Open Graded Friction Course by Marshall Mix Design Approach and Its Performance Studies

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Abstract— OGFC's used by several State Department of Transportation since 1950. Gap -graded aggregates and low percentage of fines is used in OGFC's Mix. Some of the Department of Transportation reports good in performance and many other states reports is unacceptable performance, using polymer modified binder reporting good performance of OGFC and also coarser aggregate gradation reporting unsatisfactory performance. The purpose of using the OGFC's to improve friction, preventing hydroplaning effect, to reduce the splash and spray and to reduce the pavement noise levels and improving night visibility. This work is on develop OGFC mix design procedure and evaluation of its performance.

Key words: OGFC, Performance

I. Introduction

Due to the frequency of high intensity of short duration rainfall in India, the vehicular hydroplaning is serious concern in the interstate facilities. Along with pavement cross slope, rutting and the surface texture of pavement plays a critical role in the improving hydroplaning on high speed and the minimizing problem. A number of states are referred to have utilized tradational Open graded friction course in order to maximize the pavement macrotexture, as it reduces splash, spray and minimizes hydroplaning potential

The OGFC and Porous asphalt are similar in design and construction. The OGFC is completely used as a wearing course. The common HMA mixtures are dense graded mixtures designed to be impermeable to water. By contrast, OGFC is formulated to result in stone on stone interconnected voids that allow water to drain through mix

The uses of open graded friction course to remove the surface water and used to reduce hydroplaning, splash and spray from tires. This course should benefit fewer glares from headlights and more visible during rainy nights. Open graded friction course are also the quietest pavement surface. The voids in mix attenuate noise like no other surface. OGFC is also used solely to reduce traffic noise particularly in sensitive areas.

II. Scope and Objectives

Purpose of the dissertation work is summarized fallowing objectives:

1) Review literature on usage, specification, aggregate gradation and mix design procedure for open graded friction course (OGFC) from past
2) To evaluate several OGFC specimens in terms of Marshall Stability hence evaluate for optimum binder content.
3) To evaluate the performance of OGFC specimens in terms Permeability, Moisture Susceptibility and Effect of temperature variation on Marshall Stability.
4) Finally based on the experimental results; to establish relationships between various parameters of OGFC's

III. Literature Review

A. Georgia OGFC Mixture Design:

The Open graded friction course mixture are gap graded its should consisting a high percentage of single sized coarse aggregate. The Open graded Friction Course having high asphalt cement content, a thick asphalt cement film, low percentage of material passing through 0.075mm sieve, high volume of air voids about 10 to 20 percent and in place thickness up to 31.75mm.

1) Material Composition:

The Job Mix Formula (JMF) consists of coarse aggregate, typically granite, with small quantity of fines. The binder is used very stiff such as PG76-22 made with polymer.

Sieve size in mm	Percentage Passing of 12.5mm down size aggregate
19	100
12.5	80-100
9.5	35-60
4.75	10-25
2.36	5-10
0.075	1-4

Table 3.1: Georgia Pem Gradation Band

B. British Design:

The mix design approach followed in Britain is summarized as follows

1) The aggregate is considering two different nominal sizes, namely 10mm and 20mm. the gradation

Sieve Size(mm)	Percentage of passing	
	20mm	10mm
28	100	-
20	95-100	-
14	55-80	-
10	-	90-100
6.3	20-30	40-55
3.35	8-14	22-30
0.075	2-7	2-7

Table 2: British gradation for OGFC/Porous asphalt

2) The aggregates is tested for following specifications
   - Los angeles value of aggregate should be less than 12%.
   - Maximum flakiness index is 25 percent.
3) The minimum asphalt content is 4.5 percent modifier used is SBS.
4) The minimum air voids is 20 percent.
5) Specimens are compacted using 50 Marshall blows.
6) v. The durability is influenced by the selection of binder grade and minimum asphalt content.

C. Spanish Design:

The mix design approach followed in Spain is summarized following

1) The two gradations of porous asphalt used in Spain. Both are 12.5mm nominal maximum size.

