

Deformation Behaviour of Asphaltic Mixtures under Constant Strain Rate Tests

H. Taherkhani

Associate professor, University of Zanjan, Zanjan, Iran,
email: htaherkhanik@yahoo.com

Abstract

This paper explains the deformation behaviour of asphaltic mixtures under constant strain rate loading. Two types of asphaltic mixtures which are used in the UK Pavements, namely a 10 mm DBM and a HRA30/10, have been selected for this study. Uniaxial constant strain rate tests over a range of strain rates and temperatures were conducted on the specimens made of these mixtures. The radial and axial strains, and the axial loads were measured during the testing, and the results were used for investigation of the mixtures' behaviour. The elastic modulus, strength and the volumetric behaviour of the mixtures have been studied and compared for the mixtures.

Key Words: Asphaltic mixtures, strain rate, elastic modulus, axial and radial strain

Introduction

Wheel track rutting in flexible pavements can be a serious problem and permanent deformation in the asphalt layers can be a significant contributory factor. It is desirable to develop constitutive models which can well simulate the deformation behaviour of asphaltic mixtures. This needs experiments to be conducted on the materials at different conditions that they may experience in roads. In reality, the asphaltic materials in a pavement structure are under a complex three dimensional state of stress which has a significant effect on its deformation properties. These stress conditions are difficult to replicate in the laboratory and uniaxial and triaxial testing is often undertaken. Uniaxial test under constant strain rate is one of the experiments that can yield valuable data for investigation of asphaltic materials. The tests were conducted to be used for development of elasto-visco-plastic constitutive models in an ongoing joint study between the University of Nottingham and the Delft University of technology.

The Volumetric deformation behaviour of asphaltic layers affects the shape of rut in flexible pavements and needs to be investigated. Analysis of flexible pavements using elastic theory assumes that the Poisson's ratio of asphaltic mixtures is 0.5. In conditions that the materials dilate, this assumption is not correct, and; therefore, more investigation of the volumetric behaviour of the mixtures is required to be considered in the analysis and design of flexible pavements. The volumetric deformation behaviour of idealised asphaltic mixtures (bitumen and aggregate with a simplified grading) with various volume fractions (low and high volume fraction) of different types of inclusion (in terms of size and shape) has been investigated (1, 2, 3, 4, 5 and 6). These studies showed that the mixtures with high volume fraction of aggregates dilate under uniaxial and triaxial compressive loading (dilation ratio more than 1). However, the mixtures with low volume fraction of aggregate deformed at constant volume.

This paper explains the uniaxial constant strain rate test results conducted on two types of asphaltic mixtures over a range of strain rates and temperatures. A 10 mm DBM was selected as a continuously graded mixtures and a HRA30/10 as a gap-graded mixture. Deformation behaviour of the two mixtures is compared.

Materials

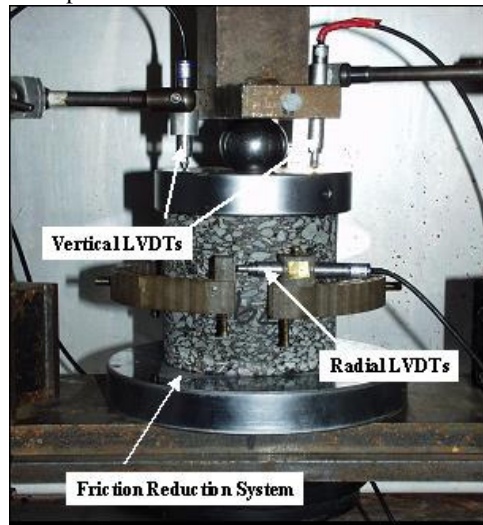
Two generic types of asphaltic mixture were selected for this study; a 10mm Dense Bitumen Macadam (DBM) (7) and a 30/10 Hot Rolled Asphalt (HRA) (8). These mixtures were chosen because different types of behaviour were anticipated. The DBM is a continuously graded mixture that relies primarily on aggregate interlock for its strength, whereas the HRA is a gap graded mixture that relies more on the properties of the bitumen/sand/filler mortar. Granite aggregates and a 70/100 penetration grade of bitumen were used to produce both mixtures. The target air void content was chosen to be 4% for both mixtures and binder contents of 5.5% and 8% were chosen for the DBM and HRA respectively.

