample preparation

A uniform gradation with nominal aggregate size of 13mm and maximum aggregate size of 20mm was selected for the present study to prepare the porous asphalt skeleton. Fig. 1 shows the particle size distribution curve.

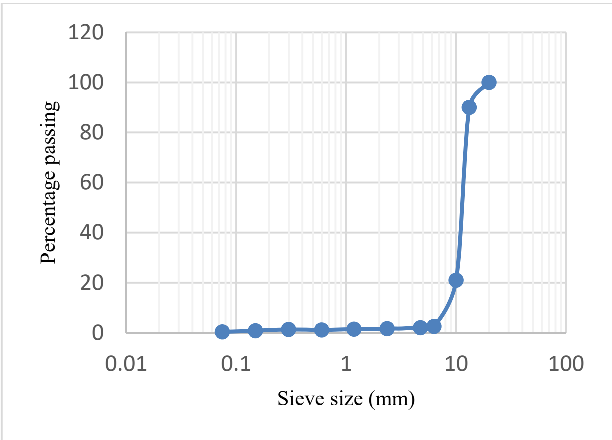

Fig. 1. Particle size distribution of the aggregates

Optimum binder content to be used for the preparation of open graded asphalt mixture was decided according to Eq. 1 as given by Anderton (2000).

$$OAC = 3.25(\alpha)\sum^{0.2} \quad (1)$$

Where, OAC = optimum asphalt content

$\alpha = 2.65/G_{sb}$;

G_{sb} = apparent specific gravity of aggregate blend

Σ = conventional specific surface area = 0.21G + 5.4S + 7.2s + 135f

G = percentage of material retained on 4.75 mm sieve

S = percentage of material passing 4.75 mm and retained on 600 µm sieve

s = percentage of material passing 600 µm sieve and retained on 75 µm sieve

f = percentage of material passing 75 µm sieve

Using Eq.1, the optimum asphalt content was estimated to be 2.88% and therefore a binder content of 3% was adopted. However, since the coarse aggregate content was high in the mix, binder draindown should be considered as an important criterion for selection of bitumen content. The draindown test was conducted as per ASTM D 6390 to check whether the amount of drain down lies within the acceptable limit of 0.3% by the weight of mixture. From the test, the binder draindown percentage was found to be 0.2%, which is within the limit. Therefore, 3% bitumen content used to prepare the open graded asphalt mix was considered appropriate.

Cylindrical compacted porous asphalt samples of 100mm diameter and 60mm height were prepared using a superpave gyratory compactor. Air voids content of the porous samples were estimated using Eq. 2.

$$VIM = \frac{G_t - G_b}{G_t} \qquad (2)$$

Where, VIM = void in mix

G_t = theoretical specific gravity of the sample

G_b = bulk density of the sample

The average air voids content of the mix was found to be 28.8% (see Table 1), which is close to the target air voids content of 30%, as suggested by Anderton (2000). It was observed that about 50 gyrations were needed to achieve the target air voids content, when about 900gms of loose mix was compacted. Slab specimens (305 mm x 305 mm x 50) mm of porous asphalt for accelerated rut testing were prepared using a roller compactor with only heat application, as vibration may damage the aggregates due to high voids content and larger proportion of coarse aggregates.

Table 1: Mean air voids content of open graded asphalt mix

Theoretical specific gravity of asphalt mix	Bulk density of compacted porous asphalt mix	Air void content of compacted porous asphalt mix	Mean air void content
	(gm/cc)	(%)	(%)
2.69	1.93	28.38	28.88
	1.9	29.5	
	1.92	28.75	

Cement slurry with a w/c ratio of 0.3 was used in the study to prepare the high strength grout. The optimum dosage of the chemical admixtures used in this study were determined through trial and error. Theoretically, to fill all the interconnected voids in a specimen the volume of slurry filling the specimen should be same as the volume of water saturating the specimen. Hence, the weight of slurry penetrating a cylindrical sample of porous asphalt mix was determined, which was converted into its equivalent volume by dividing it with the bulk density of the fresh slurry. This volume was compared to the volume of water saturating the porous bituminous samples to understand whether all the interconnected voids are getting filled or not. The results in terms of volume of cement grout penetrated are shown in Table 2.