2) P12 has larger gap gradation between 12.5mm and 10mm.
3) P12 has larger gap gradation between the 10mm and 5mm.

The gradation is shown in table 3.3

Sieve Size (mm)	Percentage passing	
	PA 12	PA 12
20	100	100
12.5	70-100	75-100
10	50-80	60-90
5	15-30	32-50
2.5	10-22	10-18
0.63	6-13	6-12
0.075	3-6	3-6

Table 3: Spanish gradation for porous asphalt

1) The aggregate should be tested for the following specifications
2) Los angel value of aggregate is less than 20 percent. The maximum flakiness index of 25 percent.
3) The modified asphalt binder used in high volume traffic and hot climate is 60/70 penetration asphalt is used. For low volume roads and cold climate conditions 80/100 penetration asphalt is used.
4) The maximum binder content is based on air voids of compacted specimen. Typical asphalt content is 4.5 percent.
5) The Specimens are compacted using 50 Marshall Blows.
6) The minimum air voids should be considered 20 percent.

D. Italian Design:

The mix design approach followed in Italy as followed

The single nominal maximum size of 16mm crushed aggregate gradation is used as fallowing gradation shown in table 3.4.

1) The maximum los angel abrasion value is 16 percent for aggregates.
2) The modified binder with 6 to 8% Modifier a added to 80/100 penetration asphalt.
3) Mix temperature is 190 to 200'c.
4) The minimum asphalt content is 4.5%. and based on cantabro test the maximum weight loss of 25% is allowed.
5) The allowable asphalt content range is from 4 to 6%.
6) It should targeted air voids is 18-23%.

Sieve Size (mm)	Percentage passing of 16mm down size aggregate
20	100
14	75-100
10	15-40
5	5-20
2	0-12
0.075	0-7

Table 3.4: Italian Gradation for Porous Asphalting

E. Performance Evaluation:

Based on the optimum binder content and air voids, performance tests carried out for open graded friction course specimens.

1) Modified Lottman Test:

Modified Lottman test indicate that the Tensile Strength Ratio (TSR) value for G 64-28 was determined to be 65 percent and Tensile Strength Ratio (TSR) value for PG70-28 was determined to be 84.6 percent. Based on requirement of TSR value for porous asphalt greater than 80%, PG 70-28 binder is require for porous asphalt 84.6% of its tensile strength under freeze-thaw conditions.

2) Permeability:

The permeability test is conducted on open graded friction course sample using Gilson Asphalt Field parameter. The test is conducted on falling head permeability method. The test was conducted to be used in laboratory setting.

Type of Mix	Avg Coefficient of Permeability in cm/s
PG 64-28	0.99
PG 70-28	1.00

Table 3.5: Permeability Test Results for porous asphalt

F. Design of New Generation Open Graded Friction Course (NCAT Report 99-03):

Following observation is obtained from the various results of laboratory tests:-

1) The gradation should not be exceeding 20 percent passing through 4.75mm sieve is required to achieve adequate permeability for open graded friction course.
2) Mix should be prepare using only 15% aggregate passing through 4.75mm sieve are prone to significant drain down of the binder. Therefore suitable stabilizer is used to prevent excessive drain down such as fibre.
3) Abrasion loss of open graded friction course mixes resulting from aging can be reduced with addition of the modifiers. The modified binder has less Abrasion loss compare to unmodified binder. Using a Polymer modified binder and fibre increase the durability of OGFC.
4) In this study the binder used, the rut depth is measured with asphalt pavement analyser it is not vary wide range. However range of rut value is obtained. In this observed that mixes with modified binders had shown a less rut compare to unmodified binder.
5) Tensile strength ratio is obtained from Moisture susceptibility test, hence the value of TSR is more in unmodified binder mix compare to the modified binder mix. all of the modifiers binders except slag wool produce mixes which had tensile strength ratio value in excess of 80%. Polymer modified binder and fibre should be most effective in cold climate with freeze/ thaw cycle.

