International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 8 (2015) pp. 20067-20079
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Design Of Open-Graded Frictional Course (OGFC) In Pavements With Polymer Modified Bitumen

Dr.G.Malarvizhi[1]* C.Kamaraj[2] Athira P K[3] Dr.P.K.Jain[4]Dr.S.Gangopadhyay[5]

Abstract

Pavements are subjected to constant deterioration due to the dynamic loading of the moving traffic, improper drainage of rain water and climatic variations. Excessive water content in the pavement causes early distresses like stripping of bitumen in flexible pavements, reduction of subgrade and base/sub-base strength, differential swelling in expansive subgrade soils leading to structural or functional failure of pavement. The surface texture of an asphalt pavement also plays a critical role in the prevention of hydroplaning on high-speed, multi-lane facilities. The conventional pavement mixture usually being dense graded bitumen is designed to be impermeable pavements and the drainage of these pavements is only by way of cross slopes. In India, the high frequency and high intensity of rainfall causes stagnation, splash and spray of rain water and vehicular hydroplaning. In the absence or inadequate drainage and poor pavement cross-slope, there is retention of water on the pavement surface leading to increase in skidding of vehicles and wet weather accidents. Open Graded Friction Courses (OGFC) are formulated to result in an internal structure of interconnected voids that allow water to drain through the mix.OGFC is a porous, gap- graded, predominantly single size aggregate bituminous mixture that contains a high percentage of air voids. The high air void content and the open structure of this mix promote the effective drainage of rainwater, which also minimizes hydroplaning during wet weather. This characteristic also reduces splash and spray behind vehicles and improves wet weather skid resistance. Other purported benefits of this type mix are lower pavement noise and reduced roadway glare during wet weather, which improves the night visibility of pavement markings.The properties of OGFC are found to have increased with the addition of various additives and with the use of Modified Binders like PMB (Polymer Modified Bitumen), CRMB (Crumb Rubber Modified Bitumen) etc.This study is intended to develop a mix design of OGFC for the Indian pavement conditions with different gradation and with conventional bitumen and Polymer Modified Bitumen and to suggest a rational mix design and to evaluate the performance of OGFC in the laboratory and field test.

Key words: Open Graded Friction Courses, Drain down Test, Cantabro Abrasion, Dynamic Creep, Fatigue analysis, Indirect Tensile Strength and Permeability.

1. Introduction

Open Graded Friction Course (OGFC) mixture is a special purpose mixturethat is being recommended for high-speed, high-volume roads, and expressways toimprove surface frictional resistance, minimize hydroplaning, reduce splash andspray, improved night visibility, and lower pavement noise level. This results insufficient interconnected voids to provide drainage. OGFC mixes are designed insuch a way that they form a surface with a percentage air voids 20% throughwhich water can be removed from the pavement surface. Gradation of OGFC isgiven in Figure 1.

OGFC has been used since 1950 in different parts of the United States to improve the frictional resistance of asphalt pavements. Average service life of such pavements was in the range of 6-12 years and 43% states reported more than 10 years [1]. In terms of durability and surface friction the ratings and percentage of states are given in Table 1 [2].Ohio agencies had used a specialty mix i.e Rubberized Open-Graded Friction Course (OGFC), to provide high skid resistance and superior surface drainage[3,4] with the following guidelines for the use of OGFC:

- Use where surface water drainage is a concern, a high-skid condition exists or it is desired to control sound in abnormally high-sound problem areas.
- Not to be applied over milled surfaces but to be applied over surfaces that have sound aggregate and no visual evidence of stripping.
- No special maintenance or traffic considerations

Table 1.Durability and Surface Friction Ratings

Rating	Poor	Fair	Good	Very Good	Excellent
Durability, %	11	11	37	37	4
Surface Friction, %	0	4	11	55	30

