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The Effect of Mode of Loading on the Comparison between Asphalt Rubber and Traditional Hot Mixes Laboratory Performance

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ABSTRACT: *Experience has demonstrated that Asphalt Rubber Hot Mix (ARHM) is particularly effective in inhibiting reflective cracking through thin overlays placed above cracked pavement surfaces. However little numerical work has been published in this area.Numerical computer analysis using finite element approach investigated the predominant mode of loading in reflective cracking and flexural fatigue phenomena in AC pavements and the results suggest that the reflective cracking phenomena is best simulated in the laboratory by executing tests under controlled load by applying a combination of shear and tensile/compressive loads.This paper presents the comparison between the laboratory flexural and reflective fatigue performance of two hot mixes: a traditional mix and a mix modified with Crumb Rubber. Laboratory tests were executed under stress control and strain control both for flexural fatigue tests and reflective cracking tests. Flexural fatigue tests were performed using SHRP–M009 flexural 4-point bending procedure while and reflective cracking tests were performed using the Reflective Cracking Device. The results indicate that mode of loading effects not only affect the number of cycles to failure but the ratios between the failure modes are different for the two types of mixes studied.*

KEY-WORDS: *Mode of Loading, fatigue and reflective cracking, laboratory tests.*

1. Introduction

Mode of loading affects expected material performance. Until such time as fatigue models based on intrinsic constitutive properties of mixes are known and widely accepted performance tests to capture the fatigue performance must be execute under load, displacement or work control. Furthermore when comparisons between materials performance are to be made them acceptable laboratory standards must be followed.

This paper investigates the effect of mode of loading in raking the fatigue characteristics of two mixes. One mix used conventional binder and a dense aggregate gradation (DGAC) and another used crumb rubber modified binder with a gap graded aggregate gradation (ARHM).

The two modes of loading investigated were controlled load and controlled displacement. To best capture the flexural fatigue in pavements, the flexural fatigue tests should be executed under controlled "work" (stress times strain) by keeping the product of the load times the displacement imposed to the specimen constant. However, controlled stress tests are also adequate for relative performance comparisons as long as they are only carried out until the modulus of the specimen decreases by 50%.

California and Arizona specifications, allow up to a 50% reduction of the bituminous layer thickness, if ARHM is used to inhibit reflective cracking. In the present study, some of these differences were quantified based on behavioral performance tests conducted in the laboratory.

The addition of properly graded crumb rubber to the binder used in the bituminous mixture gives it more resilience, such that it slows down the crack propagation mechanisms. This increase in resistance has been broadly proven by the vast experience in the American Southwest, especially in Arizona.

The capability of a mix to resist reflective cracking was also investigated using the reflective cracking device. In this case only controlled load was used. A combination of shear and tension/compression axial loads was imposed to the specimen.

2. Materials

The material used in this study was crushed granite to which a small percentage of lime was added. Figure 1 shows a comparison of the aggregate gradation used in the ARHM and DGAC mixes used.

The bitumen used was a PEN 35/50, which graded as a PG64-16 from a light Arabian crude source. In the ARHM case, the bitumen was modified through the addition of 18% tire crumb rubber.

Stress control tests under flexural fatigue and reflective cracking tests under load control ranked by the same ratio the fatigue lives of AHRM and DGAC. That ratio was about 10.

It appears possible to develop correlations between flexural fatigue life and reflective cracking fatigue life.

7. References

[PAI 2000] Pais, J.C., Sousa, J.B., Way, G.B. and Stubstad, R.N. "An Overlay Design Method for Reflective Cracking", Asphalt Rubber 2000, Vilamoura, Portugal, 2000.

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[SOU 2000 b] Sousa, J.B., Pais, J.C., Saïm, R. and Stubstad, R.N. "Development of an Overlay design Method based on Reflective Cracking Concepts " *CONSULPAV report to Rubber Pavements Association, Walnut Creek 2000.*

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This paper presents the comparison between the laboratory flexural and reflective fatigue performance of two hot mixes: a traditional mix and a mix modified with Crumb Rubber. Laboratory tests were executed under stress control and strain control both for flexural fatigue tests and reflective cracking tests. Flexural fatigue tests were performed using SHRP–M009 flexural 4-point bending procedure while and reflective cracking tests were performed using the Reflective Cracking Device. The results indicate that mode of loading effects not only affect the number of cycles to failure but the ratios between the failure modes are different for the two types of mixes studied.