1) Tentative Mix Design Guidelines

Based on experimental results the following Tentative mix design system is recommended for the New Generation OGFC mixes.

Step-i: Materials selection

The materials needed for open graded friction course include aggregate, asphalt binder and Additives. Additives included asphalt binder such as Polymers and fibres. The binder selection is based on environment, traffic and expected functional performance of OGFC. The high stiffness binders such as PG-22 Polymers are recommended for hot and cold climate with freeze-thaw cycle. The High to Medium volume traffic condition and mixes with higher air voids about 22%. The addition of fibres in mixes reduces drain down. And the medium to low volume traffic conditions use of Polymer modified binders or fibres may be sufficient.

Step-ii: Selection design gradation

The based on the study and recent experiences in Georgia as following Gradation band is recommended.

Sieve size mm	Percentage passing (%)
19	100
12.5	85-100
9.5	55-75
4.75	10-25
2.36	5-10
0.075	2-4

Table 3.6: Master Gradation Band

2) Evaluate For Moisture Susceptibility:

Mix design evaluate the Moisture Susceptibility using the Modified Lottman method (AASHTO T283) with five freezing and thaw cycle in lieu of one cycle. The tensile strength ratio is at least 80%.

IV. Methodology

The methodology adopted for this dissertation study titled "Open Graded Friction Course by Marshall Mix Design Approach and its Performance Studies" includes selection of aggregate from locality, tests on its suitability and achieving desired gradation as per NCAT gradation criteria for open graded friction course (OGFC). Marshall specimen with 75 blows on both sides were subjected to air voids confirmation tests for varying 0.5% binder contents and hence obtain a optimum binder content. Using optimum binder contents, specimen prepared are checked for Marshall Stability, Permeability, Moisture susceptibility and effect of temperature variation on Marshall Stability tests to evaluate the performance of OGFC. Then finally relationships are established between the open graded friction course (OGFC).

A. Aggregate Properties:

Sl.no	Desirable Properties of Aggregate	Experiment name	Results	Permissible value specified by IRC(for bituminous surface course
1	Specific gravity	Specific gravity	2.67	2.5to 3.2
2	Toughness	Aggregate impact test	22.28%	< 30%
3	Strength	Aggregate crushing test	19.21%	<30%
4	Shape of aggregate	Flakiness index	11.50%	<15% and should not exceed 25%
5		Elongation index	9.22%	<15%
6		Angularity number	6.80	0 to 11
7	Hardness	Abrasion loss	31.32%	< 40%
8	Water Absorption	Water absorption	0.68%	Should not exceed 1%

Table 4.1: Physical characteristic of road Aggregates Test results

B. Bitumen:

Bitumen Viscosity grade-40 (VG-40) was used as the binder for the mix design of OGFC throughout the dissertation works. On the Basis of atmospheric temperature of the locality the grade of bitumen was chosen. The binder was tested for various characteristics as per Bureau of Indian Standards (BIS). The test results are shown in table 4.2 and for test certificate from the manufacturer –Gulf Asphalt Private Limited

Sl no	Characteristics	Results	Permissible values	Method of Test
1	Penetration, mm	47	40 to 60	IS: 1203-2013
2	Softening Point, °C	52	50	IS:1203-2013
3	Specific Gravity	0.989	0.97 to 1.02	IS: 1203-2013

Table 4.2: Characteristic of VG-40 Test Results

C. Achieving the Desired Gradation:

Sieve Size (mm)	Percentage of Aggregate Fraction (Obtained by Rothfutch Methods)				Percentage Passing for OGFC Mix as per NCAT
	20 mm	12.5 mm	Quarry dust	Combined	
	14%	76%	10%		
19	14	76	10	100	100
12.5	4.01	76	10	90.01	85-100
9.5	1.54	55.39	10	66.93	55-75
4.75	0.075	1.07	9.79	10.94	10-25
2.36	0.037	0.368	8.78	9.19	5-10
0.075	0.014	0.19	0.91	1.11	2-4

Table 4.3: Sieve Analysis Results of Aggregate after Proportioning by Rothfutch's Method