Table 2: Optimum dosage of the Superplasticizer

Superplasticiser dosage	Average volume of water saturating HMA sample	weight of cement grout penetrated	Bulk density of fresh cement slurry	volume of cement grout penetrated
(% by wt of cement)	(cc)	(gm)	(gm/cc)	(cc)
0.6		276		138
0.5		276		138
0.4	138	276	2.01	138
0.35		276		138
0.3		246		123

From Table 2, it may be observed that a minimum of dosage 0.35% ensures that the volume of cement grout penetrating the asphalt sample becomes equal to the volume of water saturating the same sample indicating that all the interconnected voids are filled. Earlier researchers (Hassan et al., 2002, Koting et al., 2014) used higher SP dosages varying from 0.5% to 2.5% in similar studies. Therefore in this investigation, trials were started with a higher SP percentage of 0.6%. But it was found that such high percentage of SP increased the setting time undesirably. Even after 24 hrs the sample was not set properly. Accumulation of bleeding water was also observed. Therefore, the SP dosage was gradually reduced to determine the optimum value. The flowtime of the grout at optimum SP dosage was determined using Marsh cone having a 4 mm diameter orifice. The time required for 500 ml of prepared grout to flow through the Marsh Cone was found to be around 3.5 minutes. For grouting, compacted cylindrical samples were put inside moulds made of PVC pipe as shown in Fig. 2. The junction between the pipe and base plate was sealed with leak proof sealant to prevent leakage of the fresh cement paste. The sample was clamped with the mould to prevent extra grout from entering the mould. The prepared slurry was then poured on top of the samples. The grout flowed through the sample and filled all the voids under the action of gravity. Slab samples were grouted inside the moulds used for compacting them.

Fig. 2: Process of grouting

The samples were cured by wrapping them in thin polythene films to prevent the evaporation of water from the specimen. Fig. 3 shows typical CGBM sample after hardening of the grout. Beam samples were obtained by cutting the slab samples after the desired curing period.

Fig. 3: Typical CGBM sample

3.2. Mechanical characterisation

3.2.1. Determination of bulk density

After the cement grout hardened completely, the bulk density of CGBM samples was estimated as per ASTM D2726-17.

3.2.2. Marshall stability test

In this test, samples were loaded in a direction perpendicular to the cylindrical axis at a constant rate of 50.8mm/ min at 60^{o}C according to the guidelines of ASTM D 6927-15. The stability values indicate the maximum load sustained by the specimen under the specified conditions. In order to understand the strength gain in CGBM, Marshall stability tests were carried out on CGBM samples subjected to 1day, 7 days and 28 days of curing as well as porous bituminous samples.

3.2.3. Indirect tensile (IDT) strength test

Failure in bituminous layers due to fatigue cracking occurs due to development of tensile stresses at the bottom of the layer. Hence, it is important to know the tensile properties of the asphalt. IDT strength is one such parameter which indicates the maximum tensile stress that can be sustained by the material. To determine the IDT strength, cylindrical samples were loaded along the diametric plane and a compressive load at a rate of 51mm/min was applied to the vertical diametrical plane of the specimen through two opposite loading strips. The test specimen ultimately fails by splitting along the vertical diameter. The failure load is recorded and IDT strength is obtained using Eq.3.

$$St = \frac{2P}{\pi DT} \quad (3)$$

where, St = IDT strength in kPa

P = maximum load in N

D = specimen diameter in mm

t = height of specimen in mm

In this study, IDT strength was determined for un-grouted samples as well as grouted samples subjected to 1 day, 7 days and 28 days of curing. The tests were conducted according to the guidelines of ASTM D 6931-17. Fig.4 and 5 presents an IDT test specimen after testing and a picture of a broken sample respectively.

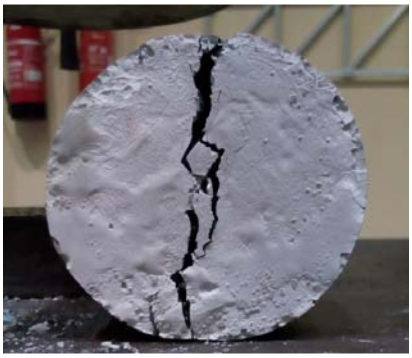

Fig. 4: IDT test on grouted sample

Fig.5: Broken specimen after IDT test

3.2.4. Moisture susceptibility of CGBM

Tensile strength ratio (TSR) was determined to evaluate the moisture susceptibility of CGBM according to the guidelines of ASTM D 4867-09. TSR is defined as the ratio of the IDT strength of conditioned samples to the IDT strength of unconditioned samples. The CGBM samples were tested after 7 days and 28 days of curing. The samples were divided into two groups; conditioned and unconditioned. The conditioned specimens were kept in water bath at 60 ºC for 24 hrs before determining their IDT strength whereas the unconditioned specimens were directly tested after the desired number of curing days.