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The bitumen used was a PEN 35/50, which graded as a PG64-16 from a light Arabian crude source. In the ARHM case, the bitumen was modified through the addition of 18% tire crumb rubber.

The addition of rubber was achieved through a rotational mixer, at a 180°C temperature and approximately 60 minutes reaction time.

The rubber used for the modification of the bitumen is supplied as crumb (ambient grind); the grading of the rubber is shown in Figure 2.

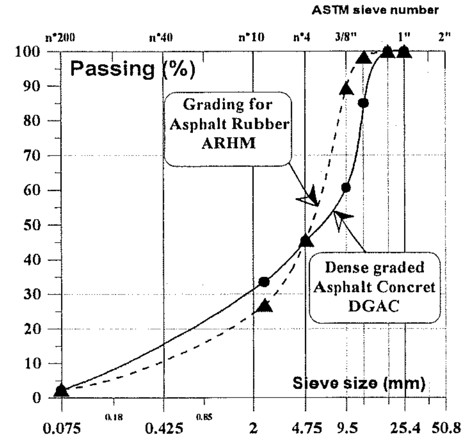

Figure 1. *ARHM and DGAC Gradation Comparison*

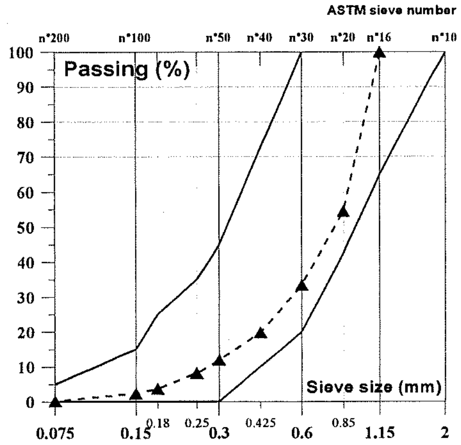

Figure 2. *Rubber Grading Curve*

2.1. Manufacture of Samples

The binder content for each grading was 8% for ARHM and 5% for DGAC. Compaction was made with a steel roller in a heating mould, in order to maintain compaction temperature (AASHTO PP3-94: *Standard Practice for Preparing Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor*). The compacted slabs were sawed and cored with the appropriate dimension for each type of test.

For determining flexural fatigue life, beam specimens of 380 mm long by 50 mm thick by 63 mm wide were used. For determining the reflective cracking fatigue behavior, core specimens of 150 mm diameter and 50 mm height were used.

The specimens were submitted to bulk density tests, with and without paraffin, respectively in accordance with Standards Test Method:

- ASTM D 1188-96 (*Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens*)
- ASTM D 2726 –96a (*Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures*).

The theoretical maximum density test at 25°C (ASTM D 2041-95: *Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures*) was achieved after flexural fatigue testing in order to determine air void content. Some additional tests like determining the asphalt content was performed in accordance with ASTM D 6307: *Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method*), this test was done to verify the content of asphalt binder.

All the results are presented in Table 1 and the influence of paraffin on porosity is represented in Figure 3.

The Hot Mix Asphalt (HMA) was submitted to short-term aging to simulate the pre-compaction phase of the construction phase, and the specimens were subjected to long-term aging to simulate the aging that occurs over the service life of a pavement (AASHTO PP2-94: *Standard Practice for Short and Long Term of Hot Mix Asphalt (HMA)*).

It can be observed from Table 1 that the ARHM was compacted to lower air void contents than the DGAC mix. Because the actual goal of this paper is to demonstrate the differences in mode o loading and not actually between mixes the specimens were used. However comparisons between mix performance are appropriate the air void content difference is kept in perspective.