D. Determination of Air Voids and Optimum Binder Content:

Using the selected design gradation, OGFC mixes were prepared at eight binder contents in increments of 0.5%. The mixes were compacted using 75 blows of the Marshall rammer .The Marshall Stability test is conducted on compacted cylindrical specimen of open graded friction course mix of diameter 101.6mm and thickness 63.5mm. The load is applied perpendicular to the axis of the cylindrical specimen at constant rate of deformation of 51mm/min at temperature of 25°C. determined for Marshall Stability Value, Flow Value, Unit Weight, Percent void in total mix (Vv), Percent voids filled with bitumen (VFB).

Optimum binder content for the mix design is selected by using following three criteria\

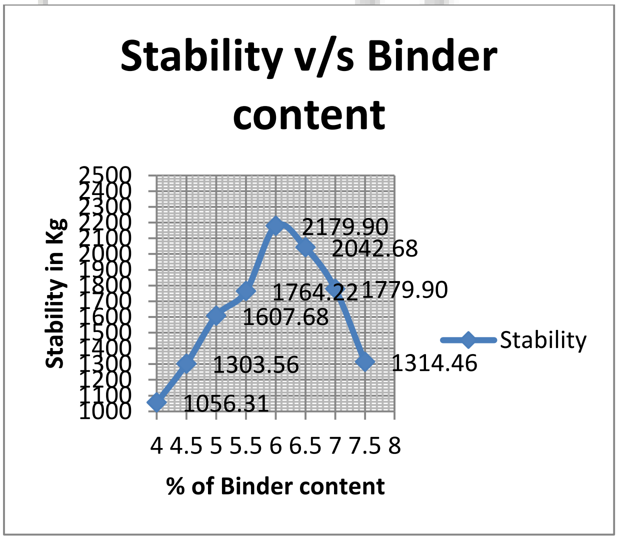
1) Bitumen content corresponding to maximum stability.
2) Bitumen content corresponding to maximum unit weight.
3) Bitumen content corresponding to the median of the designed limits of percent air voids in total mix.