3.2.5. Drying shrinkage of grout

Drying shrinkage is the reduction in volume of hardened cement paste due to loss of moisture with time. Due to excessive shrinkage micro cracks might develop throughout the surface which might widen, propagate throughout the depth of the layer and adversely affect the pavement performance. To prevent this, shrinkage micro-strain of the grout should be within acceptable range. In this study the test was conducted on three cement beams each of dimension 285 mm x 75 mm x 75mm as shown in Fig. 5. As soon as the cement paste became hard enough, it was demoulded and dial gauges were fixed at both the ends of the beam to monitor the change in length. During the curing process the beams were kept exposed to air. For the first 6 hours readings were taken at an interval of half an hour and then for the next one week readings were noted at an interval of 24 hours. Afterwards the readings were recorded once in a week up to a period of 90 days. The first dial gauge reading was taken as reference to determine shrinkage strain with respect to the original length of the beams i.e. 285 mm in this case.

Fig. 6: Drying shrinkage test on the grout

3.2.6. Wheel tracking test

The rut resistance of CGBM at high temperature was evaluated by conducting the wheel tracking test. For this test rectangular slab samples of dimensions 300mm x 300mm x 50mm were prepared and grouted. After 7 days of curing the test was conducted at 60ºC using the unitracker wheel tracking apparatus as per the specifications given in EN 12697-22. After conditioning the specimen at the test temperature for four hours, the grouted slab was subjected to a load of 700 kPa through a tyre of thickness 20mm. The tyre moved to and fro over the slab for 10,000 cycles at a speed of 26 cycles/min. LVDTs were used to measure the rut depth of the sample at an interval of 100 cycles.

3.2.7 Flexural strength test

Flexural strength tests were conducted to determine the modulus of rupture of CGBM. The tests were conducted on 300 mm x 50 mm x 50 mm beam samples after curing for 7 days and 28 days. These beams were cut from rectangular slabs of CGBM. Pure bending condition may be generated by choosing equidistant loading points. Therefore to facilitate this condition the set up was made similar to 4 point bending test. The test span was taken as 3 times the depth of the beam i.e. 150 mm in this case according to the specifications of ASTM C78-16. The loading points were spaced 50 mm apart in order to generate conditions of pure bending. Load was applied continuously at a rate of 0.9 MPa/min. Modulus of rupture was estimated using Eq. 4.

$$R = \frac{Pl}{bd^2} \tag{4}$$

where, R = modulus of rupture

P = maximum applied load

L = span length

b = width of specimen

d = depth of specimen

3.2.8. Determination of flexural modulus

Flexural modulus of CGBM was determined by four-point bending tests under repeated loading at a temperature of 25^0C. Beam samples of dimensions 300 mm x 50 mm x 50 mm were used in a similar experimental set up as that of flexural strength test. Cyclic load was applied at a frequency of 1 Hz without any rest period. The load level adopted in this test corresponds to 30% of its modulus of rupture, which was obtained earlier from flexural strength test.

The modulus value for each cycle is calculated as the ratio of maximum stress to maximum strain as shown in Eq.5

$$E = \frac{\sigma}{\varepsilon} \tag{5}$$

where, σ is the maximum stress in one cycle and ε is the corresponding maximum strain. The stress (σ) and strain (ε) were determined using Eq. 6 and Eq. 7 respectively.

$$\sigma = \frac{P.l}{b.d^2} \tag{6}$$

$$\varepsilon = \frac{108.\delta.d}{23.l^2 + 36.d^2.(1+\mu)} \tag{7}$$

where, P = maximum load applied per cycle

d = beam height

δ = maximum deformation at one cycle

μ = Poisson's ratio

The flexural modulus value is reported as the average of the moduli values of 100 cycles.

4. Results and discussion

4.1. Bulk density

The bulk density of CGBM was found to be 24.4 kN/m^3. It is comparable to the values of 23.6 kN/m^3 and 22.7 kN/m^3 as reported by Hasan et al. (2002) and Husain et al. (2010) respectively.

