Experimental investigation of Open Graded mixes using Reclaimed Asphalt Pavement

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Abstract Open Graded Friction Course is widely used as a surface layer in the flexible pavement which is also termed as porous asphalt or popcorn mix. Open Graded Friction Course (OGFC) mix has various advantages such as increased permeability, noise reduction and enhanced surface friction, mix is mainly comprises of large coarse aggregates, little fine aggregates and maximum percentage of asphalt content which makes mix more expensive. In the present research work an attempt is made to reduce the cost of the mix by using reclaimed asphalt pavement (RAP) by replacing with conventional aggregates with increase percentage of 10, 20, 30, 40 and 50% with addition PMB 40 and Arbocell fiber as a stabilizing agent to prevent drain down. In order to determine the feasibility of using reclaimed asphalt pavement (RAP) in open graded mixes various tests such as indirect tensile test, fatigue test and rutting test is carried out. By conducting test on Air voids, Cantabro test and Drain down the optimum binder content for conventional mix and for mix with RAP is determined. From the test results it is found that 30% of RAP can be replaced with conventional aggregates in open graded mixes.

1. Introduction
Friction course, popularly known as porous asphalt, has become popular in recent years in European countries and the United States for addressing environmental and safety needs. Friction-course mixtures are special-purpose mixtures recommended for new or old high-speed, high-volume roads and expressways to improve surface frictional resistance, minimize hydroplaning, reduce splash and spray, improve night visibility, and lower pavement noise levels.

The Federal Highway Administration (FHWA) established a mix design procedure for OGFC in 1974, which was used by many state Departments of Transportation (DOTs). While several DOTs reported good achievement, several other states stopped using OGFC because of improper performance and/or absence of sufficient durability. Although, substantial improvements have been made through the last few years in the gradation and binder type utilized in the OGFC, recently, a survey on the experience of states with OGFC was by the National Centre for Asphalt Technology (NCAT). (NCAT). However, experience of states with OGFC has been modified, half of the states surveyed in this research showed good experience with OGFC.

Open graded-friction course (OGFC) mixture is a type of mix which is mainly used in pavement surfacing around the world. OGFC is characterized by the use, predominantly, of narrowly graded crushed coarse aggregate without significant proportion of fines. This results in sufficient interconnected voids to provide high permeability for subsurface drainage. Asphalt content is slightly higher than dense mixes of the same maximum aggregate-size to enhance the durability of the Mix.
Reclaimed asphalt pavement have a natural effect at each progression like extraction of the raw materials, manufacturing, transportation, and disposal of the such materials towards the end of pavement valuable life. Government over the world has reacted to the need to diminish the solid waste. Reclaimed asphalt pavement (RAP) material substance of 30 percent are normally utilized for the construction of flexible pavements. Because of expanding environmental issues, cost of aggregates, bitumen and also disposing of such materials can be minimised and which contributes in resolving disposal of RAP and in turn makes pavements economical.

1.1. Background
OGFC as high air voids content in reducing the noise and contributing surface drainage in pavements. OGFC has many advantages as compared with dense graded surfaces which are, a) Reduced vehicle Splashing and spray behind the vehicle, b) Better visibility of pavement markings, c) Reduced night time glare during wet weather condition and d) Reduced tire-pavement noise.

Bradley J Putman et.al. (2019)\[1\] the effect of aggregate gradation and nominal maximum aggregate size (NMAS) on the performance properties of open graded friction courses (OGFC) mixtures. The study provide adjusting the OGFC gradation by increasing the allowable percent passing the 4.75mm sieve toward the higher end of the current specification range could potentially have positive effects on mixture durability while also maintaining adequate permeability for water drainage.

Xueqin Chen et.al. (2016)\[2\] study was to evaluate the performance effectiveness and cost-benefit of OGFC pavements by analysing the field performance and accident rate of OGFC and adjacent non-OGFC projects. Four pavement condition indices, including international roughness index, pavement distress index, rutting depth and friction number, were investigated to evaluate the performance of OGFC. In the performance and benefit evaluation, the short-term performance effectiveness was the immediate performance improvement due to resurfacing, while long-term performance effectiveness was the average performance level over the service time.

S. N. Suresha et.al (2009)\[3\] study on laboratory investigation of characterization of OGFC mixes with four different gradation and bitumen percentage of 4.5 and 5.0, for three different Marshall Compaction efforts. The results of the study indicated that the compaction effort should be based on the gradation that is adopted for the design and the design traffic. A compaction level of 50blows on one side or 25 blows on either side of the specimen is optimum for the open graded mixes.