In OGFC asphalt content is slightly higher than that in the dense mixtures ofthe same maximum aggregate size so as to enhance the durability of the mixture.The macro texture of the OGFC mixture is higher than the dense mixture.Because of this increased macro texture, Roughness increases which in turnsincrease the surface friction. Drainage provided by OGFC facilitates the flow ofwater even from the surface below the highest asperities of the aggregates.OGFC improves the skid resistance at high speeds during wet weather. WithOGFC, much of the water generally is flowing below the highest points of thesurface, thus between the tyre and the pavement, there is initially less waterpresent that must be removed, or splashed, to retain pavement contact. Due tocorrection of minor surface irregularities, road smoothness is improved.OGFC depends on the aggregate interlock for its stability and is generallyplaced at a thickness of approximately 19mm. Another advantage of OGFC isthat it reduces the wheel track rutting. Rutting is minimized because there is novisco-elastic flow in the surface layer. It reduces glares at night during wetweather. This is a well-established and significant advantage of OGFC. Reflectedlight from oncoming vehicles and light from objects adjacent to the highway aredispersed by the angularity of the OGFC surface. Noise gets dissipated throughthe voids. As a result of which the riding surfaces are quieter. Considering allthese properties of OGFC and mainly the drainage properties, many countrieshave been using it for surface course [4-14].

In this study the conventional gradation using the regular aggregate gradationalong with an additional aggregate size of 16mm was used. In India manyhighway projects have used CRMB as a binder. Since the properties of modifiedbinder especially with respect to its durability, are better when compared to thatof unmodified binders, Crumb Rubber Modified Bitumen (CRMB)-55manufactured in refineries and available in market was used for the OGFC mix.Apart from this, ordinary lime was used as an additive and leather fiber used as astabilizer.

2 NEED FOR THE STUDY

In India, the high frequency and high intensity of rainfall causes stagnation,splash and spray of rain water and vehicular hydroplaning, which in turn causeskidding of vehicles. For drainage of rain water from pavement surface, crossslopes are provided. In the absence of proper drainage facilities, water retentionhappens on pavement surfaces. Even though adequate drainage is provided, theroad surface is stagnated with water during rainy season. One of the majorproblems faced by highway agencies in India is the wet weather accidents. Thereduction of such accidents due to wet weather to at least 70 percentages is themain objective of many highway agencies. Anything related to highwaysincludes the interaction of road, road users, vehicles and the environment. Theprimary solution to minimize wet weather accidents is to provide pavementsurface suitable for safe movement of vehicles during wet weather season.

OGFC is a special mix with large amount of voids content to facilitate easydrainage of water through the mix. OGFC has many other advantages likereducing the highway noise (up to 3 Decibel), avoiding hydroplaning, improvedskid resistance, better night visibility, glare reduction, improved surfacesmoothness and reduced rutting. In India there is only limited study on OGFC.Hence in this study a mix design of OGFC with CRMB-55 is carried out.

3. Laboratory Investigation

3.1 Bitumen

In this study, CRMB-55 has been used as binder. The physical properties of bitumen is given in Table 2.

Table 2. Results of bitumen tests

SL NO.	TESTS	CRMB 55
1	Penetration Test	60
2	Softening Point Test	55
3	Specific Gravity Test	1.01
4	Ductility Test	50

3.2 Aggregate

The aggregate is study is obtained by Chennai granite. The physical properties of aggregate is given in Table 3.

Table 3. Results of aggregate tests

Sl. No.	Tests	Obtained Value	Recommended Value
1	Impact Test	17.70%	Max 27%
2	Los Angeles abrasion value	27.22%	Max 35%
3	Specific Gravity Test	2.85	2.6- 2.9

3.3 Gradation

The conventional gradation for OGFC was chosen as per the MoRTH specification in which the size of aggregate varies from 12.5mm to 0.0075mm as shown in Table 4 and Figure 1. In this study, Leather Lime (LL)and Leather fiber (LF) was used as the additive as well asstabilizing agent.

