Triaxial testing of asphalt

Essais triaxiaux de l'asphalte

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ABSTRACT: The response of asphalt in conventional triaxial tests has received very little attention in the soil mechanics or pavement literature. As a result, the relative importance of the aggregate and the asphalt binder are not well understood, and in particular how they contribute towards the resistance to permanent deformation. This paper describes the results of a series of conventional drained and undrained triaxial tests on two types of asphalt, stone mastic asphalt (SMA) and dense asphaltic concrete (DAC). Tests without the asphalt binder have been conducted for each asphalt type. Results show that the DAC, which is well-graded and has a bitumen content of about 5%, behaves similarly to the aggregate without the bitumen at conventional soil mechanics rates of loading. However, significant strain rate effects are observed as the rate of loading is increased. For the SMA mixture, which has a higher bitumen content of about 6%, the asphalt appears to affect the frictional resistance of the mixture, and it is also far more significantly affected by strain rate. It is also noted that the asphalt binder has the effect of reducing the effects of strain localisation and allows uniform and barrelling type deformations despite the very dense aggregate.

RÉSUMÉ : La réponse de l'asphalte dans les essais à triaxiaux conventionnels a suscité peu d'intérêt dans la littérature de la mécanique des sols et des chaussées. Par conséquence l'importance relative de l'agrégat et du liant asphaltique n'est pas bien comprise, notamment comment ils participent à la résistance à la déformation permanente. Cet article décrit les résultats d'une série d'essais triaxiaux drainés et non drainés sur deux types d'asphalte, l'asphalte coulé gravillonné (SMA) et le béton asphaltique dense (DAC). Des essais sans liant asphaltique ont été effectués pour chaque type d'asphalte. Les résultats montrent que le DAC, qui à une granulométrie continue et une teneur en bitume d'environ 5 %, se comporte de manière similaire à un agrégat sans bitume pour les taux de chargement conventionnels en mécanique des sols. Cependant, on observe des effets significatifs de taux de contrainte à mesure que le taux de chargement augmente. Pour le mélange de SMA qui a une teneur plus élevée en bitume d'environ 6 %, l'asphalte semble affecter la résistance à la friction du mélange, qui est beaucoup affectée par le taux de contrainte. On note également que le liant asphaltique a l'effet de réduire les effets de la localisation de la contrainte et permet les déformations de type uniforme et en tonneau, malgré la très grande densité de l'agrégat.

KEYWORDS: aggregate, asphalt, triaxial tests.

1 INTRODUCTION

Analysis of asphalt materials has focused on their response under traffic loading, and in particular on the effects of temperature and stress level on the resilient stiffness and permanent deformation (Antes et al, 2003, Li et al, 2010). However, there has been much less interest in the behaviour of asphalt under slow rates of loading, and of the role of the aggregate skeleton (Muraya et al, 2009). The latter can be important when a pavement is subject to subsidence, for example caused by underground mining. In this situation the role of the aggregate controls the asphalt behaviour and the stiffness can be as much as 2 orders of magnitude lower than the resilient modulus determined from conventional asphalt testing. To capture this behaviour elastic-visco-plastic models of asphalt have been developed, but there is little data available to determine the parameters for these more sophisticated models.

The triaxial tests described in this paper are part of a study designed to provide the basic soil mechanics framework for the aggregate and to enable the effects of different aggregate gradations and bitumen contents to be more rigorously interpreted. The paper will describe a series of triaxial tests performed on two types of asphalt, stone mastic asphalt (SMA) and dense asphaltic concrete (DAC). Tests of the two materials without the bitumen have also been performed. The gradations of the materials, their method of preparation and the results of the triaxial tests are presented.

1.1 *Specimen preparation*

Asphalt test specimens for these tests were provided by the Roads and Maritime Services (RMS) and were manufactured in the Fulton Hogan (FH) asphalt laboratory in Sydney. The majority of the aggregates in the asphalt mix were comprised of crushed basalt from the Bass Point quarry.

Dense graded asphalt mixes with 14mm nominal aggregate size conforming to RTA Roadworks specifications R116 (DAC) and R121 (SMA) were used in testing. The particle size distributions are outlined in Table 1, and the materials and their proportions used to achieve these gradations are shown in Table 2.