V. S. Punith et.al (2011)\[4\] study aims with the viability of using reclaimed polyethylene (PE) fibers derived from low-density polyethylene (LDPE) tote bags collected from domestic waste as an additive in OGFC mixtures. Mixture designs were performed for a range of 4.5–6.0% asphalt content. Laboratory tests were carried out on OGFC mixtures to determine the resistance to fatigue damage, unaged and aged abrasion, tensile strength, moisture-induced damage, and plastic deformation.

Hossam F Hassan et al (2005)\[5\] the studies shows that results of investigating four different OGFC mixes containing no additives, cellulose fibers, styrene butadiene rubber mix designs were performed according to the design procedure proposed by the National Centre of Asphalt Technology for a range of 4.5–6.5% asphalt content. The mixture containing fibers- and SBR polymer was selected as an acceptable mix design with an optimum asphalt- content of 6.5%. The moisture susceptibility of the selected mix at optimum asphalt content was evaluated. Results were compared with that for a dense mix.

Michael Barrett (2008)\[6\] investigated on the quality of the water obtained and the amount of runoff on OGFC surfaces. From the studies, it was found that the quality of storm water was improved with the use of OGFC as surface course. The amount of the particles and particle related pollutants were less in the runoff from the OGFC surfaces when compared with the conventional bituminous surfaces.

Ahmed Mohammad et al (2014)\[7\] the study aims to investigate the use of recycled aggregate pavement (RAP) materials in highway and to determine the optimum reclaimed percent. After choosing the study
materials, qualification tests were conducted on the study materials.

Imad L. Al-Qadi et al (2014) \cite{8} the study aims on milled materials, RAP, can be reused in virgin HMA to reduce the amount of new material that needs to be used. However, it is necessary to account for old materials in the HMA design process.

1.2 Objectives
The objective of the study was to evaluate the performance studies of Open graded friction course mixes with replacement of recycled asphalt pavement and addition of Arboceil fiber to the mix. The 12.5mm grade OGFC is selected for the study purpose on various engineering properties of the mix. The variation in air voids, draindown and Cantabro abrasion for different binder content with replacement of RAP materials were evaluated. The effect of OGFC with replacement of RAP on the performance parameters such as moisture susceptibility, tensile strength, fatigue and rutting properties are evaluated.

2. Materials and Methodology
2.1 Materials
Determination of physical properties of materials used i.e. Conventional aggregates, bitumen, cement, RAP aggregates and Arboceil fiber is important step in any research work.

Aggregates
The Aggregates for the present study is procured from the crusher at Bidadi, Bengaluru. For the present investigation, RAP materials from Rock crystal Yelahanka Bengaluru and conventional aggregates have been used. Basic physical properties tests of aggregates were conducted according to IS: 2386 and MoRTH specification are in the given Table 1.

| Property evaluated                      | Conventional aggregates Value | RAP aggregates Value | Specification as per MoRTH V revision | Test Method                  |
|-----------------------------------------|-------------------------------|---------------------|--------------------------------------|-----------------------------|
| Aggregate Impact (%)                    | 18                            | 25                  | Max 24                               | IS: 2386-1963 (PART 4)     |
| Los Angeles Abrasion (%)                | 21                            | 28                  | Max 30                               | IS: 2386-1963 (PART 4)     |
| Crushing Strength Test (%)              | 23                            | 26                  | Max 30                               | IS: 2386-1963 (PART 4)     |
| Combined Flakiness and Elongation (%)   | 27                            | 24                  | Max 30                               | IS: 2386-1963 (PART 1)     |
| Specific Gravity                        |                               |                     |                                      | IS: 2386-1963 (PART 3)     |
| Coarse aggregates                       | 2.67                          | 2.63                | NA                                   | IS: 2386-1963 (PART 3)     |
| Fine aggregates                         | 2.66                          | 2.7                 |                                      | IS: 2386-1963 (PART 3)     |
| Water Absorption (%)                    | 0.18                          | 0.7                 | Max 2%                               | IS: 2386-1963 (PART 3)     |

