Investigation of an Open Graded Asphalt Concrete Overlay for the Mitigation of Reflection Cracking Phenomenon

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Abstract: The conventional technique of rehabilitating pavement through the application of an asphalt concrete (AC) overlay is often plagued by the issue of reflection cracking. This paper addresses the challenges associated with the reflection of pre-existing distress patterns onto newly laid AC overlays, leading to premature deterioration and a significant reduction in overlay lifespan. Laboratory investigations were conducted using open graded asphalt concrete (OGAC) as a crack relief layer, examining its performance under opening and mixed modes of displacement on Asphalt Concrete Slab Fatigue Testing Equipment. The study included an evaluation of conventional dense bituminous macadam (DBM) overlays and OGAC overlays subjected to simulated thermal as well as traffic loading, further monitoring of tensile strain and strength variation in the asphalt concrete overlay for a specific number of load cycles thermally simulated. Additionally, the cumulative decay parameters such as tensile force and stiffness modulus were computed, and decay parameters were analyzed along with overlay life. The results reveal that the implementation of an OGAC overlay effectively serves as a crack relief layer, offering a potential sustainable solution to mitigate reflection cracking in asphalt pavements.

Keywords: Reflection Cracking, Open Graded Asphalt Concrete, Crack Propagation, Differential Deflection, Base Isolation

1. Introduction (Times New Roman 10 Bold)

Reflection cracking emerged out as most important challenge in design of pavement. Figure 1 shows the appearance of reflected cracks. It has been noted that in addition to traffic stresses, thermal loads brought on by daily and seasonal temperature variations lead the existing fracture to spread upward through freshly put overlay. Open graded asphalt concrete (OGAC) field tests have showed some promise for reducing fracture propagation (Hani et al., 2003). Since there are more than 20% air gaps in it, which is substantially higher than in typical asphalt concrete mixes, the term "open graded" is used to describe it. As a "Crack Relief Layer (CRL)," the OGAC mix is used to lessen the reflection of cracks on recently put asphalt overlays. The motion induced by the underlying pavement is relieved by the vast interconnected voids obtained by gap grading an aggregate before it stresses the upper layers of the overlay.

Figure 1. Reflection cracks on overlays with further weakening due to propulsion of secondary cracking

In the event that an aggregate skeleton with positive contact does not form, this could result in a highly compressible mix. According to Vavrik et al. (2002), the Bailey Method of Aggregate Gradation assures strong aggregate interlock, which results in CRL layer that is essentially incompressible un a constrained condition of stress. Therefore, a CRL would act as both a structural layer and a delay mechanism for crack formation. The aim of this work is to describe the laboratory result of experiments conducted using the "Asphalt Concrete Slab Fatigue Testing Equipment" (Bhosale and Mandal, 2007), which was created and built locally. The experiments examined the crack retardation capabilities of newly installed 40mm thick OGAC overlays.

2. Asphalt Concrete Slab Fatigue Testing Equipment

With a maximum differential deflection of 5 mm and zero load efficiency factors, this locally developed and manufactured equipment replicates both daily contraction and expansion phenomena due to varying temperature for pavement. Figure 2 displays the equipment's overall perspective. You may find more information on the equipment in Bhosale and Mandal (2007).

(Figure 2 is on the final page.)

3. Experimental Configuration

The experiment is carried out in a strain-controlled setting with a 29 °C average room temperature. The initial fracture width in an ancient, distressed pavement was 5 mm, and this gap is kept between two pavement plates. It is possible to simulate the thermal contraction and expansion cycle on daily/seasonal basis, by repeatedly opening and closing of an initial existed opening by 1.83 mm at a strain rate of 4.547 mm/min. A 5 second rest period is maintained between the pull and push cycles, and vice versa, for the electric motor's safety and the assembly of the gear system. Thus, the thermal loading cycle somewhat resembles that with a triangle waveform as shown in Figure 3 in the simply opening mode of displacement.