4.2. Marshall stability

Fig. 7 shows increase in Marshall Stability of CGBM with time. The un-grouted specimen resulted in a stability value of only 4.1 kN. Japanese researchers suggested that the stability value of the porous mix for CGBM should be greater than 3 kN to facilitate construction (Pei et al., 2016). The open graded mix used in the present study satisfies this criterion. The strength of the samples increased significantly after grouting. Only after one day of curing, the specimen achieved a stability value of 29.5 kN, which satisfies the requirement of 9kN stability value for high traffic volume conditions as per Ministry of Road Transport and Highways in India.

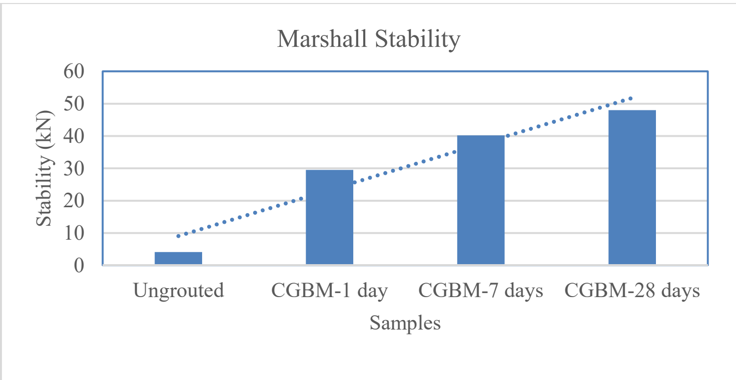

Fig.7: Marshall Stability of Grouted and Un-grouted Samples

It may also be observed that 83% strength gain occurred within 7 days of curing. The stability value of 48 kN at 28 days is quite high. This may be attributed to using 100% cementitious products for making the slurry. The bitumen content is also less than that used in conventional flexible pavements.

4.3. Indirect tensile strength

Fig. 8 shows the indirect tensile strength of the un-grouted and grouted specimens. It may be observed that grouting resulted in significant increase in the strength. After a curing period of 28 days, the strength increased from 1.51 MPa to 2.48 MPa. The 7-day strength was observed to be 2.12 MPa, which indicates about 85% of strength gain within 7 days of curing.

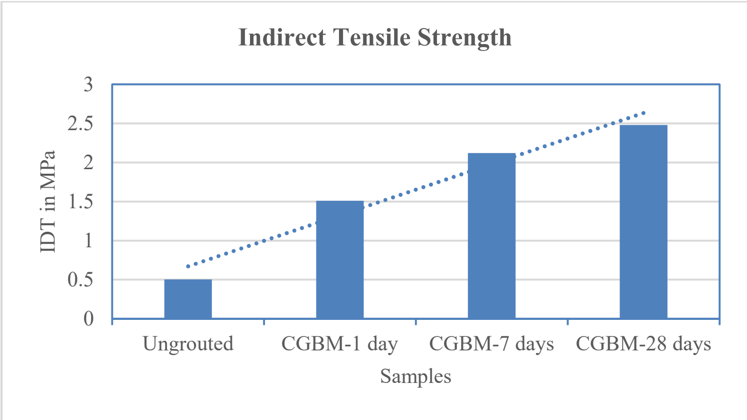

Fig.8: Indirect tensile strength of grouted and un-grouted samples

4.4. Moisture sensitivity

Fig. 9 shows the indirect IDT strength values in MPa for conditioned and unconditioned grouted samples. The tensile strength ratio for the 7 days and 28 days cured samples were obtained as 95.75% and 95.32% respectively. It may be observed that the tensile strength ratio is much higher than the minimum required value of 70% as specified by AASHTO T283 for asphalt mixes. The high moisture stability may be attributed to the presence of the cementitious compounds within the slurry. It was also observed that the number of curing days did not affect the tensile strength ratio significantly.