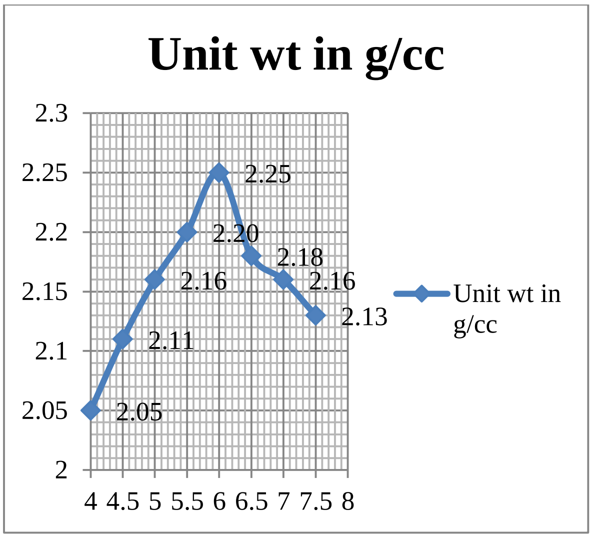
Specimen	Bitumen content(%)	Weight of specimen(gms)		Dia (mm)	thickness mm)	Volume(mm)	Unit wt (g/cc)	Avg Unit weight(g/cc)	Stability (div)	Correction factor	Stability in kgs	Avg stability (kgs)	Flow value (mm)	Avg flow(mm)
		In air	In water											
1	4	1196.30	460.00	100	75	589.29	2.03		410.00	0.80	1041.07		2.20	
2	4	1203.00	460.00	100	75	589.29	2.04	2.05	420.00	0.80	1066.46	1056.31	2.00	2.10
3	4	1218.20	461.00	100	75	589.29	2.07		418.00	0.80	1061.39		2.10	
4	4.5	1236.50	472.00	100	70	550.00	2.25		490.00	0.89	1384.18		2.50	
5	4.5	1205.30	477.00	100	75	589.29	2.05	2.11	500.00	0.80	1269.60	13303.56	2.30	2.33
6	4.5	1195.90	486.00	100	75	589.29	2.03		495.00	0.80	1256.90		2.20	
7	5	1247.50	495.00	100	70	550.00	2.27		605.00	0.89	1709.04		3.10	
8	5	1150.40	490.00	100	70	550.00	2.09	2.16	590.00	0.89	1666.67	1607.68	3.20	3.13
9	5	1246.50	480.00	100	75	589.29	2.12		570.00	0.80	1447.34		3.10	
10	5.5	1240.00	512.00	100	70	550.00	2.25		650.00	0.89	1836.16		4.10	
11	5.5	1246.20	510.00	100	72	565.71	2.20	2.20	610.00	0.86	1665.08	1764.22	4.20	4.07
12	5.5	1223.00	500.00	100	73	573.57	2.13		680.00	0.83	1791.41		3.90	
13	6	1221.90	510.00	100	68	534.29	2.29		780.00	0.93	2302.42		4.30	
14	6	1215.90	515.00	100	70	550.00	2.21	2.25	760.00	0.89	2146.89	2179.90	4.50	4.33
15	6	1235.00	508.00	100	70	550.00	2.25		740.00	0.89	2090.40		4.20	
16	6.5	1229.60	525.00	100	72	565.71	2.17		775.00	0.86	2115.47		4.60	
17	6.5	1232.80	530.00	100	72	565.71	2.18	2.18	735.00	0.86	2006.29	2042.68	4.80	4.70
18	6.5	1241.40	530.00	100	72	565.71	2.19		735.00	0.86	2006.29		4.70	
19	7	1239.30	534.00	100	70	550.00	2.25		645.00	0.89	1822.03		4.80	
20	7	1257.30	540.00	100	75	589.29	2.13	2.16	650.00	0.80	1650.48	1720.36	5.00	5.03
21	7	1226.50	540.00	100	75	589.29	2.08		665.00	0.80	1688.57		5.30	
22	7.5	1267.90	552.00	100	75	589.29	2.15		510.00	0.80	1294.99		530	
23	7.5	1251.20	550.00	100	75	589.29	2.12	2.13	528.00	0.80	1340.70	1314.46	5.20	5.13
24	7.5	1250.80	552.00	100	75	589.29	2.12		515.00	0.80	1307.09		4.90	

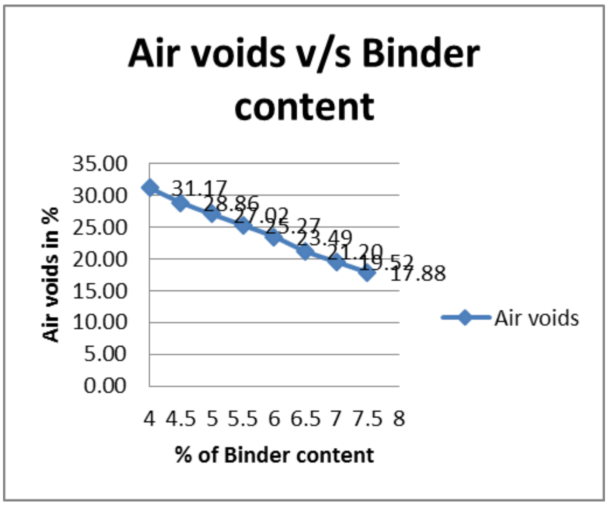
Table 4.4 Marshall Mix design test results

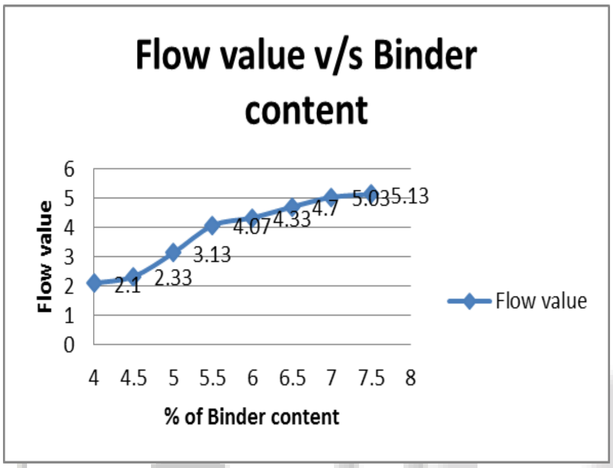
Table 4.4 Continued….