Cylindrical specimens, 100mm in diameter and 100mm in height, were manufactured for the testing programme. The mixtures were compacted in a 150mm diameter gyratory compactor at a temperature between 150°C and 156°C. After cooling, the mixtures were extruded from the mould and a 100mm diameter core was

taken from the centre of the specimen. Both ends of the specimen were trimmed and the air void content was measured. Only specimens with an air void content between 3% and 5% were selected for testing. The specimens were stored in a cold room at 5°C until they were required for testing.

Test Equipment and Instrumentation

An Instron 1332 loading frame with a temperature-controlled cabinet (-5°C to 50°C) and a servo-hydraulic actuator with a load capacity of ±100 kN and ±50mm axial stroke was used for the testing programme. Photograph 1 shows the experimental set-up for the compressive uniaxial testing undertaken in this study. In this test, the specimen is placed between two polished chrome plates. A friction reduction system, comprising a layer of plastic film sandwiched between two layers of soap, was used to minimize lateral confinement due to friction between the platens and the specimen. Two LVDTs, positioned on the top platen were used to measure the axial deformation of the specimen and an LVDT mounted on the collar was used to measure radial deformation at the mid-height of the specimen.



Photograph 1- Uniaxial test set-up.

Using the equipment and instrumentation explained above, uniaxial constant strain rate tests were undertaken at the conditions summarised in Table 1. Each specimen was kept in a temperature-controlled cabinet and conditioned at the testing temperature, for at least 12 hours before commencement of the test to ensure that it was at a uniform temperature. When ready to start a test, the specimen was taken from the conditioning cabinet and the specimen's end surfaces were lubricated with the liquid soap called 'Zalpon' supplied by Diverseylevler Limited. The specimen was then placed on a polished chrome platen whose surface had also been lubricated with the liquid soap. A thin layer of the plastic film was placed between the specimen and the polished plate. The plastic film was a polyethylene foil, named EXCEEDTM, supplied by Exxon Mobil with low yield strength, high ultimate strain and high resistance to rupture. Before placing the top platen, the collar, instrumented with the radial LVDT, was fitted at mid-height of specimen. The top platen was then placed centrally on the specimen after lubricating its surface with the liquid soap and putting the plastic film between the platen and the specimen. The axial LVDTs, mounted on two magnetic bases, were then placed on the top platen diametrically opposite each other. After placing a steel ball on the top platen, the actuator was brought into position using the Rubicon control system so that the ball was nearly touching the upper ram.

As the temperature-controlled cabinet door was open during the specimen instrumentation, therefore, before starting the test, the door was closed for 20-40 minutes, depending on the difference between the room and test temperature, to ensure that the temperature of the specimen and the cabinet were both at the testing temperature. Before starting the test, a compressive pre-load of approximately 2% of predicted strength in constant strain rate tests, was applied to the specimen. This pre-loading was to take up any slack in the system and allow the friction reduction system to deform in order to minimise subsequent measurement errors.

Following the preloading, a constant axial displacement rate was immediately applied to the specimen and was maintained constant until an axial strain level of 13%. Visual inspection of specimens in the trial tests showed that above an axial strain level of about 13% the specimen had wide vertical cracks and the axial strain increased

at a high rate which could damage the instrumentation. During the testing, the axial and radial deformations of the specimen and load measurements at pre-set time intervals were logged.

Table 1-Uniaxial constant strain rate test conditions.

Temperature (°C)	Strain Rate (1/s)	
	HRA30/10	10mm DBM
10	0.00005, 0.0005, 0.005	0.00005, 0.0005, 0.005
20	0.00005, 0.0005, 0.005	0.00005, 0.0005, 0.005
40	0.00005, 0.0005, 0.005	0.00005, 0.0005, 0.005

Test Results

Figures 1 and 2 show typical results from the constant strain rate tests for the 10 mm DBM and HRA30/10, respectively, at the same selected test conditions, where the axial stress is plotted against the axial strain. In all of the experiments, the stress-strain (axial and radial) relationships were similar, consisting of an ascending portion, up to a peak stress, known as steady-state stress (9), followed by a descending softening portion. The following points are the observations from the constant strain tests:

- Irrespective of temperature, strain rate and type of mixture, the plot of axial stress against the axial and radial strain can be divided into four distinct regions: an initial linear region, an inelastic strain hardening region, the peak stress and the descending strain softening region, as shown in Figure 3.
- Both mixtures showed an increase in the peak stress with increasing strain rate and/or decreasing temperature. Figure 4 shows the peak stress as a function of strain rate and temperature for the mixtures. It can also be seen that the peak stress values for the DBM are higher than those for the HRA.
- For each test conditions, Young's modulus of the mixtures was calculated from the axial stress and strain data taken at the beginning of the test (the linear region in Figure 3). Figure 5 shows Young's modulus of the mixtures as a function of strain rate and temperature. The figure shows that, in a similar manner to the peak stress, Young's modulus increases with decreasing temperature and/or increasing strain rate. It can also be seen from the figure that, for comparable test conditions, Young's modulus of the continuous graded DBM mixture is higher than that of the gap graded HRA mixture.
- Consistent with Dunhill (10) and Erkens's (11) findings, there is an approximately linear relationship between the peak stress (compressive strength) and Young's modulus, which can be seen in Figure 6.
- As can be seen in Figures 1 and 2, the stress-strain curves for the DBM show a sharper peak stress-strain response compared to a more rounded peak stress-strain response of the HRA, which means that the DBM mixture fails in a more brittle manner compared to the HRA.
- The axial strain levels corresponding to the peak stress were taken for all test conditions which are summarised in Figure 7. The data points at each temperature are for different strain rate levels with no strain rate dependent pattern. The scattered values are thought to be because of experimental errors. It was observed that the strain values are independent of the strain rate. Figure 7 shows that the magnitudes of the axial strain for the DBM mixture were generally lower than those for the HRA. As can also be seen in the figure the axial strain levels corresponding to the peak stress decrease with increasing temperature.

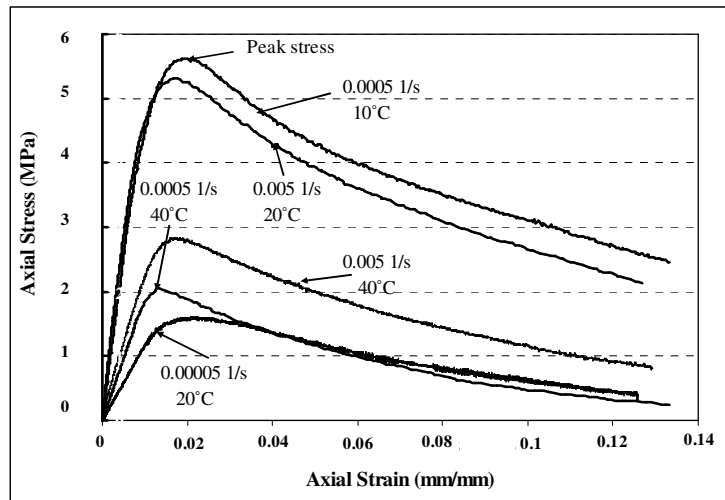


Figure 1-Typical constant strain rate test results for the DBM at selected test conditions.

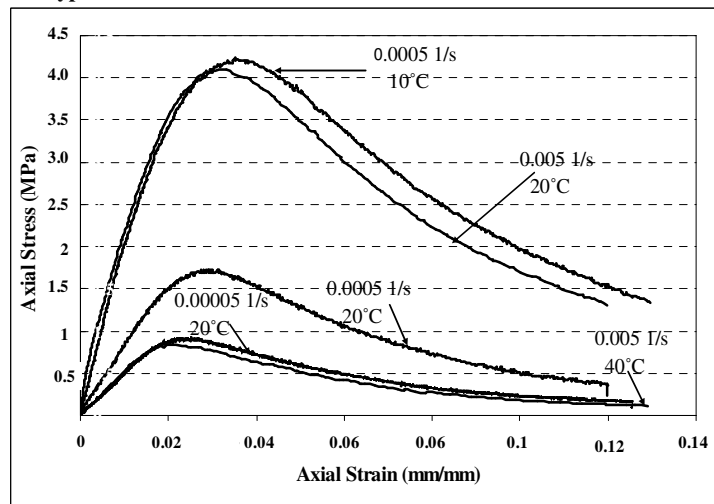


Figure 2-Typical constant strain rate test results for the HRA at selected test conditions.