Table 4. Adopted Grading

Sieve, mm	Adopted	Limits
26.5	100	100
19	95	95-100
16	65	50-80
12.5	43	35-50
9.5	16	12-20
4.75	13	10-15
2.36	8	5-10
0.075	3	2-5
Filler	3	2-4

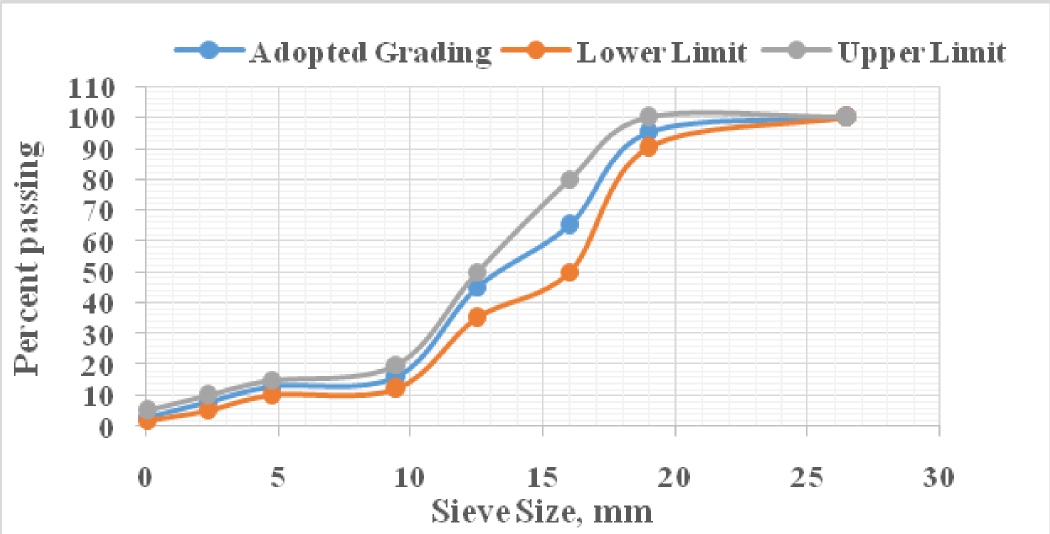

Figure 1.Gradation of OGFC

4. LABORATORY INVESTIGATION

4.1 Marshall Mix Design

The Marshall Mix design was adopted. Marshall Samples were prepared using various blows at different binder contents. The design criteria to meet the optimum binder content was adopted using (a) Air voids in the rage of 20-30 % and (b) Maximum Cantabro abrasion loss of 25%. Various permutation and combinations were made to achieve the design criteria. It can be seen from the Figure 2, the air voids at 30 blows fulfilled the design criteria.