Samples of at least 200 kg of each SMA and DAC mix were taken from a plant production run and were delivered to the FH asphalt laboratory. Care was taken during handling to avoid any segregation of the mixes. In the laboratory the asphalt mixes were reheated and compacted in a shear box compactor to produce prismatic compacted specimens with dimensions of 450 mm x 150 mm x 185 mm. Approximately 10 cylindrical specimens with diameter of 70 mm and length of 140 mm were cored from each of the compacted rectangular prisms. The cylindrical specimens were then subjected to conventional CIU and CID triaxial tests.

Table 1. Particle size distributions.

Sieve Size	DAC (%)	SMA (%)
19.0	100.00	100.00
13.2	99.00	90.24
9.5	83.38	50.06
6.7	66.74	30.98
4.75	56.81	24.14
2.36	39.97	20.78
1.18	27.44	17.92
0.60	20.74	15.79
0.30	11.79	13.04
0.15	7.69	11.53
0.075	5.92	10.27
Filler/Binder	1.15	1.55
Bitumen	5.17	6.64

Table 2. Mix proportions.

Aggregate	DAC %	SMA%
14mm Basalt	19.8	57.98
10mm Basalt	19.4	14.22
7mm Basalt	6.40	0.00
Basalt Dust	35.1	9.52
Benedict's Glass Sand	13	3.27
Hydrated Lime	1.14	5.24
Finely Ground Limestone	-	2.97
Cellulose Fibres	-	0.28
C450 Bitumen	5.20	6.50

Additional triaxial tests have been performed on aggregate specimens with identical gradings to the asphalt specimens, except for the absence of the bitumen. These specimens were 100 mm in diameter by 200 mm tall, and were prepared by tamping the moist aggregate mixture into a split mould located on the triaxial base platen.

The asphalt specimens had nominal air voids of 5.5% and very low permeability. To saturate the specimens elevated back pressures of between 600 kPa to 1000 kPa were used, but even so several days were required for the rate of water inflow to drop below 3 mm^3/min at which stage the specimens were considered to be effectively saturated.

2 RESULTS AND DISCUSSION

The results of drained triaxial tests on the DAC mix are shown in Figures 1 and 2. These figures compare the response of asphalt specimens isotropically compressed to 200 kPa and 700 kPa, with a specimen comprised only of the aggregate compressed to 500 kPa.

Figure 1 shows that the differences between the two asphalt (DAC) specimens and the aggregate only specimen are primarily due to the different effective stress levels, and that the effects of the bitumen on the stress-strain response are relatively minor for these tests, which were conducted at a strain rate of 0.5%/hr. From the volume strain responses shown in Figure 2 it is evident that the asphalt specimens are more dilative. This is a consequence of the asphalt specimens being denser than the aggregate only specimen.

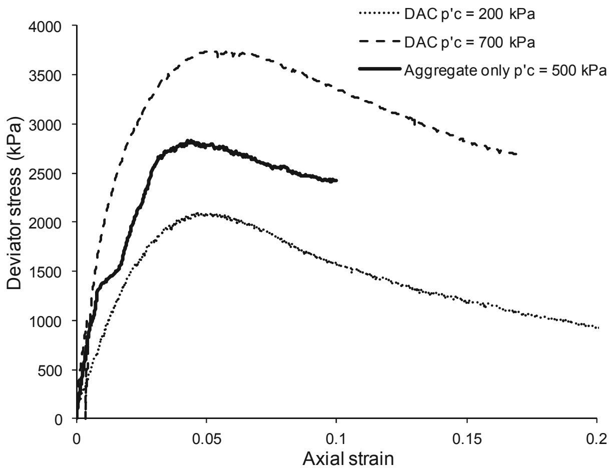

Figure 1. Deviator stress, strain responses from drained tests of DAC.