Table 1. *Specimen characteristics*

Type of Mixe	*Mode of Loading*	Beam Sample	Density (g/cm3)		TMD (g/cm3)		Asphalt Content (%)		Porosity (%)	
			ASTM D1188	ASTM D2726	Theorical	ASTM D2041	Mixing (Theorical)	ASTM D6307	ASTM D1188	ASTM D2726
DGAC	**Strain 10 Hz, 20 °C**	MDA-L2	2.089	2.287	2.400	**2.418**	5.0	/	13.6	5.4
		MDF-T2	2.100	2.301					13.1	4.8
		MDA-L3	2.139	2.284					11.5	5.5
		MDA-L4	2.149	2.275					11.1	5.9
ARHM		RDB-L4	2.238	2.282	2.322	**2.317**	8.0	**7.9**	3.4	1.5
		RDA-L1	2.204	2.259					4.9	2.5
		RDA-L2	2.215	2.268					4.4	2.1
		RDB-L3	2.228	2.271					3.8	2.0
DGAC	**Stress 10 Hz, 20 °C**	MFA-L2	2.111	2.294	2.400	**2.418**	5.0	**4.9**	12.7	5.1
		MDF-T4	2.168	2.279					10.3	5.7
		MFA-L3	2.120	2.294					12.3	5.1
		MFA-L4	2.169	2.286					10.3	5.5
ARHM		RFA-L1	2.207	2.257	2.322	**2.312**	8.0	/	4.6	2.4
		RFB-L4	2.237	2.290					3.2	1.0
		RDF-T2	2.215	2.269					4.2	1.8
		RFB-L3	2.216	2.261					4.1	2.2
		RFA-L2	2.227	2.273					3.7	1.7
		RDF-T1	2.210	2.264					4.4	2.1

TMD: Theoretical Maximum Density

ASTM : American Society for Testing and Materials

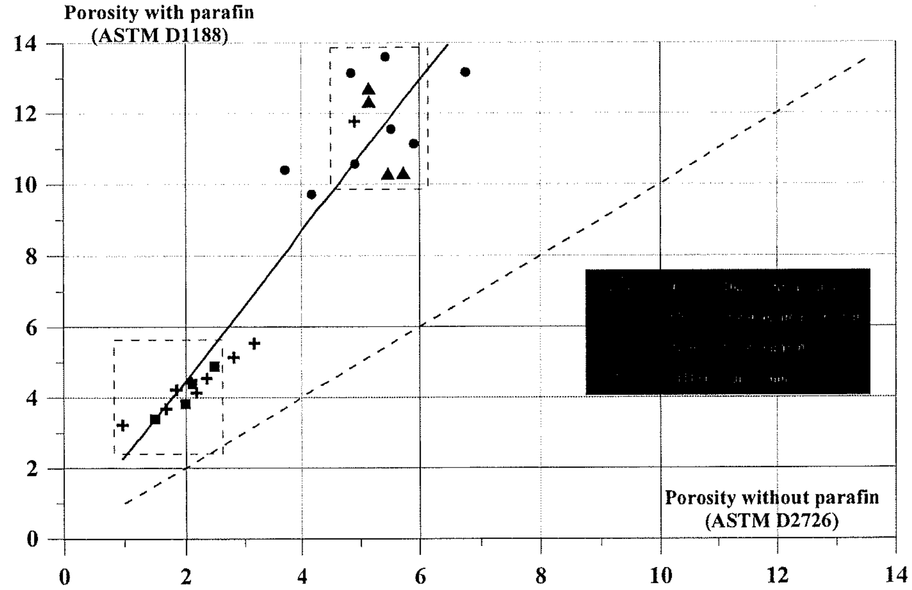

Figure 3. *Influence of paraffin on porosity measurements*

3. Testing program

3.1. Bending tests to determine flexural fatigue life

Flexural fatigue tests were conducted according to the AASHTO TP 8-94 (*Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending*). They are intended to simulate pavement distress due to traffic loads during its expected design life. They also determine fatigue life, stiffness modulus, and the phase angle of the bituminous beams. Fatigue Life is defined as the number of cycles until a 50% decrease of the initial stiffness of the test beam is achieved.

Tests were executed at 20°C and at 10 Hz frequency rate of loading. The schematic configuration of the equipment and mode of operation is presented in Figure 4.