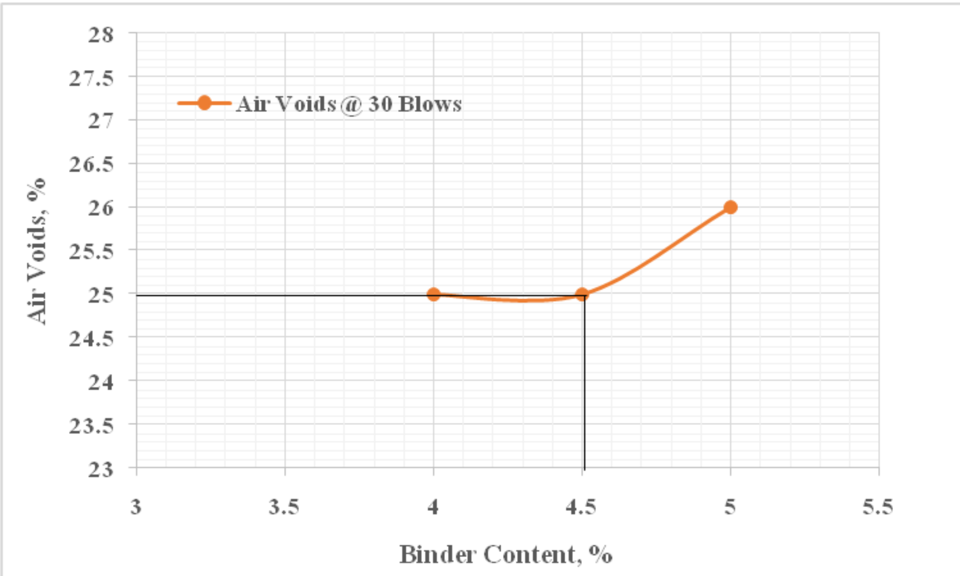

Figure 2. Binder content Versus Air Voids of OGFC Mix

3.1 Drain down Test

The drain-down test is performed to evaluate the draining of bitumen fromthe loose bituminous mix samples under increased temperature. The test wasperformed in Lab as suggested by MORTH (2001). The loose un-compacted mix wastaken and transferred to the drainage basket and kept in a pre-heated ovenmaintained at 160°C for three hours. Pre weighed plate was kept below the drainagebasket to collect the drained out binder drippings. From the drain down test the binder drainage had been calculated from theequation:

$$d= (W2 – W1) / W \quad [equ.1]$$

Where, W1 = initial mass of the plate; W2 = final mass of the plate and drained binder; W = Total weight of the mix

The test results of drain down value is given as Figure 3.

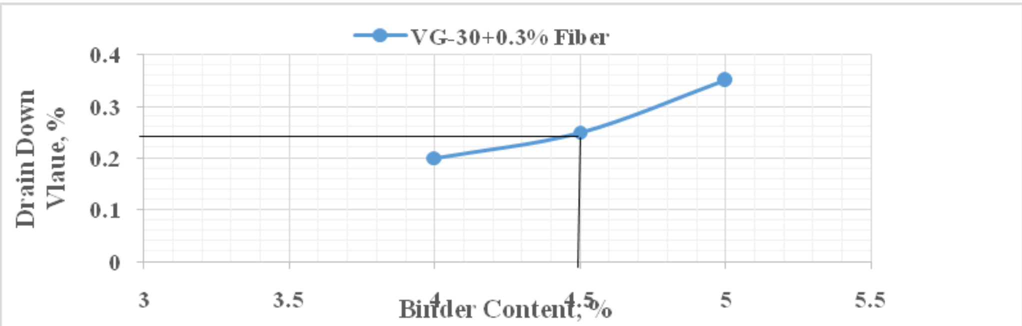

Figure 3. Binder content Versus Drain down value of OGFC Mix

3.3 Cantabro Abrasion

This test was done to evaluate the abrasion loss of the mix. Apparatus usedwas Los Angeles abrasion machine. Marshall Sample of 10cm diameter and height6cm was placed in the Los Angeles apparatus without steel charges. The cylinderwas made to rotate 300 revolutions at 30-33 rpm. The weight of the sample beforeand after the test was noted down. The loss due to abrasion was calculated using the equation:

$$L = (W1 – W2) / W1 \ldots \quad [equ. 2]$$

Where, W1 = Initial weight; W2 = Final weight

Abrasion loss obtained at 30 blows is illustrated as Figure 4. The allowable value is 25% if fibre is not used and 30% if fibre is used. Since leather fiber is used, the value is within the range.

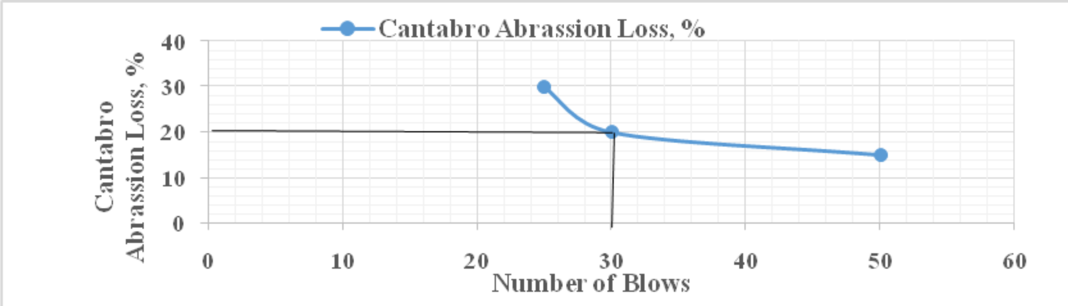

Figure 4. Number of Blows versus Cantabro Abrasion Loss

4 PERFORMANCE EVALUATION TESTS

The performance of the mix with respect to its strength and stability as a pavement layer subjected to dynamic loading were evaluated by the following tests:

- Dynamic Creep Test
- Fatigue Beam Test
- Indirect Tensile Strength(ITS) Test
- Permeability Test

3.1 Dynamic Creep Test

Dynamic creep test was conducted by applying a dynamic load using creepapparatus (Figure .5) to a specimen and then measuring the permanentdeformation and the total deformation of the specimen after unloading. The test isused to determine the permanent deformation of the asphalt mixtures. he observedpermanent deformation of the asphalt mixtures was correlated with the ruttingpotential. The creep deformation of a cylindrical specimen under a dynamic loadwas measured as a function of time, and the sample dimensions and test conditionsare standardized.Test was done on a cylindrical sample of diameter 10cm and height 6+/- 2 cm.A cylindrical iron surcharge having the same diameter as that of the sample andlesser height was kept on the sample. Two LVDTs (Linear Variable DifferentialTransducers) were connected to the surcharge. Load was applied through a roundended loading edge. Stress was applied at the rate of 69 KPa. Total 10000 cycleswere performed.

After initial elastic response, the creep portion of the response curveeventually became linear, giving constant slope. After the release of the appliedstress the elastic deformation started getting recovered, followed by the timedependent recoverable elastic deformations. The residual strain that existed aftercomplete elastic recovery was the non-recoverable permanent deformation.Permanent deformation risk was greater under heavy loads and high temperature.So the following test parameters were selected: the uniaxial load was 100 KPa (0.1MPa), the temperatures were 25°C , 35°C and 45°C, and totally 10000 cycles wereperformed.

Figure 5. Dynamic creep test

Dynamic Creep Test result for the sample at 25^0C is given in Table 4 and Figure 6 (a&b) shows the software output for the test.

The graph of Strain (%) against numbers of cycles is shown in figure 4.2. The graph is elastic in the beginning and after a point it is constant. The total permanent strain is 1.473%.

Table 4.Dynamic creep test result

Temperature	**25^0C**
Cyclic stress (kPa)	69
Seating stress (kPa)	11
Load cycle repeat time (ms)	1000
Confining stress (kPa)	100
Termination cycle count	10000
Termination strain (%)	5
Total permanent strain	1.473
Min strain rate (µ€/cycle)	0.06
Strain @ min strain rate (%)	1.464