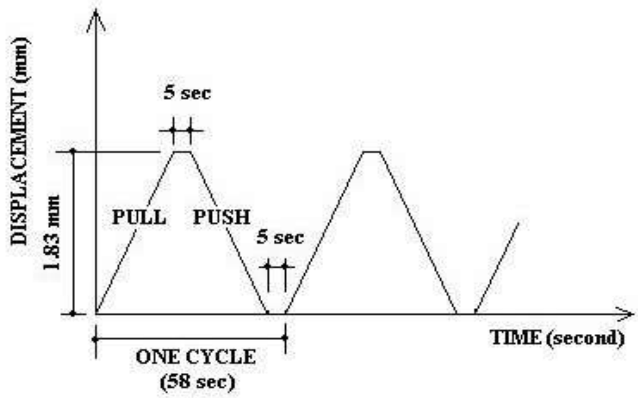

Figure 3. Loading wave form simulating thermal contraction and expansion in purely opening mode of displacement.

A pneumatic jack and a pressure plate of thickness 15 mm is used to imitate the on-highway vehicle dual tire assembly, 478.7 kPa contact pressure is generated using a vertical compressive load for an axle weight of 80 kN is delivered in mixed mode of displacement. The vertical load is also applied while the simulated thermal load cycles of the opening mode of displacement take place, with a 3 seconds load pulse and a rest interval of 3 seconds, simulating a vehicle speed of 0.333 miles per hour (0.533 kilometers per hour). For the purpose of this inquiry, differential deflection caused by the imposed vertical load with zero load efficiency factors and a maximum magnitude of 5 mm is taken into consideration.

4. Material Characterization

Basalt aggregates having particle size of25.4 mm to 0.075 mm was utilized. According to the "Guidelines on selection of the grade of bitumen" (MORT&H, 2001), "paving grade bitumen of 60/70 penetration" (Pen 60/70) is chosen. Bitumen and aggregate are both found to have physical and engineering characteristics that meet the requirements of the corresponding Indian standards.

5. Asphalt Concrete Mix Design

The Marshall stability test (ASTM D 1559) is used to find the ideal bitumen percentage of the three types of asphalt concrete mixes: DBM, BC, and OGAC. The aggregate gradation for DBM and Bituminous Concrete (BC) mixtures is adopted based on The MORT&H (2001) specification. Even though DBM and BC mixes had greater flow values and voids in the mineral aggregates, they were found to have 80% and 75% more stability, respectively, than what MORT&H had requested. In order to satisfy the unique criteria of the crack relief layer of more air gaps and voids in mineral aggregate, the aggregate gradation of OGAC was finalized (Bhosale, 2006). Table 1 shows the Marshall Stability test results for the designed OGAC mix with 75 numbers of blows on each of the two faces of the specimen.

Parameter	Experimental Result
Bitumen Content by mass of total mix (%)	3.845 (4 % of the total dry mix)
Stability at 60^{o}C (kN)	2.453
Flow (mm)	4.78
Air Voids (%)	24.75
Voids in mineral aggregate (VMA) (%)	33.24
Voids filled up with bitumen (VFB) (%)	22.42
Bulk Density (kN/m^3)	19.29

Table 1. Marshall Stability test results for open gradedasphalt concrete (OGAC).

6. **Test Procedure**

According to MORT&H's (2001) recommendations, a test slab for overlays that is 500 mm long, 400 mm wide, and 65 mm thick is cast using real-world AC mixes.. Every AC overlay test slab consists of 40 mm thick base course of DBM or OGAC and 25 mm thick surface course of BC as shown in Figure 5.

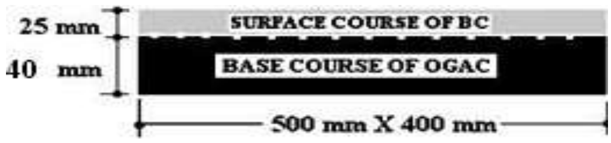

Figure 5. Typical sketch of AC overlay test slab

The flexible foundation used in this experiment has four numbers of springs with a maximum permitted differential deflection of 5 millimeters, simulating a subgrade reaction with a modulus of 93.17 MPa/m (9.5 kg/cm^2/cm). To measure the deformation in the AC overlay, all potentiometers have gauge lengths of 80 mm. The failure criteria is established as (1) until no additional decrease in the tensile load is detected for a number of load cycles, for both opening and mixed modes of displacement testing or (2) until the existing crack spreads and looks on the top surface of the overlay test slab. Every one second, the data logger is set to scan and record the data. Every overlay test slab's performance is autonomously examined in both mode of displacement. The overlay test slab is put through repeated parallel pull (tension) and push (compression) operations to simulate displacement in the purely opening mode caused by daily/seasonal thermal contraction and expansion. It is therefore put through a simulated thermal load cycle. To simulate actual field conditions of pavement loading situations of thermal load cycles of contraction and expansion due to induced thermal stresses and the traffic loads, the freshly cast comparable kind of overlay test slab is exposed to mixed displacement mode. By providing cyclic vertical load with a load efficiency factor of zero, which introduced differential deflection at the level of the existing fracture, the traffic load is replicated.