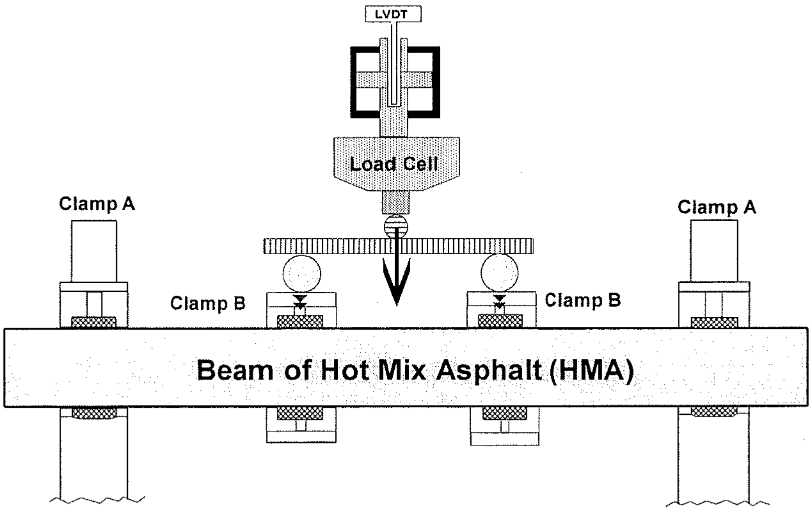

Figure 4. *Schematic representation of flexural beam device to execute fatigue tests*

Two types of testes were executed. One under controlled displacement where the amplitude of the displacement imposed is kept constant throughout the test. It can be observed in Figure 5 that while the strain is kept constant the stress is decreasing. Therefore the modulus decreases and failure is reached when the modulus is 50% of the modulus value at cycle 100. It can also be observed that the amplitude of the phase angle keeps increasing as the specimen sustains more and more damage.

The other mode required a special modification to the ATS program [SOU 2000 b]. If a test is executed only under controlled load them the specimen is forced to accumulate permanent deformation (either in tension or in compression depending on the load). Because failure modes must be isolated, and in this case the investigation was based only on fatigue, it was necessary create a software control algorithm that would permit application of always the same load even when the fatigue damage was occurring while forcing the specimen to return to its original position. This was achieved by executing the test always under control displacement (therefore programming the sine wave to return always to the initial position) but the magnitude of the sine displacement was changed (increased) at each cycle to insure that the amplitude of the load remained constant (as the modulus decreased).

The typical results of the test are presented in Figure 6. It can be observed that as the stress was maintained constant (with an acceptable tolerance level programmed into to the software) the amplitude of the strain (displacement) was always increasing. It can be observed that the magnitude of the modulus decreased and the phase angle increased as expected. However the rate of change in the modulus was much higher because the damage due to higher strain levels is higher at each load cycle.

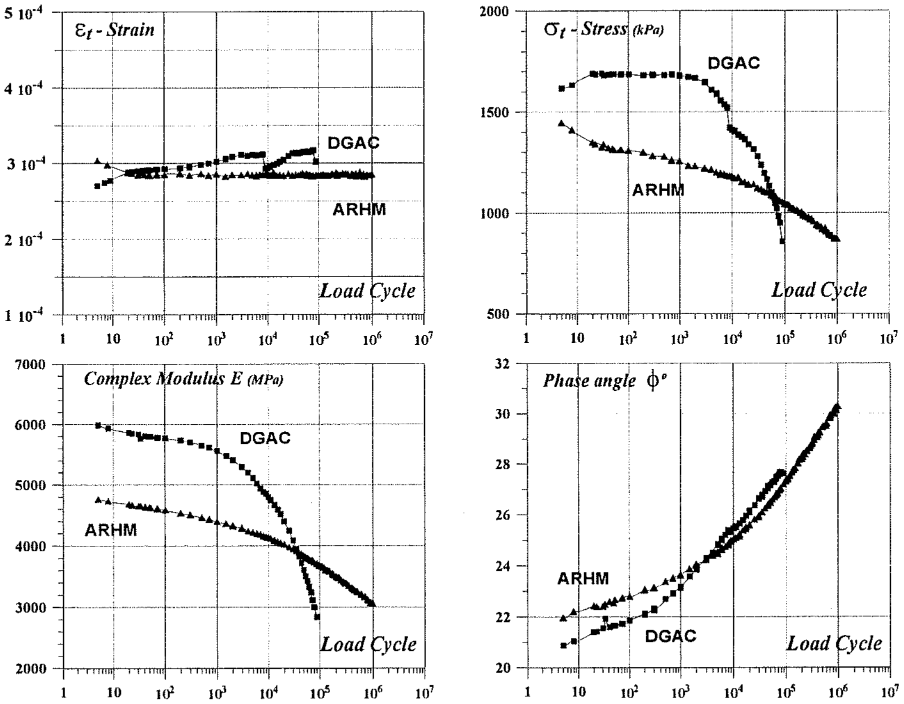

Figure 5. *Typical results of displacement controlled test*

A total of 8 specimens were tested under displacement control and a total of 9 specimens were tested under load control. The results of these tests are presented in Table 2.