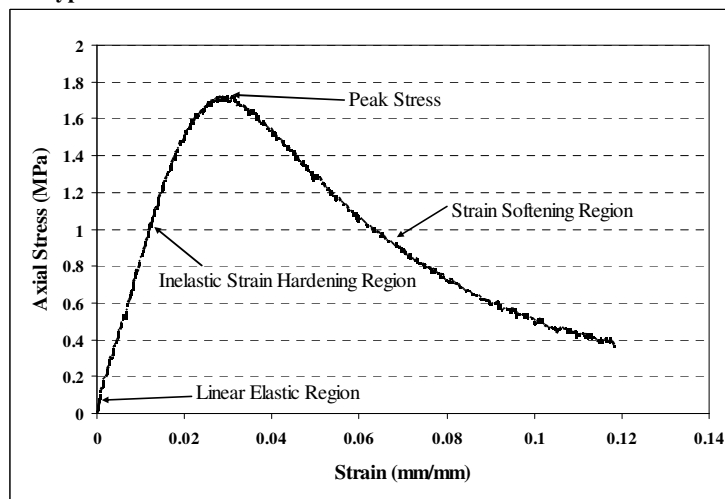


Figure 3-A typical constant strain rate test result for the HRA30/10.

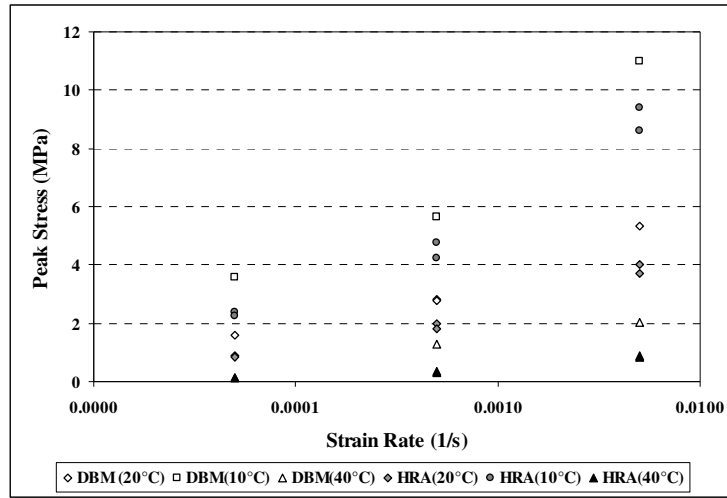


Figure 4-Peak stress of HRA and DBM as a function of strain rate and temperature.

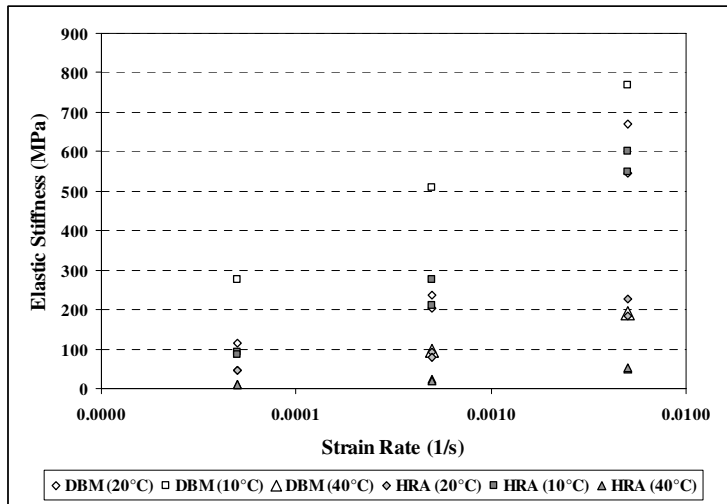


Figure 5- Elastic stiffness of HRA and DBM as a function of strain rate and temperature.