Bitumen
In the case of the conventional hot mixture asphalt, a PMB-40 bitumen was used. The bitumen was procured from Hindustan Colas Pvt. Limited, Mangalore. The engineering properties investigated are in the Table 2.
Table 2. Properties of PMB 40 bitumen

| Property evaluated                                      | Test Value | Specifications as per IRC SP 53:2010 | Standard Test method |
|---------------------------------------------------------|------------|--------------------------------------|----------------------|
| Penetration at 25°C,100g,5s,0.1mm                       | 36         | Min 45                               | IS 1203              |
| Flash Point °C                                          | 270        | Min 220                              | IS 1209              |
| Softening Point ( R &B) °C                             | 60         | Min 55                               | IS 1205              |
| Ductility at 27 °C,cm                                   | 100+       | --                                   | IS 1208              |
| Specific Gravity at 27 °C                              | 0.99       | --                                   | IS 1202              |
| Separation Test, difference in softening point max. °C  | 2          | 3                                    | IS 1205              |
| Thin Film Oven Test                                     | 0.23       | Max 1                                | IS 9382              |
| Loss in mass (%)                                        | 1.35       | Max 5                                | IS 1205              |
| Reduction in penetration (mm)                           | 26         | Max 35                               | IS 1203              |

Cement
Cement used in the present study was Ramco 53 grade cement and tests are carried in accordance to IS 12269-1987 and as per MoRTH table 500-36. Properties of the cement is given in Table 3.

Table 3: Properties of the cement used

| Properties evaluated                                      | Test Value | Specifications as per IS 12269(1987) |
|---------------------------------------------------------|------------|--------------------------------------|
| Fineness, m2/kg                                         | 260        | 225 min                              |
| Standard Consistency,%                                   | 33         | --                                   |
| Initial Setting Time, min                                | 80         | 30 min                               |
| Final Setting Time, min                                  | 470        | 600 max                              |
| Specific Gravity                                        | 3.10       | 3.15                                 |

Fiber (Cellulose – Arbocell Fiber)
Fibers are used as stabilizer in OGFC mixture. It helps to increase the strength and stability also decrease the drain down in OGFC Mix. In the present study, the fiber used is ARBOCEL® ZZ 8/1G. It was procured from Strategic Marketing and Research Team, Bangalore. Arbocell is natural cellulose fiber produced from cellulose and it is a powdery to fibrous cellulose additive for use in construction chemicals products. The Characteristics of Arbocell fiber as shown in Table 4.

Table 4: Characteristics of Arbocell Fiber

| Sl.No | Characteristics       | Values from Testing Certificate |
|-------|-----------------------|---------------------------------|
| 1     | Physical appearance  | Long fiber, Grey                |
| 2     | Cellulose content     | 80±5 %                          |
| 3     | Average fiber length  | 1100 µm                         |
| 4     | Average fiber thickness| 45 µm                          |
| 5     | Bulk density          | 200 g/l – 280 g/l               |
| 6     | Temperature resistance(°C) | Up to 200°C                   |
| 7     | pH value              | 7.5±1                           |

2.2 Selection of Aggregate selection
First thing is selection of aggregate gradations was to fix the sieve sets for open graded mix. In this study aggregate gradation was adopted according to the master gradation provided by the ASTM D7064. The mid-range of the percentage passing is taken for mix design.
2.3 Methodology
The OGFC aggregate gradations on mixes for different bitumen contents were evaluated in mix design properties (Air voids, stone to stone contact, drain down, abrasion loss and permeability) and performance (Indirect tensile strength, Resistance to rutting and fatigue). The following tests were carried out on OGFC mixtures.

- Open graded Bituminous mix prepared using 50 blows on one side
- Air void content in mix
- Stone to stone contact
- Draindown test
- Abrasion loss by Cantabro test
- Permeability test
- Determination of OBC for mix
- Replacement of different percentage of RAP materials to optimum OGFC mix
- Resistance to rutting for optimum percentage of RAP in OGFC mix
- Indirect tensile strength for optimum percentage of RAP in OGFC mix
- Fatigue for optimum percentage of RAP in OGFC mix

Open Graded Bituminous Mix design
The aggregate structures of open-graded surface mixtures are often made up solely of coarse aggregates to maximize the void space. Materials selected for the mix are aggregates, bitumen and additives that meet specification are selected. Optimum gradation is selected in accordance with test method C29/C29M. For each trail grading, an initial bitumen content between 4.5 to 6.0% is selected at an increment of 0.5% and specimens are compacted with 50 blows on one face of the specimen using Marshall Compactor. Optimum bitumen content is determined by Marshall Method of mix design as per codal provision conforming to ASTM-D-1559. Aim of the Marshall method of mix design is to look into an appropriate content of black-top binder to hold aggregates with a stone to stone contact and providing sufficient percentage of voids of air.