3.2. Reflective cracking tests

The Reflective Cracking Device (RCD) [SOU 96] was used to simulate the crack phenomena on an overlay. Tests were executed under controlled force at 20°C, as recommended by [SOU 2000 a]. Combined shear and axial forces were applied to the specimen at a 10 Hz frequency rate of loading. The crack width used was 10 mm. The horizontal force was always twice the shear force as per recommendations presented in [PAI 2000]. The schematic configuration of the crack zone and test equipment is presented in Figure 7.

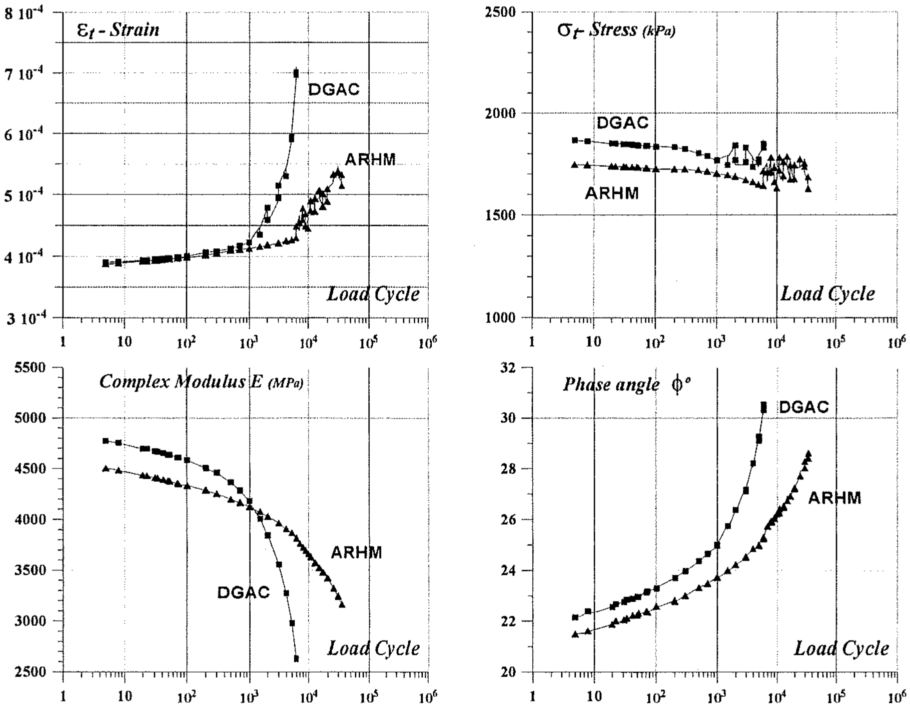

Figure 6. *Typical results of load controlled test*

Table 2. *Flexural fatigue test results*

Type of Mixe	*Mode of Loading*	**Beam Sample**	ε_{100} (10^{-6})	E_{100} (MPa)	φ_{100} (°)	σ_{100} (kPa)	**Nf (50%)** Cycles
DGAC	**Strain 10 Hz, 20 °C**	MDA-L2	660	4037	26.8	2664	1,416
		MDF-T2	688	4201	25.3	2892	2,278
		MDA-L3	292	5770	21.9	1687	89,657
		MDA-L4	380	5892	21.7	2239	27,728
ARHM		RDB-L4	699	3967	29.1	2774	65,511
		RDA-L1	705	3523	26.4	2483	87,916
		RDA-L2	290	4812	21.6	1395	4,108,505
		RDB-L3	315	4251	24.6	1339	1,976,901
DGAC	**Stress 10 Hz, 20 °C**	MFA-L2	594	4719	25.3	2802	1,510
		MDF-T4	581	5777	24.0	3358	2,170
		MFA-L3	400	4587	23.3	1835	7,660
		MFA-L4	271	5640	21.2	1528	35,100
ARHM		RFA-L1	857	3507	27.6	3005	3,660
		RFB-L4	704	3940	28.7	2774	6,658
		RDF-T2	649	4477	23.7	2907	6,850
		RFA-L2	290	4902	20.9	1423	537,749
		RDF-T1	398	4337	22.5	1727	99,608