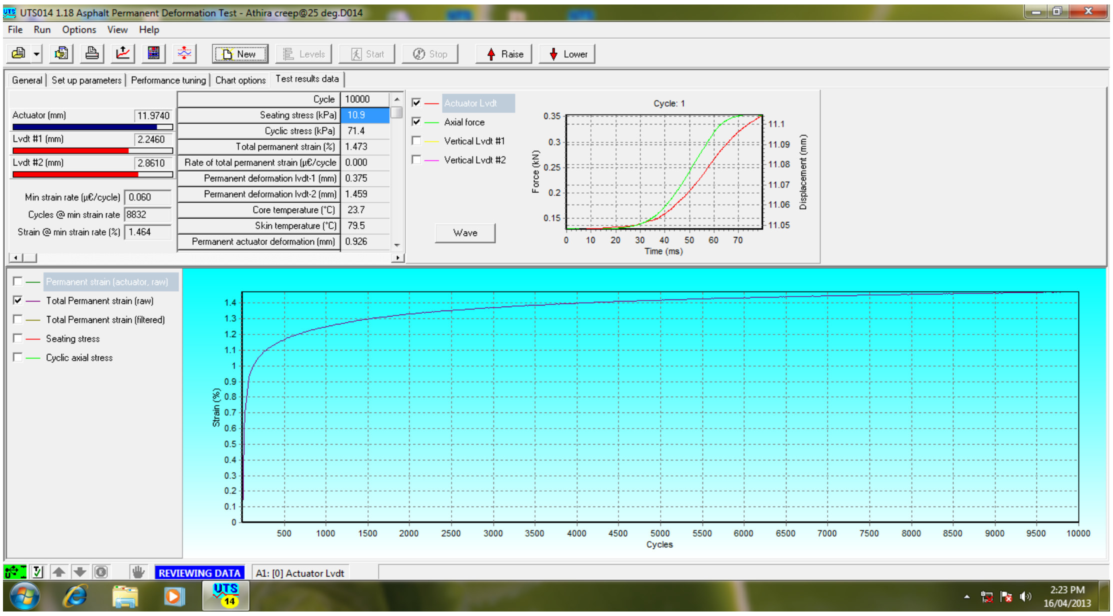

Figure. 4 (a).Software output of Dynamic Creep @ 25^{0}C

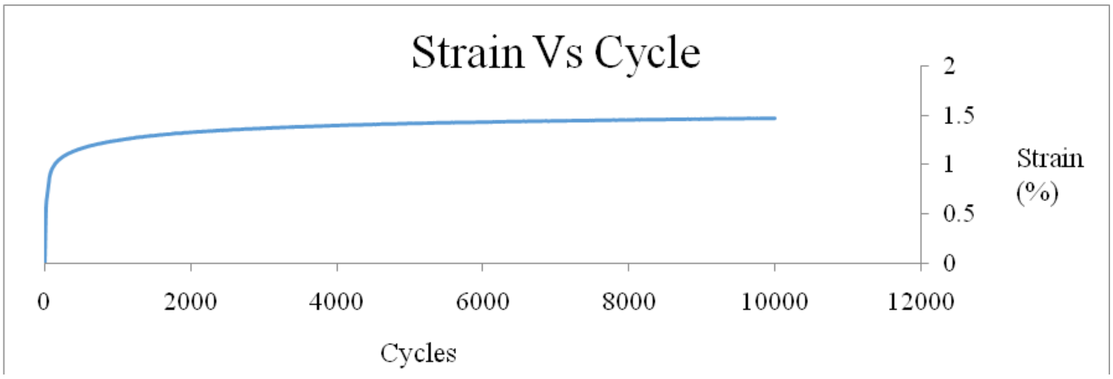

Figure 4(b). Strain versusNumber of Cycles

3.2 Fatigue Beam Test

Wheel loads caused by heavy traffic on the top of the asphalt pavementstructure cause deflection of the pavement and induce stresses and strains at thebottom of the asphalt layer. These repetitive loadings will increase the deflectionsand decrease the pavement stiffness which will conduct increase in stresses andstrains. After a certain number of load repetitions fine cracks will be initiated in thebottom of the asphalt layer. These cracks propagate and penetrate through the wholeasphalt layer until they are visible on the surface. This deterioration process iscalled fatigue. The fatigue criteria are applied in mechanistic design of asphaltpavement structures. The repeated loadings can be simulated by laboratory tests.

The test sample was loaded repetitively until failure occurs. Tests are usuallycontrolled either with controlled stress or controlled strain mode of loading.

Thesize of the fatigue beam sample was 400x50x65 mm. The machine consisted of four point bend fixture. The temperature at whichtest was conducted was 20°C. The machine operates as an electro hydraulicfeedback closed-loop servo system where load was applied by a servo-controlledhydraulic actuator mounted on the table of a loading frame. Load on the beam specimens and displacement of the actuator were sensedby a load cell situated on the crosshead and an internal LVDT running on theactuator. For the dynamic tests an external LVDT was mounted to measure centralbeam specimen deflections.