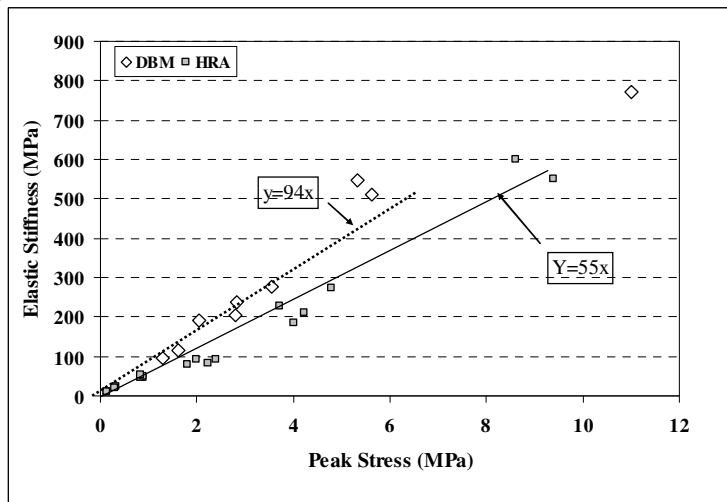


Figure 6-Elastic stiffness of the HRA and DBM against peak stress.

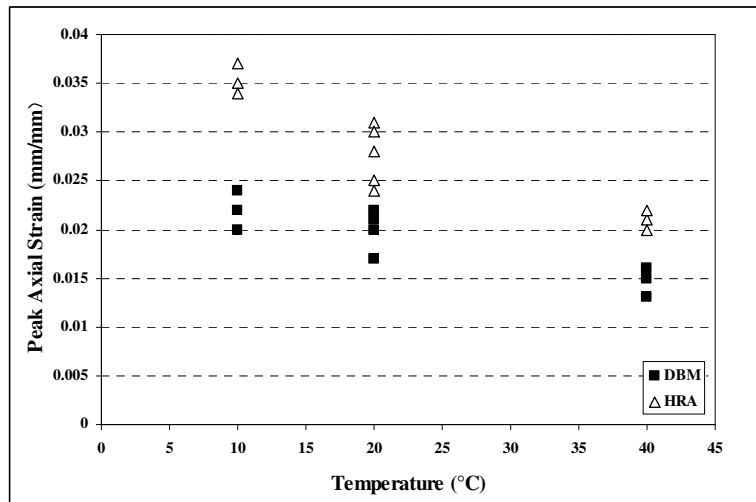


Figure 7-The axial strain at the peak stress for the mixtures.

To study the volumetric behaviour of the mixtures, the radial deformation of the specimens was measured during the constant strain rate tests.

Figure 8 shows a typical result from the constant strain rate tests for the HRA at the test conditions of 0.0005/s and 20°C, where the axial stress is plotted against the radial and axial strains. It can be seen from this figure that, the curve for the radial strain is similar to that for the axial strain with four distinct areas as explained in earlier. The figure shows that, the radial strain values are less than the axial strain up to a level after which, because of dilation, it becomes greater in magnitude than the axial strain. Figure 9 shows the variation of radial strain with axial strain for the HRA at selected test conditions. The figures show that, up to a level, the radial strain increases with axial strain at an increasing rate after which the radial strain varies almost linearly with the axial strain. Similar behaviour has been observed for uniaxial creep tests (12). Figure 9 also shows that, for both mixtures, the dilation gradient increases with increasing temperature. The DBM mixture showed a higher dilation gradient than the HRA. Within the experimental errors, at a specified temperature, the dilation gradient obtained from the constant strain rate and constant stress creep tests (12) were found to be the same.

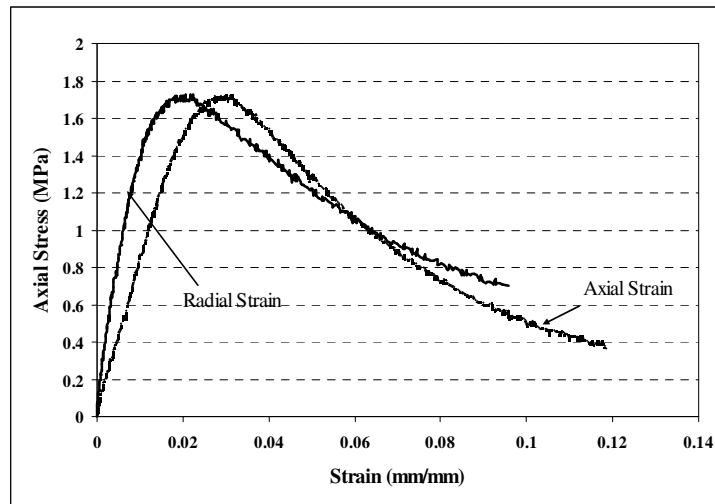


Figure 8-A typical constant strain rate test result for the HRA at 20°C (strain rate of 0.0005/s).