7. **Method of Analysis and Performance Indicators**

The stiffness modulus and shear modulus of the overlay test slab are estimated based on the variation in tensile strength that is meticulously documented during testing. Investigation is done into how those parameters degrades / decays throughout the course of a simulated heat cycle. Utilizing the notion of cumulative decay, the important engineering parameter that exhibits the lowest number of thermal load simulation cycles for 100%

cumulative decay is chosen. The number of thermal load simulation cycles necessary to achieve 100% cumulative decay of a key parameter—hereafter referred to as the overlay life—is also calculated. Base isolation effectiveness factor (BIEF), which takes crack relief ness of the OGAC into consideration, is evaluated using computed overlay life. Performance indices for overlay life include the number of simulated thermal load cycles and BIEF. The decay parameters of the overlay material are thought of as the regression coefficients of trend line equations fitted in power series for the cumulative decay. The resulting fundamental equation is in terms of "N," or the number of thermal load simulation cycles, but it may also be rewritten in terms of "D," or cumulative decay, which is a more practical form that is comparable to the fatigue law explaining fracture onset. In order to represent the combined phases of fracture initiation and propagation, the equation of cumulative decay in the following form may be used:

$$N = aD^b, \qquad (1)$$

where, N = number of simulated thermal load cycles;

D = cumulative decay of either tensile force, stiffness modulus, or shear modulus;

a and b = regression coefficients representing decay parameters for the asphalt concrete overlay.

Regression coefficient “a” characterizes overlay life in terms of number of simulated thermal load cycles for 100 % cumulative decay. Regression coefficient “b” is the index of durability of an overlay.

8. Results and Discussion

Fig. 6 shows the variation of cumulative decay of tensile force with number of simulated thermal load cycles under both mode of displacement for various overlay test slabs investigated during experimentation. From Fig. 6, the following observations are noted.

1. The rate of cumulative tensile force decay sustained by an overlay in the mixed mode (M) of displacement is substantially larger than the rate in the opening mode (O) of displacement.
2. The bending stiffness of the asphalt concrete (AC) mix near the existing crack plays a crucial function and influences the rate of degradation of tensile strength as a result of the introduction of differential deflection with zero load efficiency factors in mixed mode of displacement.
3. The traditional overlay of DBM exhibits less cumulative deterioration in tensile force at the beginning for mixed mode than for opening mode, in contrast to the overlay of porous OGAC mix. This might be explained by the fact that DBM overlay has a higher initial bending stiffness than OGAC overlay. The intersection of two curves, in the case of DBM overlay, indicates the number of cycles past which the bending stiffness is not a factor in tensile strength. According to DBM, there are 55 cycles after which it stops enhancing tensile strength; as a result, the rate of cumulative tensile force degradation grows considerably more quickly than it would for merely opening mode of displacement.
4. Due to its porous nature, open graded asphalt concrete (OGAC), especially the unreinforced OGAC overlay, has essentially little bending stiffness.
5. Even though the cumulative decay of tensile force for the mixed mode of displacement for the unreinforced OGAC overlay starts out less than the opening mode, it increases at a significantly faster pace with the quantity of simulated thermal as well as traffic loading cycles. Cumulative decay of the tensile force for OG-M is 100% whereas that for OG-O is roughly 75% at the 550th thermal load simulation cycle.

