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# Strength evaluation of fiber reinforced hot mixed open graded asphalt concrete

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ABSTRACT: Hot mixed asphalt concrete is a composite material of aggregate particles of crushed rock of different sizes, glued together with an asphalt binder, which is much softer than the aggregate. The term open graded is used since the percentage of air voids in it, are more than 20%, which is much higher than that in the normal asphalt concrete mixes. These mixes are used as a crack relief layer for mitigation of reflection cracking on asphalt concrete overlays.

Bailey Method for gradation selection (Vavrik et al. 2002) is used for deciding aggregate gradation, because the method advocates a strong aggregate skeleton for rut resistance along with adequate voids in mineral aggregate for good durability. Cylindrical sample of diameter 101.6 mm and height of 203.2 mm (ASTM D 1074 – 1996), is utilized for the testing work. The Unconfined Compression Test (ASTM D 1074 – 1996), Triaxial Compression Test, and Resilient Modulus Test (TRB Special Report 162) are used for the strength evaluation of the open graded asphalt concrete mix. PET Fibers are used as reinforcement in the open graded asphalt concrete mixes. These reinforced samples are also tested for their mechanical properties. The testing is performed at a room temperature of 27°C.

The aim of this paper is to present and compare the test results of the unreinforced and fiber reinforced open graded asphalt concrete mixes.

## 1 INTRODUCTION

Hot mixed asphalt concrete is a composite material of aggregate particles of crushed rock of different sizes, glued together with an asphalt binder, which is much softer than the aggregate. The term open graded is used since the percentage of air voids in it, is more than 20%, which is much higher than that in the normal asphalt concrete mixes. The open-graded asphalt concrete mix, hereinafter will be termed as OGAC mix, is used as a "Crack Relief Layer (CRL)", to mitigate the reflection of cracks on the newly laid asphalt overlays. It is due to the large interconnecting voids, obtained by gap grading an aggregate, that relieve motion caused by the underlying pavement, before it creates a stress on the upper layers of the overlay. This may give rise to highly compressible mix if aggregate skeleton with positive contact is not formed. Bailey Method of aggregate gradation (Vavrik et al. 2002) ensures good aggregate interlock that gives CRL layer which virtually incompressible in a confined state of stress. Hence fear of rutting under heavy wheel load, at high tyre pressure can be dispensed (Nataraj et al. 2000). A CRL would therefore serve two purposes, both as a delay mechanism for crack growth as well as a structural layer. The following paragraphs describe various tests performed for the strength evaluation of OGAC mix to check its suitability as a structural layer. Few samples reinforced with PET Fibers and one sample reinforced with polyester fibers cut from the multifilament woven polyester geotextile is also tested and the results are compared.

## 2 MATERIAL CHARACTERIZATION

Paving grade bitumen, having penetration 60-70 and aggregates having nominal maximum particle size of 25 mm, derived from freshly crushed basalt rock are used for preparing open graded asphalt concrete mix. Materials are tested as per Indian Standards. Tables 1 and 2 show the physical and engineering properties of aggregate and bitumen used in this study. The obtained test results match well with the Indian standard specified values.

Table 1. Physical and engineering properties of aggregate.

| Test Description | Indian Standard | Recommended Values* | Authors Test Results |
|---|---|---|---|
| Specific Gravity | 2386 Part III | | |
| Bulk | | – | 2.760 |
| Apparent | | – | 2.809 |
| Water Absorption | 2386 Part III | ≤ 2% | 1.97% |
| Crushing Value | 2386 Part IV | ≤ 30% | 18.78% |
| Los Angeles Abrasion | 2386 Part IV | | |
| Grading – B (20–12.5 mm Sieve) | | ≤ 40% | 13.28% |
| Grading – C (10–6.3 mm Sieve) | | | 18.84% |
| Aggregate Impact Test | 2386 Part IV | ≤ 30% | 15.37% |
| Shape Test | 2386 Part I | | |
| Flakiness Index | | ≤ 30% | 19.22% |
| Elongation Index | | ≤ 30% | 20.82% |
| Angularity Number | | 0 – 11 | 10.4 |
| Soundness Test (Sodium Sulphate) | 2386 Part V | ≤ 12% | 8.5% |
| Stripping Value Minimum Retained Bitumen Coating | 6241 | ≥ 95 % | 99% |

* These recommended values are for "Bituminous Macadam", which is of open graded in nature. No specification other than this is available for comparing pre-mixed OGAC. Hence these are used only to compare authors test results for OGAC.