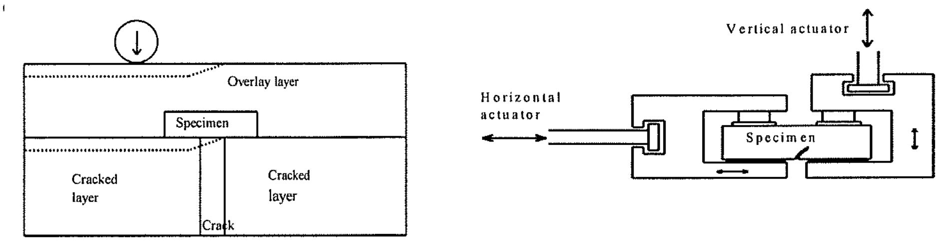

Figure 7. *Schematic representation of the crack zone and Reflective Cracking Device*

Figure 8 shows the amplitude of the shear force (vertical) and the amplitude of the axial force (horizontal) applied to the specimen. The initial 100 cycles correspond to the gradual adaptation of the software under automatic gain control. However it can be observed that after the 100th cycle the amplitudes are kept within very narrow margins. It can be observed that the input to ARHM and DGAC mixes was identical. The resulting displacements can be observed in Figure 9 however are not identical. It can be observed that DGAC mixes started increasing the displacement amplitude much sooner then AHRM.

In consequence the equivalent shear (vertical) and axial (horizontal) modulus changed as presented in Figure 10. For the purpose of this research it was decided to consider failure when the modulus reached 20 MPa.

4. Results from flexural fatigue tests

Figure 11 presents a summary of strain-controlled tests and displacement controlled test plotted against the strain at cycles 100 (in displacement control tests that same strain was maintained while in the load control tests that stain was progressively increasing)