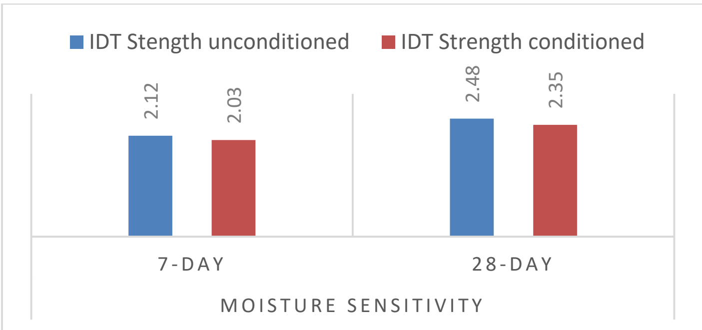

Fig. 9: Moisture sensitivity of grouted samples

4.5. Drying shrinkage of grout

Fig.10 presents variation of shrinkage micro-strain with respect to the number of days. The shrinkage value obtained after an observation period of 90 days was 1155 micro strain. This is less than the value of 1803 micro strain obtained by Hassan et al. (2002) over a period of 28 days for 250 mm x 50 mm x 50 mm beams made with OPC. This may be due to the presence of GGBS, as slag reduces shrinkage by virtue of their high fineness. Oliveira (2006) carried out the drying shrinkage tests on beams of 350 mm x 50 mm x 50 mm made of commercially available Densit grout. He reported a much higher shrinkage value of 3341 micro strain after a study of 28 days. However, Densit grout is being used successfully commercially for many years. Hence, on comparing the shrinkage values of Densit with that of grouted beams used in this study, it might be said that the obtained shrinkage values are within acceptable range.

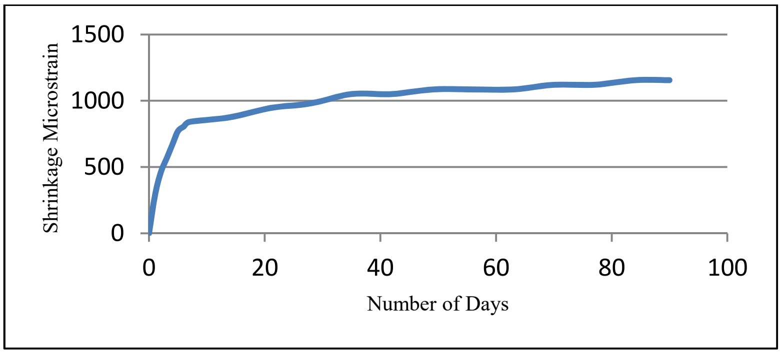

Fig. 10: Drying shrinkage of grout

4.6. Flexural strength

It was observed that the flexural strength of CGBM increased with time. During this test tensile cracking was initiated at the bottom of the beam specimen and the specimen undergoes failure due to cracks originated within the two loading points. All CGBM specimens met this failure criteria. The average modulus of rupture of CGBM after 28 days of curing was found to be 3.46 MPa.

4.7. Flexural modulus under repeated loading

Flexural modulus was determined using a four point bending test with a test span of 150 mm. A peak load of 800 N per cycle was applied, which caused an average maximum deformation of 0.013 mm per cycle. As suggested by Oliveira et al. (2006), Poisson's ratio was assumed to be 0.27. The flexural modulus value was estimated to be 8700 MPa at 25°C.

4.8. Rut resistance

In this test after subjecting the CGBM slab to 10,000 loading cycles at 60 °C the permanent deformation value was found to be only 0.03 mm. This indicates that CGBM possess high rut resistant properties. The presence of the cementitious slurry makes the mix stiffer than conventional asphalt pavements. Moreover, the aggregate gradation consists of 98% of coarse aggregates and the binder content is also less than that of conventional asphalt pavements which increases the internal friction between the aggregate which in turn helps to prevent permanent deformation. When the cement paste gets hardened it forms a stiff network surrounding the bitumen coated aggregates. The adhesion between the asphalt skeleton and the cement paste further helps to prevent rutting.

5. Conclusions

By carrying out the present investigation on CGBM with PSC, the following conclusions may be drawn:

- Portland Slag cement can be successfully used to prepare a strong CGBM.

- To achieve desired fluidity, the minimum dosage of PCE based superplasticizer was found to be 0.35% by weight of cement. The time required for 500 ml of grout with adequate fluidity to flow through 4 mm diameter orifice of the Marsh cone was found to be 3.5 minutes.
- Shrinkage of the grout made with PSC was observed to be less than for the grout made with OPC (as reported by other researchers).
- Flexural modulus of this CGBM was found to be 8700 MPa at 25°C, which is much higher than the modulus of asphalt mixes prepared with VG-30 grade bitumen (i.e. 3000 MPa).
- The wheel tracking test results proved that CGBM possesses high rut resistant properties.