Air Void Content \((V_a)\) of Mix
After the trail samples have been compacted and allowed to cool, they are removed from the moulds and tested to determine their bulk specific gravity using geometric measurements of diameter and height as per the test method ASTM D3203. It is the total volume of the small pockets of air in a compacted bituminous mix, expressed as a percent of the total volume of the compacted mix and is calculated from the following Equation: 1. The minimum criteria for Air void content is of 18% to meet the requirements of mixes.

\[
V_a = \frac{(G_{mm} - G_{mb})}{G_{mm}} \times 100
\]  (1)
Stone to stone Contact
The Open graded gradation was selected based on the evaluation of stone-on-stone contact with consideration of air voids. This criterion is checked by comparing the voids in the coarse aggregate (retained on a 4.75mm IS sieve) in the bituminous mix achieved after compaction with the voids between the same coarse aggregates that is achieved after compacting coarse aggregates blend alone as per the dry rodded technique based on the ASTM C29 test. In order to ensure stone on stone contact in an Open graded mix, voids in the coarse aggregate of the compacted bituminous mix (VCA\textsubscript{mix}) should be equal to or less than the voids in coarse aggregate in the dry-rodde condition (VCA\textsubscript{drc}). The VCA\textsubscript{drc} and VCA\textsubscript{mix} values were determined using Equation 2 and 3

\[
VCA\textsubscript{mix} = 100 - \frac{G_{mb}}{G_{CA}} P_{CA} \tag{2}
\]

\[
VCA\textsubscript{drc} = \frac{G_{CA} \gamma_w - \gamma_s G_{CA} \gamma_w}{G_{CA} \gamma_w} \times 100 \tag{3}
\]

Drain Down Test
The binder drainage test, combined with determination of volumetric properties, is often used to determine the target binder content for porous asphalt mixtures to maximize binder content and thus optimize durability, while eliminating possible binder drainage. Basket drainage tests were carried out on mixtures at mixing temperatures of 160°C. Test was conducted according to the AASHTO T305. As per codal provision, drain down value should be less than 0.3%.

Abrasion Loss Test
The resistance to compacted porous asphalt mixtures to abrasion loss was analysed by means of the Cantabro test. This is an abrasion and impact test carried out in the Los Angeles Abrasion Machine. The test is carried out for unaged specimens. The test is conducted according to the ASTM D 7064. As per codal provision, loss value for Cantabro abrasion test should be less than 25% for unaged.

Permeability Test
Permeability test is performed to evaluate drainage characteristics of mix. Test was conducted according to ASTM D2433-68. For conducting test, sample is placed in Permeability test setup and sealed to prevent leakage of water. Water is poured through mix sample and interval of time in seconds is recorded for water to fill from fixed initial head to final head. Coefficient of Permeability is calculated according to formula given below. The range for coefficient of permeability varies from 104 to 159 mm/day.

\[
K = \left(\frac{3600 \times 24}{1000}\right) \left(\frac{dL}{AT}\right) \ln\left(\frac{h1}{h2}\right) \tag{4}
\]

Determination of Optimum Bitumen Content
Open Graded Bituminous mix specimens for different bitumen content 6%, 6.5%, 7%, 7.5% and 8% prepared. Optimum bitumen content is determined by satisfying air void, stone to stone contact, drain down, abrasion loss, and permeability. Binder content 7% & 7.5% satisfies all criteria as per the specification ASTM D7064, by interpolating the above value is 7.3% fixed as Optimum bitumen content.
3. Experimental Analysis

**Determination of Optimum RAP replacement in OGFC mix**

The different percentage of RAP materials introduced in the OGFC Mix. RAP (Aggregates and Bitumen) varied in the percentage ranges from 10%, 20%, 30%, 40% and 50% to total mix. The bitumen content was optimized to maintain same OBC as obtained in the conventional mix. Tabulation of these results and the graphs pertaining to the percentages of 10%, 20%, 30%, 40% and 50% are as shown in Table 5 and Figures below. It was observed from the investigations the optimum dosage of RAP replacement for the OGFC mix is 30%. The parameters at different percentage were checked and found satisfactorily. From the table5 it is clearly observed that up 30% RAP can be replaced effectively with conventional mix for optimum binder content of 7.3%.
Table 5: Details of the test results for the replacement

| Specification | PMB+RAP | Bitumen content (%) | Cantabro abrasion loss (%) | Drain down (%) | Air voids (%) |
|---------------|---------|---------------------|----------------------------|----------------|---------------|
| 0             | 7.3+0.0 | 23.41               | 0.2                        | 19.01          |
| 10            | 6.5+0.8 | 20.39               | 0.1                        | 18.45          |
| 20            | 5.7+1.6 | 19.03               | 0.2                        | 18.75          |
| 30            | 4.9+2.4 | 18.60               | 0.2                        | 19.43          |
| 40            | 4.1+3.2 | 27.06               | 0.5                        | 15.38          |
| 50            | 3.3+4.0 | 48.53               | 0.6                        | 14.38          |