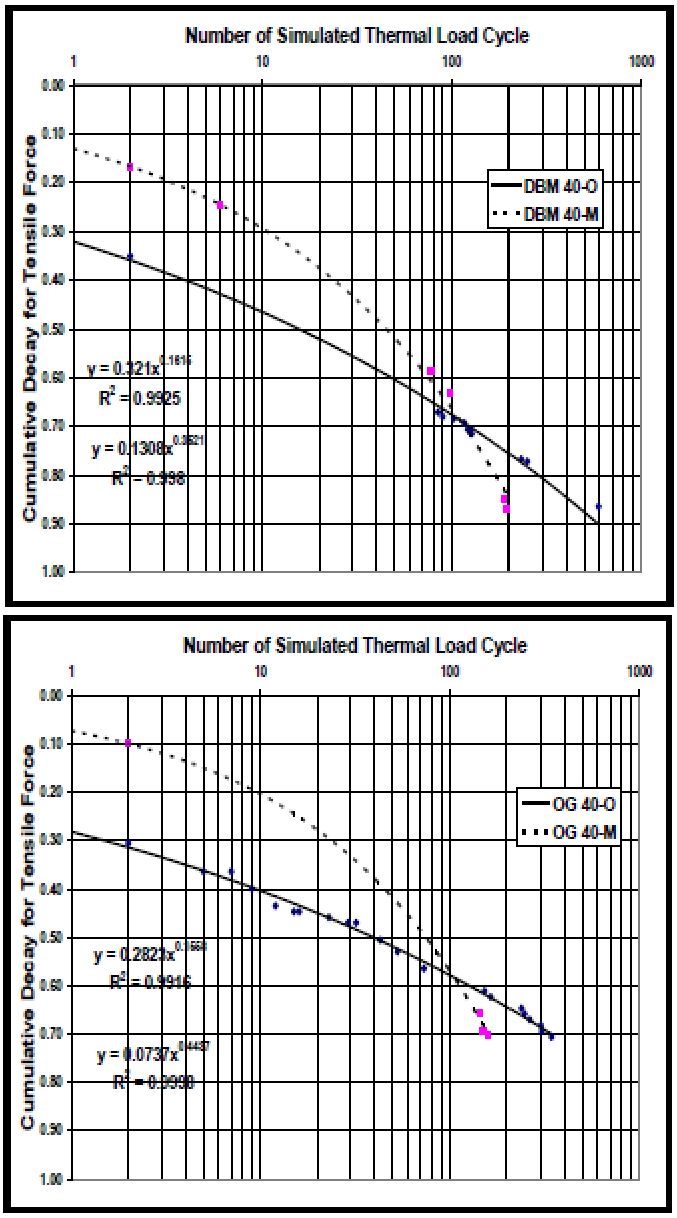

Fig. 6 Cumulative decay of tensile force with number ofsimulated thermal load cycles

For various overlay test slabs explored during investigation, Fig. 7 illustrates the variation of cumulative stiffness decay with number of simulated thermal load cycles under opening mode (O) and mixed mode (M) of displacement. The following conclusions are drawn from Fig. 7.

1. Under mixed mode (M) of displacement, the rate of cumulative stiffness modulus degradation is substantially larger than under opening mode (O) of displacement. Large tensile strain is produced when differential deflection is introduced into a mixed mode of displacement, which leads to a large cumulative decay in stiffness modulus

2. Both the DBM overlay and the OGAC overlay (OG) without reinforcement sustain the same damage as a result of differential deflection. DBM-M displays 100% at the 70th simulated thermal load cycle, while OG-M displays 100% cumulative stiffness modulus decay during the 72nd simulated thermal load cycle. This is caused by the fact that OGAC has more air gaps than DBM, which serves as a cushion layer. The open OGAC structure may prevent energy from building up at the crack tip, which is why OG-M performs well when compared to DBM-M.