Table 2. Physical and engineering properties of bitumen.

| Property | Indian Standards | Specification as per IS 73: 1992* | Authors Test values | Remark |
|---|---|---|---|---|
| Specific Gravity at 27°C | 1202: 1978 | Minimum 0.99 | 1.06 | |
| Penetration at 25°C, 100 gm, 5 Sec, 1/10 mm | 1203: 1978 | 60 to 70 | 60.9 | Bitumen Grade = S 65 or Viscosity Grade = AC-20 |
| Flash Point | 1448: | Minimum | 260°C | |
| Fire Point | 1969 | 175°C | 330°C | |
| Softening Point | 1205: 1978 | 40 to 55°C | 41.1°C | |
| Ductility at 27°C | 1208: 1978 | Minimum 75 cm | 76.7 cm | |

- Indian Standard Specification for Paving Bitumen

Polyester (PET) fibers are mixed into the OGAC mix to reinforce it. Physical and engineering properties of the fibers as specified by the manufacturer are as shown in Table 3.

Table 3. Physical and engineering properties of PET Fibers.

| Property | Specified Value |
|---|---|
| Color | Black |
| Specific Gravity | 0.9 to 0.92 |
| Density | 890 kg/$m^3$ |
| Thermal Conductivity | 6 kcal/$m^2 \cdot h \cdot °C$ |
| Tensile Strength | 509 to 755 kPa |
| Burning Point | 538°C |
| Melting Point | 163°C |
| Elastic Modulus | 3.4 to 3.7 × $10^6$ kPa |
| Average Length | 50 mm |

## 3 MIX DESIGN

Aggregate grading is decided using Bailey Method for Gradation Selection (Vavrik et al. 2002). The course aggregate ratio (CA), fine aggregate course fraction ratio ($Fa_c$) and fine aggregate fine fraction ratio ($Fa_f$) for the computed aggregate gradation are 0.96, 0.3 and 0.33 respectively. The gradation was finalized with the intention of more air voids and VMA. Figure 1 show aggregate gradation adopted in this study.

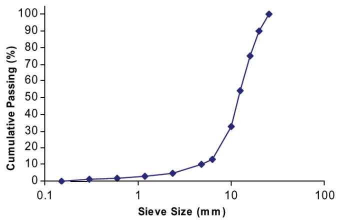


Figure 1. Aggregate gradation curve for OGAC.

Results of Marshall Stability Method of asphalt concrete mix design with 75 numbers of blows on each of the two faces of the specimen are given in Table 4.

Table 4. Marshall Test Results for OGAC.

| Parameter | Authors Result |
|---|---|
| Bitumen Content (percentage of total mix (%) | 3.85 |
| Stability at 60°C (kN) | 2.452 |
| Flow (mm) | 4.77 |
| Air Voids (%) | 25.76 |
| VMA (%) | 33.18 |
| VFB (%) | 22.36 |
| Bulk Density (kg/$m^3$) | 1966.32 |

Little bit crushing of the aggregate at its contact faces, while preparing Marshall Mold confirms strong aggregate skeleton assured by the Bailey Method.

## 4 SAMPLE PREPARATION

Cylindrical samples of diameter 4 inch (101.6 mm) and height 8 inch (203.2 mm) (ASTM D 1074 - 1996) are prepared. Sample is compacted under dynamic compaction in a cylindrical mould, using “Aggregate Impact Testing Apparatus”. The 13.5 kg weight was allowed to fall under gravity from a height of 15 cm on a penetrating plunger. Thus applying compaction energy of 19.86 N-m per drop, which is 60% less than that used for aggregate impact test. Physical and volumetric properties of cylindrical samples used for strength evaluation and their designations are shown in Table 5.

Table 5. Physical and volumetric properties of samples.

| Properties | Unreinforced Sample | | | Reinforced Sample | | |
|---|---|---|---|---|---|---|
| | O1 | O2 | O3 | RO1 | RO2 | RO3* |
| Reinforcement (% of total compacted mix) | – | – | – | 1 | 0.5 | 0.5 |
| Rate of Strain (mm/min) | – | 1.2 | 1.2 | – | – | – |
| Lateral Pressure (kPa) | 196.1 | 196.1 | 0 and 196.1 | 196.1 | – | 24.5 to 294 |
| % Marshall Compaction | 99.9 | 99.8 | 99 | 90.9 | 91.7 | 91.6 |
| Average Height (mm) | 202 | 202 | 202 | 209 | 209 | 210 |
| Air Voids (%) | 27.9 | 30.1 | 25.9 | 28.3 | 29 | 27.4 |
| VMA (%) | 35.1 | 37.1 | 33.3 | 35.4 | 36.1 | 34.6 |
| VFB (%) | 20.6 | 18.8 | 22.2 | 20.2 | 19.6 | 21 |

* Reinforcement of 5 cm long polyester fibers taken out of woven multifilament polyester geotextile is used

## 5 TESTING FEATURES AND RESULTS

All the tests are performed at room temperature of 27°C.

### 5.1 *Unconfined Compression Test (ASTM D 1074)*

This test is performed with an intension of getting an idea of range of loadings that will be required during cyclic triaxial compression test. Since manual observations are taken, strain rate of 1.2 mm/min is selected. Figure 2 shows the variation of compressive stress versus percentage strain for sample O3.