Fatigue tests were performed at a temperature of 200C using a sinusoidalload waveform at a frequency of 4 Hz, without rest periods. These tests were carriedout using a combined load and displacement mode of control to ensure that fatiguecrack damage could be observed and monitored. Load control without reversal leadto excessive permanent deformation and rapid crack growth, while displacementcontrol inhibited the development of complete fracture. The combined controlinvolved a fatigue cycle in which the beam was loaded from its datum conditions toa target load and displaced back to its zero displacement position. Specimenarrangement in a Fatigue Test apparatus is shown in Figure.5.

Figure 5. Fatigue Test Apparatus

The regression equation obtained from the test is as follows,$Y= -2E\text{-}11x^3 + 5E\text{-}07x^2 - 0.004x + 224.4$ $R^2 = 0.516$

As the R^2 value obtained is 0.516 the correlation between numbers of cycle, flexural stiffness and phase angle is negligible. The initial flexural stiffness value was 270 MPa.The software output for the fatigue beam at 25^0C is shown in figure 6 (a&b).

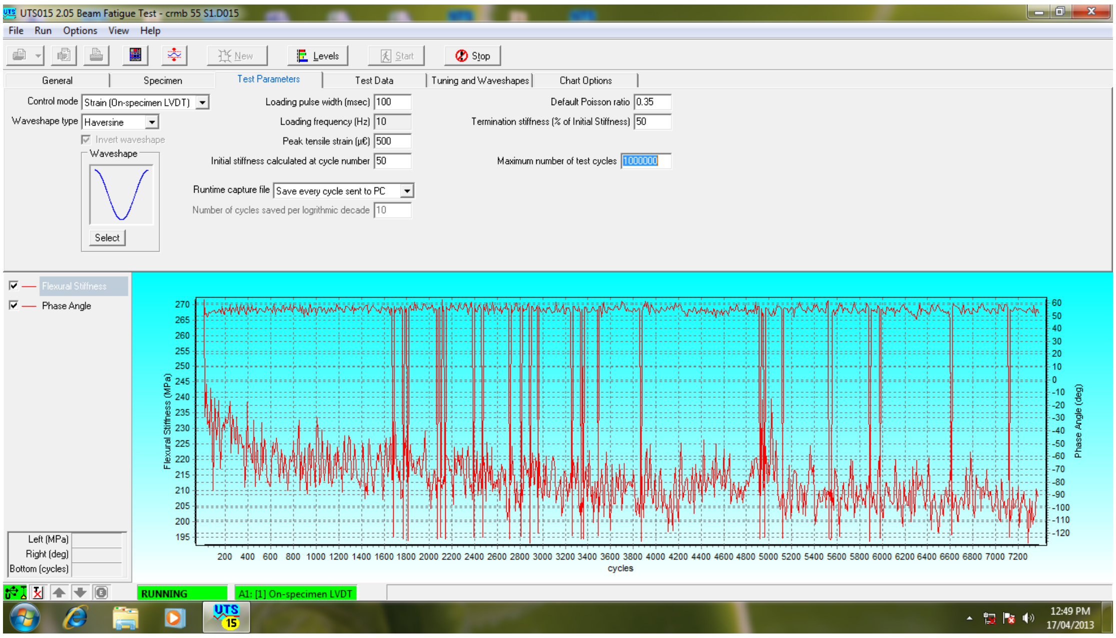

Figure 6(a). Software output of Fatigue @ 20^{0}C

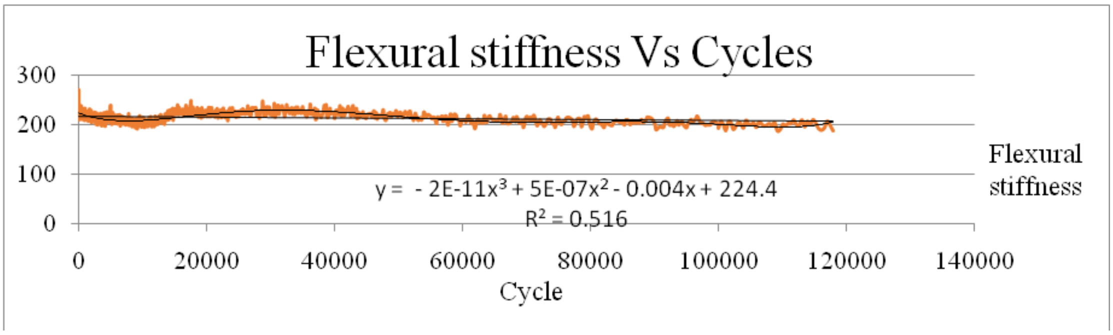

Figure 6(b) Flexural stiffness versus Number Cycles

3.3 Indirect Tensile Strength Test (ITS)

Indirect tensile strength test is useful to evaluate resistance of compactedbituminous mixture to cracking as well as sensitivity of mixture to moisturedamage. To identify whether the coating of bitumen binder and aggregate issusceptible to moisture damage, Tensile Strength Ratio (TSR) is determinedaccording to AASHTO T 283.TSR is the ratio of indirect tensile strength of conditioned specimens to theindirect tensile strength of unconditioned specimens. The specimens used in this testwere of same dimensions of Marshall Samples. To condition the specimens, a set ofthree specimens were placed in a water bth maintained at 60°C for 24 hours andthen placed in an environmental chamber maintained at 250C for two hours.Unconditioned specimens were kept at 250C for 2 hours prior to the test. Theseconditioned specimens were tested for their tensile strength. The apparatus is shownin Figure 3.

The failure load was recorded and the indirect tensile strength, St wascalculated using following equation:

$$St = 2P / \pi DT \quad \ldots \quad \text{equ. [3]}$$

Where, P is the load (kg);D is the diameter in cm of the specimen; T is thethickness of the specimen in cm.

The TSR of specimen was computed by following formulaTSR = ((ITS conditionedSpecimen)/(ITSun conditioned)) x 100 …. equ. [4]

The ITS value for OGFC with 4.5% binder was obtained as 80%.

3.4 Permeability Test

Permeability test was done for the specimen of diameter 10cm and height6+/-2 cm. The side surface of the specimen was covered with wax to prevent theseepage through sides. A collar was placed on the specimen to hold water. Agraduated scale was placed to note the drop in the level of water. Water was thenallowed to flow through the specimen, and the average time taken for a drop inwater level from 70mm to 30mm was recorded. The coefficient of permeability (K)was calculated using the following equation

$$K = 208.49 (L/t_m) \log10 ((L+70)/(L+30)) \quad \text{equ…[5]}$$

Where L is the mean length of the specimen in meters; t_m is the average timein seconds taken for a drop in water level from 70 mm to 30 mm.

The K value for OGFC with 4.5% binder was obtained as 202 m/day.

SUMMARY AND CONCLUSIONS

- OGFC mix design was done with a modification to conventional gradation.
- Aggregates of sizes 19mm, 16mm, 12.5mm, 9.5mm, 4.75mm, 2.36mm and 75□ were used.
- CRMB 55 was used as the binder at 4.5% by weight of the total mix.
- Ordinary lime as additive and LF as stabilising agent were used at 1.5% and 05% by total weight of the mix, respectively.
- Optimum mix density of 2g/cc and air voids percentage > 20% was achieved at 30 numbers of blows.
- Drain down Test was performed for the samples and the average drain down value was obtained as 0.23% at 4.5% binder content.
- Cantabro Abrasion Test was performed and the average loss due to abrasion was obtained as 18% at 30 numbers of blows.
- Dynamic Creep Test was performed at 25°C and the Total Permanent Strain after 10,000 cycles of loading was obtained as 1.473%.
- R^2 value for Fatigue Beam Test at 20°C was obtained as 0.516 and initial flexural stiffness as 270MPa after 1,18,000 cycles of loading.

- ITS value for the mix was obtained as 76.21%
- Permeability test was conducted and the coefficient of permeability was obtained as 202.73 m/day.

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