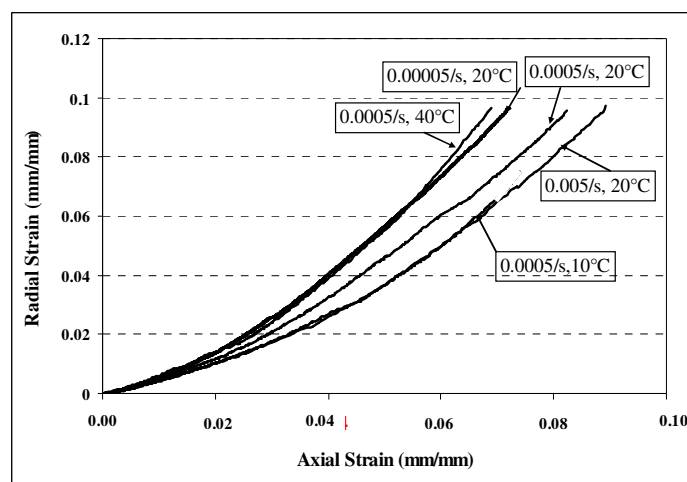


Figure 9- Variation of the radial strain with axial strain for uniaxial constant strain rate tests at selected test conditions (HRA mixture).

Conclusions

The following conclusions can be drawn from this study:

- In the constant strain rate tests, the axial strain level at the peak stress was found to be independent of applied strain rate, decrease with increasing temperature and, at the same test conditions, be generally higher for the HRA than that for the DBM.
- The peak stress in the uniaxial constant strain rate tests increases with increasing strain rate and decreasing temperature.
- At the same test conditions, the peak stress of the DBM was found to be greater than that for the HRA.
- Young modulus of the mixtures was found to increase with increasing strain rate and decreasing temperature.
- A linear relationship was found between Young's modulus and the peak stress of the mixtures.
- Both mixtures were found to dilate under uniaxial constant stress creep and constant strain rate tests.

References

1. Deshpande, V., 'Steady-state deformation behaviour of bituminous mixes.' Ph.D. Thesis, University of Cambridge, Cambridge, 1997.
2. Deshpande, V. and Cebon, D., 'Steady-state constitutive relationship for idealised asphalt mixes.' Journal of Mechanics of Materials 31(4), 1999, pp 271-297.
3. Collop, A. C. and Khanzada, S., 'Permanent deformation behaviour of idealised bituminous mixtures.' Proc. 3rd European symposium on performance and durability of bituminous materials and hydraulic stabilised composites, Leeds UK, 1999, pp 47-58.
4. Collop, A. C. and Khanzada, S., 'Permanent deformation in idealised "Sand Asphalt" bituminous mixtures.' The International Journal of road Materials and Pavement Design 2(1), 2001, pp 7-28.
5. Khanzada, S., 'Permanent Deformation in Bituminous Mixtures.' Ph.D thesis, University of Nottingham, Nottingham, UK, 2000.
6. Ossa, E. A., 'Deformation behaviour of bitumen and bituminous mixes.' Ph.D. thesis, University of Cambridge, Cambridge, UK, 2004.
7. British Standards Institution, 'Coated macadams for roads and other paved areas.' BS 4987: Part1, London, 2003.
8. British Standards Institution. 'Hot rolled asphalt for roads and other paved areas'. BS 594:Part1, London, 2003.
9. Cheung, C. Y., 'Mechanical behaviour of bitumens and bituminous mixes.' Ph.D. Thesis, University of Cambridge, Cambridge, 1995.
10. Dunhill, S., 'Quasi-static characterisation of asphalt mixtures.' Ph.D. Thesis, University of Nottingham, Nottingham, 2002.
11. Erkens, S.M.J.G., 'Asphalt concrete response -determining, modelling and predicting.' Ph.D Thesis, Delft University of Technology, Delft Netherlands, 2002.
12. Taherkhani, H., 'Experimental characterisation of compressive deformation behaviour of asphaltic mixtures', Ph.D. thesis, University of Nottingham, Nottingham, UK, 2006.