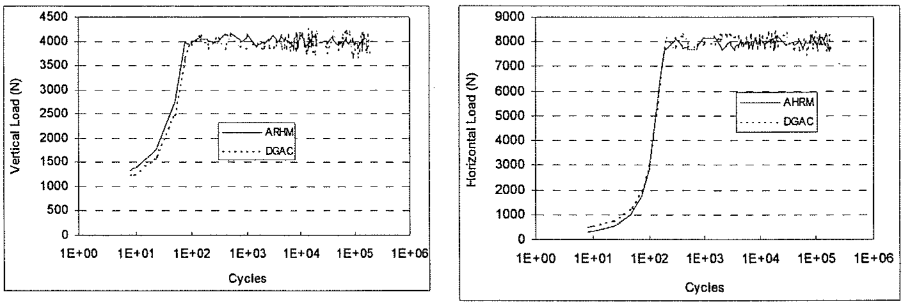

Figure 8. *Vertical and horizontal loads applied to the specimens*

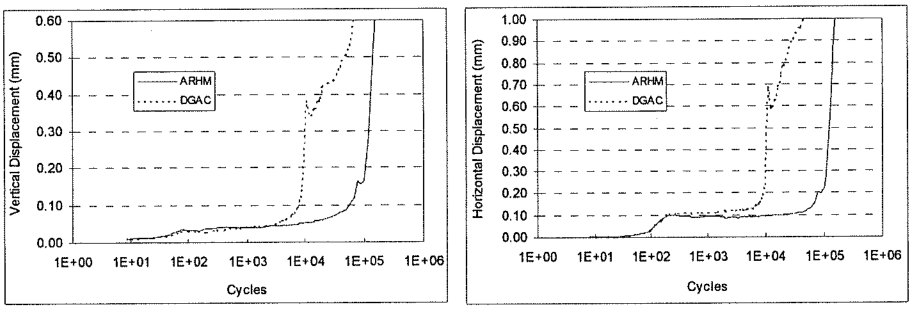

Figure 9. *Vertical and horizontal displacements measured in the specimens*

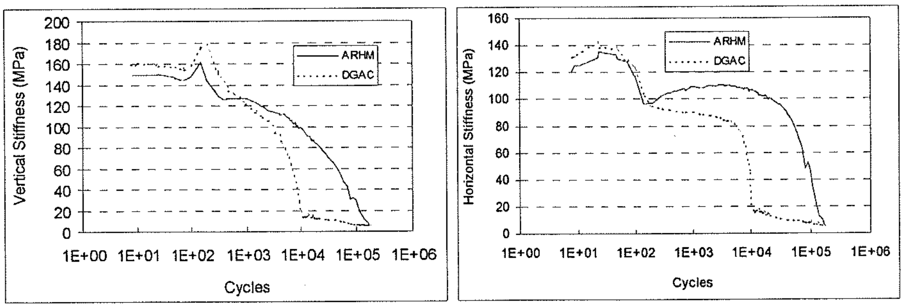

Figure 10. *Vertical and horizontal moduli calculated for the specimens*

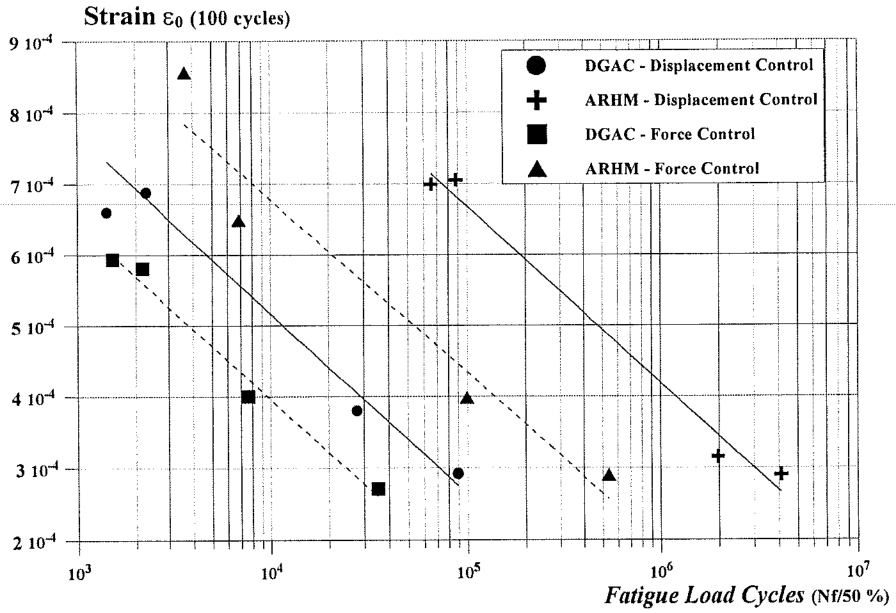

Figure 11. *Flexural fatigue results plotted against the initial strain*

It can be observed, as expected, that for the same material the displacement controlled tests do last longer then stress controlled tests. It is also interesting to note that the AHRM out preformed the DGAC by a factor of about 10 in stress control tests and by a factor of 25 in strain control tests.

In Figure 12 the same results are plotted against the stress at cycle 100 (in stress controlled tests that stress was maintained while in displacement controlled tests that stress was slowly decreasing).

Except for some minor differences in the testes under stress control due to different sample void content the trend is identical. However the differences are not as pronounced as in the displacement controlled tests. Load control tests appear to be more sensitive to air void content.