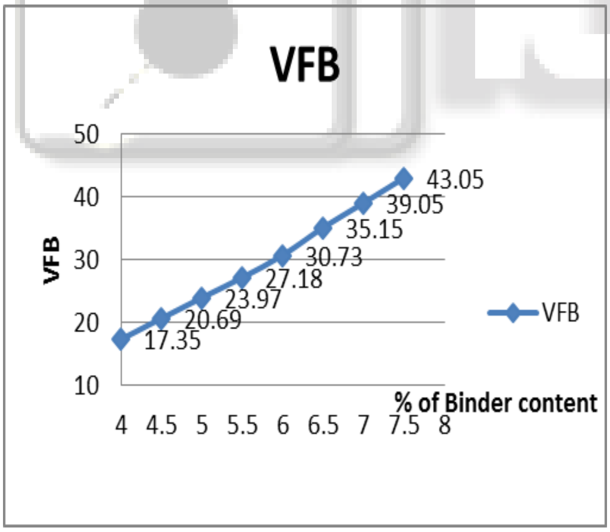
Sl.no	Bitumen content(%)	% of air voids	Avg Air voids (%)	Bulk density Gb	Avg Gb	Therotical specific gravity Gt	Avg Gt	VFB	Avg VFB	VMA	Avg VMA
1	4	30.87		1.62		2.35		17.55		37.44	
2	4	31.11	31.17	1.62	1.62	2.35	2.35	17.39	17.35	37.66	37.72
3	4	31.55		1.61		2.35		17.10		38.05	
4	4.5	30.36		1.62		2.32		19.51		37.72	
5	4.5	28.75	28.86	1.65	1.65	2.32	2.32	20.76	20.69	36.28	36.38
6	4.5	27.47		1.68		2.32		21.82		35.13	
7	5	27.78		1.66		2.30		23.17		36.17	
8	5	24.12	27.02	1.74	1.68	2.30	2.30	26.75	23.97	32.92	35.49
9	5	29.16		1.63		2.30		21.99		37.38	
10	5.5	24.94		1.70		2.27		27.52		34.41	
11	5.5	25.41	25.27	1.69	1.70	2.27	2.27	27.03	27.18	34.82	34.70
12	5.5	25.46		1.69		2.27		26.98		34.87	
13	6	23.50		1.72		2.24		30.71		33.91	
14	6	22.68	23.49	1.73	1.72	2.24	2.24	31.70	30.73	33.20	33.90
15	6	24.28		1.70		2.24		29.80		34.59	
16	6.5	21.34		1.75		2.22		34.96		32.80	
17	6.5	20.93	21.20	1.75	1.75	2.22	2.22	35.52	35.15	32.46	32.69
18	6.5	21.34		1.75		2.22		34.96		32.81	
19	7	19.90		1.76		2.19		38.45		32.34	
20	7	20.10	19.52	1.75	1.77	2.19	2.19	38.16	39.05	32.51	32.02
21	7	18.56		1.79		2.19		40.52		31.21	
22	7.5	18.37		1.77		2.17		42.23		31.81	
23	7.5	17.76	17.88	1.78	1.78	2.17	2.17	43.24	43.05	31.29	31.39
24	7.5	17.5		1.79		2.17		43.68		31.08	











E. Job-Mix Formula:

By-Passing Contamined Hubs Whats More Anomalies in Remote Sensor Networks Exploitation Bpr

The proportion of different size of aggregate, fillers and bitumen are to be mixed and implemented for the specific work at place is known as Job-Mix Formula. Table4.5 Tabulated the Job Mix Formula for the present dissertation work and is implemented in the performance studies of open graded friction course.