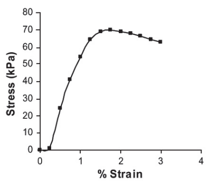


Figure 2. Stress – strain variation for sample O3 during unconfined compression test.

Initial high strain indicates the orientation of aggregates. Maximum compressive stress of 70.12 kPa with 1.75% strain is observed. Modulus of elasticity under such continuous loading is 0.081 MPa.

### 5.2 *Cyclic Unconfined Compression Test*

Field loading conditions are better simulated by this test. Figure 3 shows variation of compressive stress versus cumulative average strain.

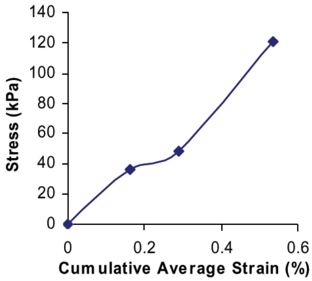


Figure 3. Stress versus cumulative strain variation under cyclic loading for sample RO2.

Kink in the curve indicates the reorientation of aggregate structure because slope of curve has increased after this kink.

### 5.3 *Triaxial Compressive Strength Test [TRB Special Report 162 (1975)]*

This test is performed to study the effect of lateral pressure on mechanical properties of AC mixes. In comparison to that of unconfined compression test, the stress conditions during this test are better simulated to that of field conditions (Pandey et al. 1989). Figure 4 shows the stress–strain variation for a lateral pressure of 196.1 kPa, for the sample O2.

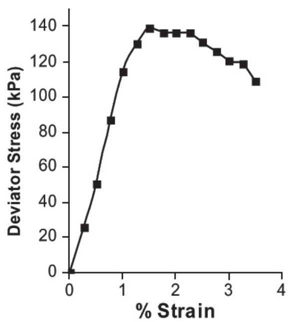


Figure 4. Deviator stress versus strain under triaxial compression test.

Due to introduction of lateral pressure, there is 44 % increase in modulus of elasticity with 43 % decrease in strain.

### 5.4 *Cyclic Triaxial Compression Test*

Test is performed under constant lateral stress and a cyclic deviatory stress under room temperature conditions (27°C). The realistic field stress conditions are best simulated by this test (Pandey B.B. et al. 1989). The vehicle speed of 1mile per hour (1.6 km/hr) was considered. This gives stress pulse rate of 1 second. The rest period of 4 seconds is assumed. The cyclic load is applied through pneumatic jack operated automatically using electronic timer and solenoid valve. For moderate stress levels, the elastic response of AC mixes becomes relatively constant after approximately 100 to 200 load repetitions. Hence load repetitions of 200 cycles are considered for this test. Test results for samples O1 and RO1 are shown in Figure 5.

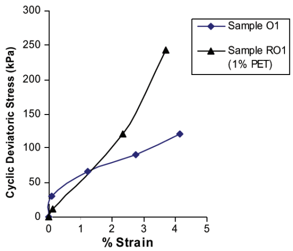


Figure 5. Variation of cyclic deviatory Stress versus % strain for samples O1 and RO1 for a constant lateral pressure of 196 kPa.

The dynamic modulus of the reinforced sample RO1 is increased by 250% in comparison to that of unreinforced sample O1. While the increase in modulus due to the cyclic loading in comparison to that of monotonic loading is about 1480%.

### 5.5 *Resilient Modulus Test [TRB Special Report 162 (1975)]*

Set-up similar to that of cyclic triaxial test is used. Regain strain is measured after applying 200 cycles of deviator stress after a duration of 30 seconds. Figures 6 and 7 show the variation of resilient modulus with deviator stress and lateral pressure respectively.

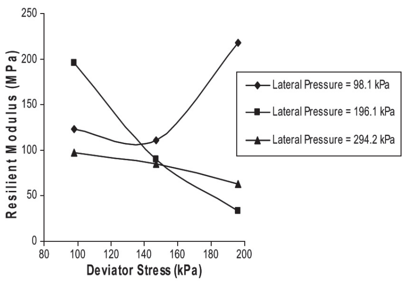


Figure 6. Variation of resilient modulus with deviator stress for sample RO3.

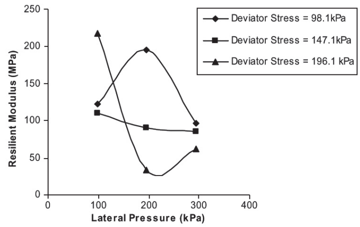


Figure 7. Variation of resilient modulus with lateral pressure for sample RO3.

It is observed that for a given lateral pressure resilient modulus decreases with the increase in deviator stress.

## 6 CONCLUSIONS

From the above limited test results following conclusions can be drawn

(a) Aggregate Impact Testing equipment can be used for dynamic compaction of cylindrical samples.
(b) Cyclic Triaxial Compression testing is the method that better simulates the field stress condition and hence realistic strength evaluation of OGAC mixes becomes possible.
(c) PET fibers outperforms as a reinforcing element.

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