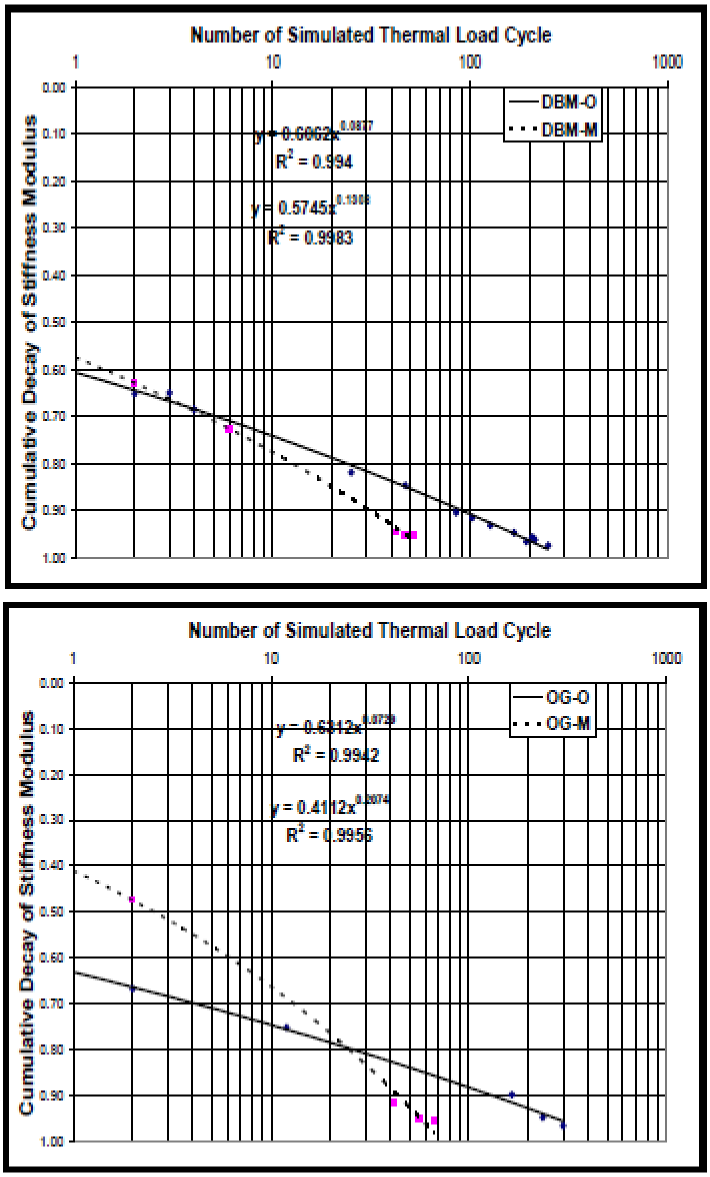

Fig. 7. Cumulative Decay of stiffness Modulus with a number of simulated thermal load cycles.

The critical overlay lifetimes for opening and mixed modes of displacement based on 100% cumulative decay are calculated using the trend line equations of cumulative decay as shown in Figures 6–8.

Table 2. Critical equation of Cumulative decay

Overlay Test Slab designation	**Critical Equation of Cumulative Decay**		**Overlay Life**	
	Opening (O)Mode	**Mixed (M) Mode**	**O**	**M**
DBM	$N=301.10Ds^{6.192}$	$N= 69.229Ds^{7.645}$	301	69
OG	$N= 551.05Ds^{13.717}$	$N= 72.590D_S^{4.821}$	551	72

The table demonstrates that differential deflection under mixed modes of displacement results in a general decrease in the lifespan of all overlays. When the stiffness modulus parameter is used to account for the tensile strain absorbed by an overlay, the overlay's life is reduced. This suggests that taking into account only tensile strength when examining the fracture retardation capabilities of overlays may not be the best course of action, especially for the porous asphalt concrete mix known as OGAC. Therefore, taking stiffness modulus into account, OGAC overlay (OG-M) has demonstrated nearly the same overlay life as the traditional DBM overlay (DBM-M) and demonstrated its usefulness as a crack relief layer. This finding demonstrates that, despite the fact that the open structure of the OGAC mix lowers the stiffness modulus of the overlay system, it also has a cushioning effect that is advantageous for restoring old, damaged pavement in which differential deflections with zero load efficiency factors are suspected. Since shearing of the overlay due to differential deflection with zero load efficiency factor is the most fatal type of action in crack propagation, every effort should be made to reduce it in order to increase the durability of the newly laid overlay. This is indicated by the large percentage reduction in overlay lives in mixed displacement mode.

9. Conclusion

According to the experimental analysis detailed in this work, the following conclusions can be made.

(i) It may be inferred that the OGAC overlay does not stop the crack from spreading since the traditional DBM overlay degrades more quickly over the course of the simulated thermal stress cycles.