Sieve size (mm)	Final Job-Mix Gradation	Optimum Binder Content
19	100	6 Percent
12.5	90.01	
9.5	66.93	
4.75	10.94	
2.36	9.19	
0.075	1.11	

V. PERFORMANCE TESTS

A. Permeability:

Permeability test is conducted on Specimen 150mm diameter and 150mm height to evaluate the rate of flow through specimen by adopting Falling Head Permeability test in laboratory. The water is allowed to flow through cylinder saturated specimen with help of measuring jar or pipe. The change in head is recorded in seconds. The coefficient of permeability of specimen is determined based on Darcy's law.

Sl.no	Bitumen content (%)	Length of specimen (L) cm	Elapsed time (t) seconds	Co-efficient of permeability 'k' cm/sec	Corrected co-efficient of permeability cm/sec	Avg Co-efficient of permeability 'kc' m/sec	Avg co-efficient of permeability 'k' m/day
1	6	16.1	2.1	0.77	0.63	0.60	518.40
2		17.0	2.4	0.72	0.59		
3		15.5	2.2	0.71	0.58		

Table 5.1: Test Results of Co-efficient of Permeability on compacted OGFC Mixes

B. Moisture Susceptibility Test Adopted For Present Dissertation Work:

To suit the climate of locality, test is conducted with certain changes is done against the Modified Lottaman Indirect Tension test as explained above section. The test is conducted using six Marshall Specimens of which three specimen should be considered as dry specimen (unconditioned) and another three specimen should be considered as conditioned. The conditioning is done by placing Marshall specimen in water bath maintaining a temperature at 60°c for 24hours. Then conditioned and unconditioned (dry) specimens should be subjected to Indirect Tensile Strength determined at room temperature

Specimen		Thickness of Specimen (t) in mm	Maximum Proving Ring Reading	Load in Kgs	Tensile strength (St) in kpa	Avg 'St' Kpa	TSR (%)
Dry	Conditioned						
L1		75	90	614.10	52.126	52.14	85.00
L2		75	85	618.13	52.46		
L3		75	88	610.88	51.85		
	H1	68	125	486.16	45.51	44.32	
	H2	70	120	484.61	44.07		
	H3	70	118	477.25	43.40		

Table 5.2: Test results of Indirect Tensile Test on Compacted OGFC Asphalt Mix

C. Effect of Temperature Variation On Marshall Stability:

The Marshall Stability test was conducted on compacted cylindrical specimen of OGFC asphalt mix of diameter 101.6 mm and thickness 63.5 mm. The test specimen is prepared by same procedure as followed as in Marshall Mix Design. The prepared OGFC asphalt mix specimen is kept in water bath at different temperature at 30°C, 40°C, 50°C and 60°C for a period of one hour, for each test three specimen is prepared.

Sl.No	Temperature (°C)	Avg thickness of specimen (t) mm	Proving ring reading	Stability value in kgs	Avg stability value in kgs	Flow value in mm	Avg flow value in mm
1	30	72	320	1637.60	1562.74	4.30	4.33
2		75	310	1532.95		4.50	
3		70	318	1517.66		4.20	
4	40	73	146	721.97	709.49	2.20	2.17
5		73	140	644.00		2.10	
6		75	149	762.51		2.20	
7	50	75	132	607.20	635.15	2.60	2.47
8		72	128	632.96		2.40	
9		70	130	665.28		2.40	
10	60	70	123	608.24	592.21	2.20	2.23
11		70	120	593.40		2.30	
12		75	125	575.00		2.18	

Table 5.3: Test results of temperature variation of Marshall Stability Test on Compacted OGFC Asphalt Mix