References

Anderton, G. L. (2000). Engineering properties of resin modified pavement (RMP) for mechanistic design (No. ERDC/GL TR-00-2). Engineer Research and Development Center Vicksburg Ms Geotechnical Lab.

AS-1478.(1992). “Chemical Admixtures for Concrete.” Australian Standards.

ASTM C78-02. (2002). Standard Test Method for Flexural Strength of Concrete (Simple Beam with Third-Point Loading). ASTM International, West Conshohocken, United States.

ASTM D2726-17. (2017). Standard Test Method for Bulk Specific Gravity and Density of Non- Absorptive compacted Asphalt Mixtures.ASTM International, West Conshohocken, United States.

ASTM D3203-17. (2017). Standard Test Method for Percent Air Voids in compacted Asphalt Mixtures. ASTM International, West Conshohocken, United States.

ASTM D3549-17. (2017). Standard Test Method for Thickness or Height of compacted Asphalt Mixtures. ASTM International, West Conshohocken, United States.

ASTM D4867-09. (2009). Standard Test Method for Effect of Moisture on Aspahlt Concrete Paving Mixtures. ASTM International, West Conshohocken, United States.

ASTM D6931-17. (2017). Standard Test Method for Indirect Tensile Strength of Asphalt Mixtures. ASTM International, West Conshohocken, United States.

ASTM D6927-15. (2015). Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. ASTM International, West Conshohocken, United States.

Ding, Q. J., Sun, Z., Shen, F., and Huang, S. L. (2011). The Performance Analysis of Semi-Flexible Pavement by the Volume Parameter of Matrix.Advanced Materials Research Volume, 351-356.

EN 12697-22. (2003). Test Methods for Hot Mix Asphalt. European Committee for Standardization.

Fang, B., Xu, T., and Shi, S. (2016). Laboratory Study on Cement Slurry Formulation and Its Strength Mechanism for emi-Flexible Pavement. Journal of Testing and Evaluation, 44(2), 20150230.

Hassan, K. E., Setyawan, A., and Zoorob, S. E. (2002). Effect of cementitious grouts on the properties of semi-flexible bituminous pavement. Proceedings of the 4th European Symposium on Performance of Bituminous and Hydraulic Materials in Pavement, 113-120.

Hou, S., Xu, T., and Huang, K. (2015). Investigation into engineering properties and strength mechanism of grouted macadam composite materials. International Journal of Pavement Engineering, 17(10), 878–886.

Husain, N. M., Mahmud, H. B., Karim, M. R., and Hamid, A. (2010). Effects of aggregate gradations on properties of grouted Macadam composite pavement. 2nd International Conference on Chemical, Biological and Environmental Engineering Proceedings, (Icbee), 128–131.

IS 455:1989. Portland Slag Cement Specification (Fourth Revision). Bureau of Indian Standards. New Delhi, India.

IS 2386 (Part III):1963. Methods of test for Aggregates for Concrete. Bureau of Indian Standards. New Delhi, India.

IS 9103:1999. Concrete Admixtures Specification. Bureau of Indian Standards. New Delhi, India.

Koting, S., Karim, M. R., Mahmud, H. Bin, and Abdul Hamid, N. A. (2014). Mechanical properties of cement-bitumen composites for semi-flexible pavement surfacing. The Baltic Journal of Road and Bridge Engineering, 9(2), 191–199.

Oliveira, J. R. M. (2006). Grouted macadam: material characterisation for pavement design (Doctoral dissertation, University of Nottingham).

Oliveira,J.,Pais, J. and Thom, N. (2007). A study of the fatigue properties of grouted macadams. International Journal of Pavements, 6, 112-123.

Pei, J., Cai, J., Zou, D., Zhang, J., Li, R., Chen, X., & Jin, L. (2016). Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement. Construction and Building Materials, 126, 206–217. https://doi.org/10.1016/j.conbuildmat.2016.09.036

Setyawan, A. (2005). Design and Properties of Hot Mixture Porous Asphalt for Semi-Flexible Pavement Applications. Media Teknik Sipil, (36), 41–45.

Zhang, J., Cai, J., Pei, J., Li, R., and Chen, X. (2016). Formulation and performance comparison of grouting materials for semi-flexible pavement. Construction and Building Materials, 115, 582–592.