(ii) It is confirmed that the OGAC overlay serves as a crack relief layer since it exhibits a greater number of thermal load simulation cycles in the opening and mixed modes of displacement, respectively.

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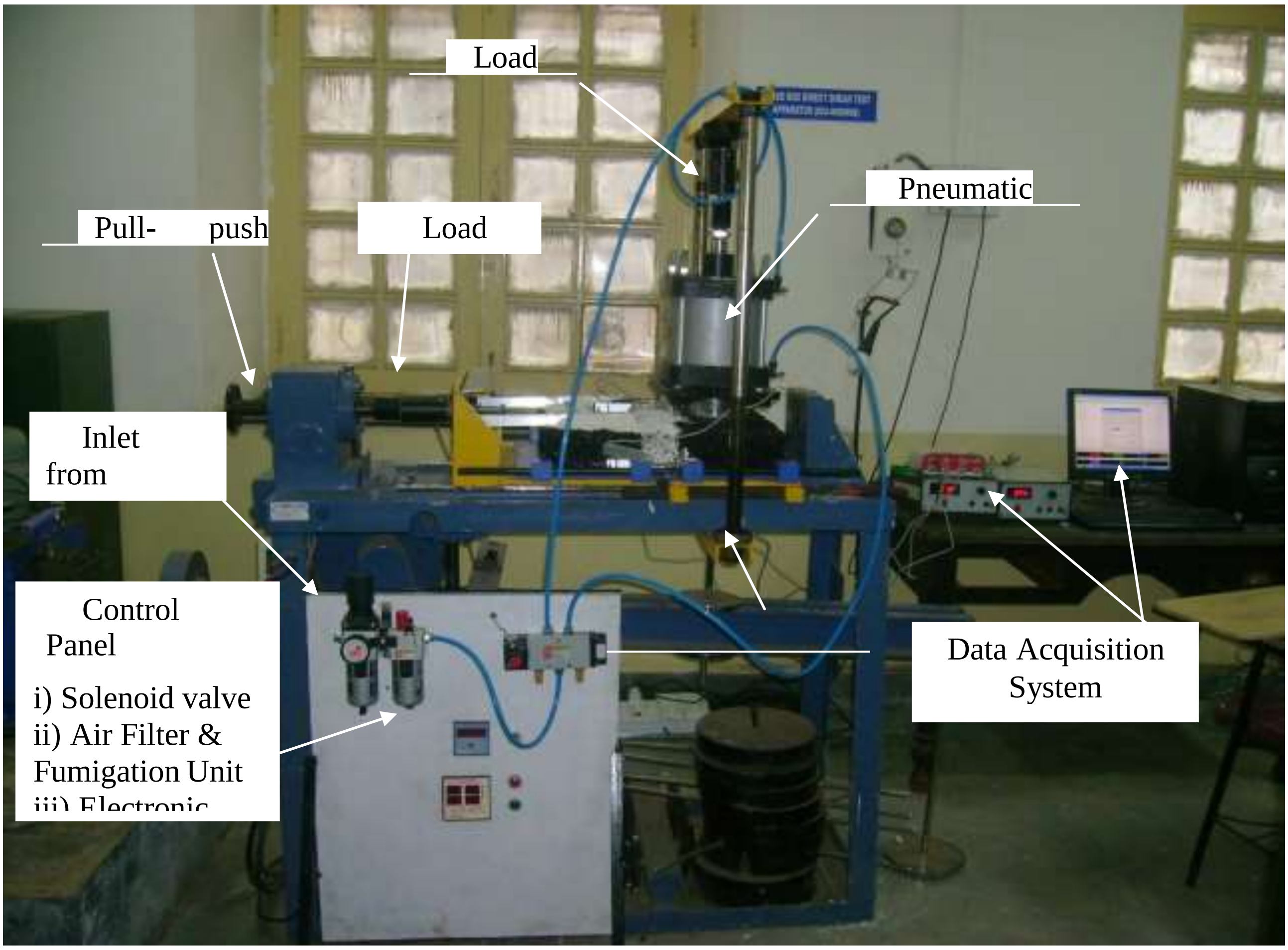

Figure 2. View of the equipment highlighting the special attachment of aluminium frame to the fabricated equipment for simulating top-down cracking.