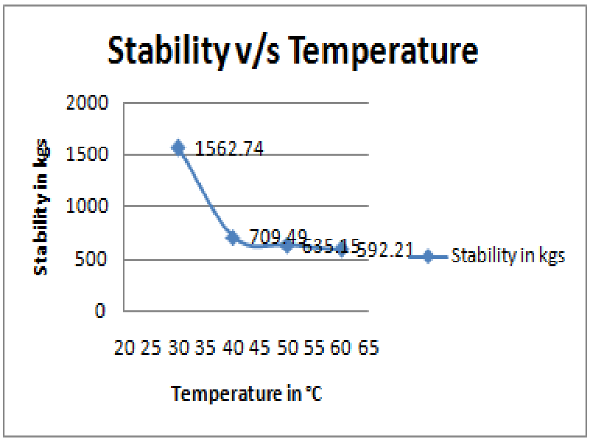


Fig: 5.1: Graphical Representation of effect of Temperature on Marshall Stability

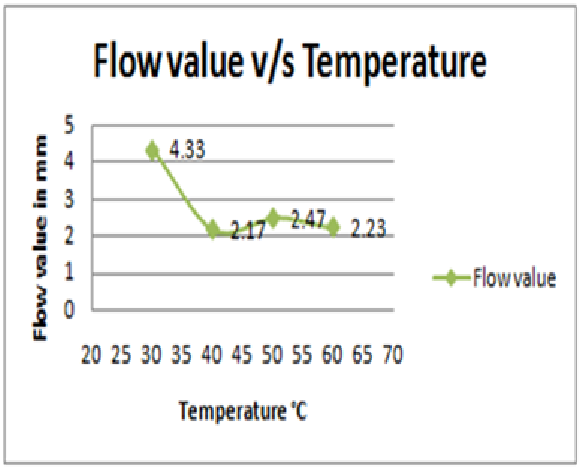


Fig: 5.2: Graphical Representation of effect of Temperature on Flow value

VI. RESULTS AND DISCUSSION

A. Permeability of Compacted OGFC Specimen:

The permeability characteristic of the open graded friction course is mainly dependent on the percentage of air voids in compacted specimen it is dependent on the gradation of the mix. The increase in the binder content reduces the air voids and vice-versa. Higher air voids in the bituminous mix show the higher permeability and vice-versa.

From permeability test we obtained the coefficient of permeability 518.40 m/day. For porous asphalt pavement should have minimum 100m/day, hence designed pavement is having a better permeability to drain off the water coming on the pavement surface.

B. Indirect Tensile Test (TSR) Of Compacted OGFC Specimen:

The long term adhesion property between the bitumen binder and aggregate is quite complex in OGFC Asphalt Mix. The stripping due to the presence of moisture in bitumen mix is depended on several factors such as characteristics of aggregate, use of bitumen binder, anti- stripping additives, compacted bituminous mix properties, construction practice and drainage etc.

The optimum binder content (6%) of the OGFC compacted specimens fulfils the requirement for minimum specified value (80%) of the retained Tensile Strength. The obtained tensile strength Ratio of the Open Graded specimen is more than required (85%).

C. Effect Of Temperature Variation On Marshall Stability And Flow Value:

The Marshall Stability test was conducted to know the maximum load carrying capacity of OGFC specimens at worst possible conditions of moisture and temperature for this, the Marshall specimens were kept in water bath maintained at different temperatures namely 30°C, 40°C, 50°C and 60°C. From the results increase in temperature decrease the stability value.

VII. CONCLUSION

The based on test results the following concluding remarks may be derived;

1) The aggregate gradation consists of 100 percent passing through 19 mm sieve size and aggregate should not pass more than 15 percent through 4.75 mm sieve size, so that the compacted mix become permeable and provide adequate permeability.
2) The stone on stone contact condition is achieved in OGFC pavements, its demands the use of Polymer Modified Binders and Crumb Rubber Modified Bitumen.
3) For OGFC to be permeable, air voids content of 18 percent and above is necessary.
4) The increase in binder content decrease the air voids, and if air voids decreases the co-efficient of permeability is low and vice versa.
5) The moisture susceptibility test conducted on OGFC specimens the Tensile Strength Ratio (TSR) value is more than the required about 85%.
6) The increase in temperature reduces the stability of OGFC specimens.

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