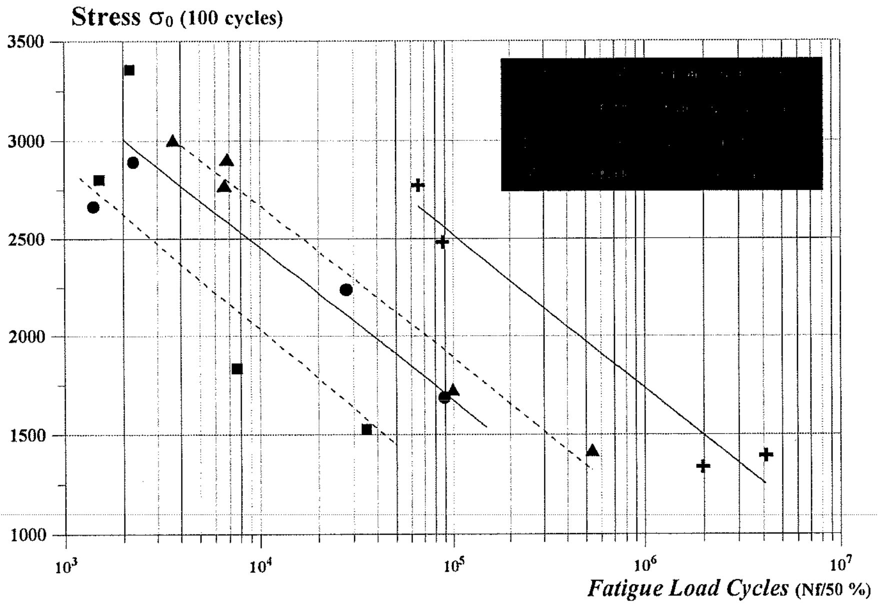

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Figure 12. *Flexural fatigue results plotted against the initial stress*

5. Results from reflective cracking tests

A summary of the results of the reflective cracking tests is presented in Figure 13. The average shear stress is computed dividing the shear load applied by the length and height of the specimen. Specimens used in this analysis had 20, 35 and 50 mm heights.

The results indicate that overall the same factor of 10 is still present in the ratio between AHRM and DGAC resistance to repeated loadings under stress control. It is clear that dispersion of the values is higher then in the flexural fatigue tests in part due to the nature of the test in it self in part due to a higher variability in air void contents (between 1.8% and 4.2% for ARHM and between 1.5% and 3.5% for DGAC)

It appears possible to develop some correlation between the results from RCD tests under stress control and those obtained from flexural fatigue tests.

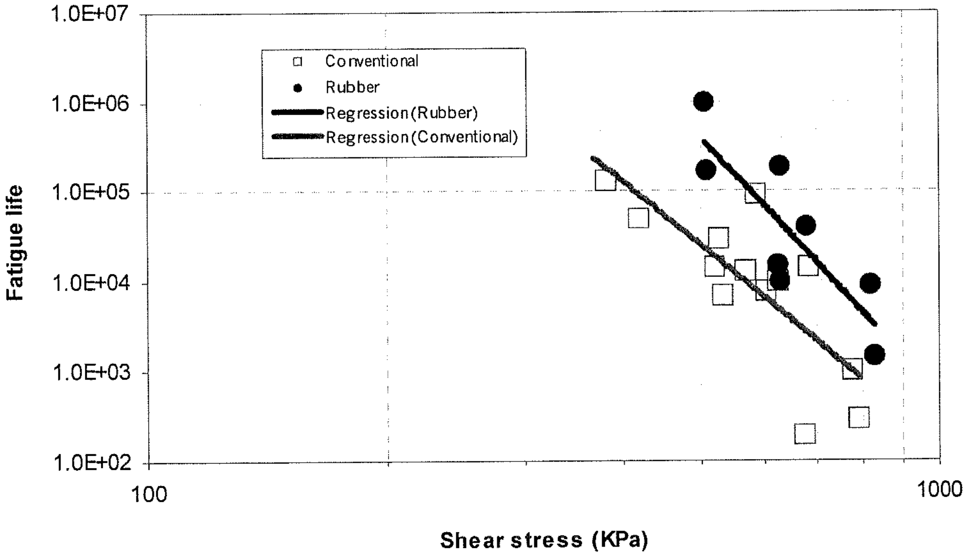

Figure 13. Reflective cracking test results

6. Summary and conclusions

Three mode of applying repetitive loading to mixes were investigated in this research; (i) flexural fatigue load control tests, (ii) flexural fatigue displacement control tests and (iii) reflective cracking load control tests.

Two types of mixes where investigates namely dense graded asphalt concrete and asphalt rubber hot mixes produce in laboratory with rolling wheel compactor and subjected to short term oven aging.

It was observed, as expected, that displacement controlled tests lasted longer then stress control tests by a factor of about 10 for DGAC and about 25 for ARHM.

It was also observed that AHRM had better flexural fatigue lives then DGAC at the same strain level.

Stress control tests under flexural fatigue and reflective cracking tests under load control ranked by the same ratio the fatigue lives of AHRM and DGAC. That ratio was about 10.

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