Figure 7: Percentage of RAP Vs Air Voids

Figure 8: Percentage of RAP Vs Abrasion loss

Figure 9: Percentage of RAP Vs Drain down

**Immersion Wheel Tracking Test**

The rutting tests were conducted on the conventional OGFC mixes and 30% RAP replaced OGFC mix. The tests were carried out on the 40mm thick specimens, with tire pressures for each specimen. The tire pressures used are 10kg/cm². The OBC for Conventional OGFC mix is 7.3% and 30% RAP replaced OGFC mix 4.9% conventional +2.4% recycled bitumen respectively. The results of the rutting of the 40mm thick specimens for conventional OGFC mixes and 30% RAP replaced OGFC mix are shown in Figure 10. The test was conducted at room temperature at 22 passes/min with the help of treaded tire.
The stiffness of porous asphalt is less than those of conventional, dense-graded wearing courses. These mixtures therefore have lesser ability to distribute traffic stresses than dense-graded mixtures. The stiffness of the porous asphalt mixtures is generally approximately one-half to two-thirds of dense-graded mixtures, depending on the amount of voids within the mixture (the higher the void content, the lower the stiffness of the mixture). The indirect tensile testing procedures were performed in accordance with ASTM D 4123. The indirect tensile strength ratio (TSR) is determined by the ratio of tensile strength value of water conditional samples to that of unconditional samples and results are shown in Figure 11.

**Repeated loading test (Fatigue test)**
Repeated application of load from the traffic causes fatigue- and in turn makes the pavement to crack. Repeated load test is conducted to determine the pavement life for fracture and to determine the pavement properties. The Marshall Samples are prepared at OBC and allowed to cool. The specimen is then placed in the repeated load apparatus to test its fatigue strength. The cylindrical specimens are in a rigid frame and the loads are applied. By using the Linear variable displacement transducers (2 vertical and 2 horizontal), the horizontal and vertical displacement caused due to the load is measured. The load is applied until the specimen fails. The number of cycles that the specimen is undergone before failure is noted. 3 cylindrical specimens are casted to their OBC. The Specimens are subjected to stress level from 10% to 30% of the average conditional load. Results of conventional and 30%RAP are shown below Figure12.
**4. Results and Discussion**

*Discussion on Conventional OGFC Mix*

To determine the optimum bitumen content there are three criteria that must be satisfied: air voids should be minimum 18%, Cantabro abrasion loss not exceed 25% and drain down value should be within the 0.3%. From the test results, the optimum bitumen content is obtained as 7.3% for conventional mix and 4.9% for 30% RAP optimized.

*Drain down Characteristics*

As the binder content increases, the drain down values go on increasing. The drain down test results yielded good results, and the drain down of bitumen of the specimens was found out to be well within the limit of 0.3% maximum as prescribed in ASTM D6390. The results are as shown in Table 5.

*Rutting Characteristics*

For 30% RAP replacement, rutting depth was found to be 5.12 which has taken 10000 passes to reach the above-mentioned depth while conventional mix taken 8000 passes to reach the same depth hence it can be concluded that 30% RAP materials have more rut resistance compared to conventional mix.

**5. Conclusions**

The following conclusions can be made from the present research work carried out:

1. It has been found that Cantabro abrasion loss can be reduced with the increasing binder content up to a certain limit. Which signifies that lower abrasion value gives better performance on the road.
2. With the addition of Arbocell fiber in the mix, the drain down properties increase with an increase in bitumen content.
3. Reclaimed asphalt pavement is replaced with virgin aggregates with the percentage of 10, 20, 30, 40, and 50, and binder content in the RAP has replaced with virgin bitumen with an increment of 10, 20, 30, 40, and 50% it has been found that 30% of RAP replacement with conventional materials has given better results.
4. For 30% RAP replacement, rutting depth was found to be 5.12 which has taken 10000 passes to reach the above-mentioned depth while conventional mix taken 8000 passes to reach the same depth hence it can be concluded that 30% RAP materials have more rut resistance compared to conventional mix.
5. As per the specification TEX 226-F required TSR is minimum 80%. In the present study, it has found that TSR value for conventional mix 89.5% and 30% RAP is 88.6%.
6. Fatigue results for conventional mix have found to be 1305, 987, and 635 cycles for 10%, 20%, and 30% stress respectively and for 30% RAP replacement 1148, 854, and 515 cycles for 10%, 20%, and 30%. Hence from the results, it can be concluded that 30% RAP replacement has good fatigue life likely conventional OGFC mix.
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