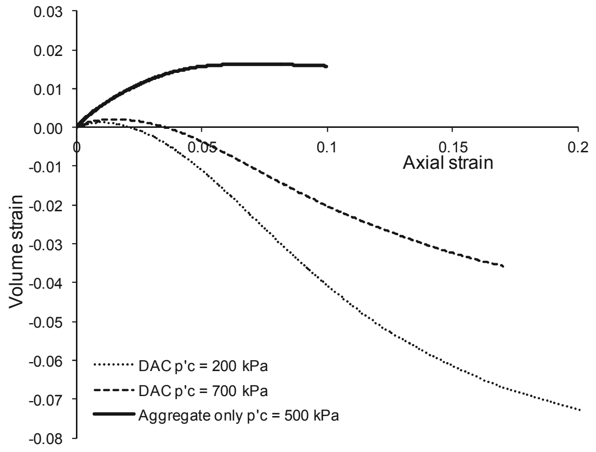

Figure 2. Volume strains from drained tests on DAC.

From a soil mechanics perspective the behaviour of the asphalt might be expected to depend on the void ratio, but for the asphalt specimens where the voids are mostly filled with bitumen a number of definitions of void ratio can be employed. The results presented in Figures 1 and 2 show the bitumen has little influence on the stress- strain response which suggests that the definition of void ratio should include the space filled by the bitumen as well as the water. For the asphalt specimens this results in a value of approximately 0.24 for the aggregate void ratio, e_{agg}. However, if the bitumen is included with the solids then a much lower void ratio of 0.08 is obtained. If the bitumen makes no contribution to the strength of the material then we might expect to observe a unique critical state line, using the aggregate void ratio, e_{agg}, which is unaffected by the presence of the bitumen. This is explored in Figures 3 and 4. Figure 3 shows the effective stress paths in deviator stress, *q*, versus mean effective stress, *p'*, from several asphalt specimens subjected to both drained and undrained tests, and Figure 4 shows the resulting changes in aggregate void ratio. It can be observed that the asphalt specimens behave as expected for dense granular materials, with significant dilation at low effective stresses and with the effects of dilation diminishing as the effective stress level increases. All specimens approach a unique critical state line described by M = 1.68, a friction angle of 41°. When the variations of the aggregate void ratio are inspected it can be seen that these also provide support for a critical state line with gradient λ = 0.056.

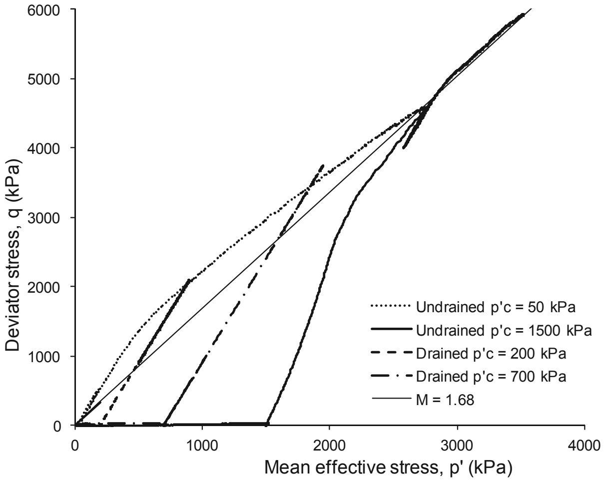

Figure 3. Effective stress paths for DAC specimens.

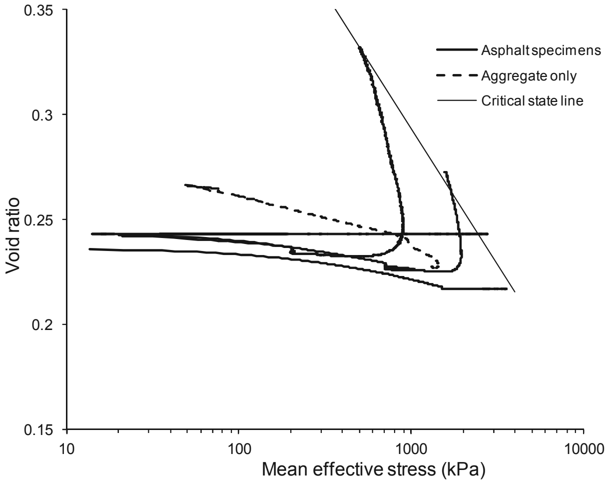

Figure 4. Variation of aggregate void ratio for DAC specimens.

When the test with aggregate only is plotted on Fig. 4 it appears that it does not reach the critical state line. However, the aggregate only specimen formed a pronounced shear plane and ruptured the membrane, and it is believed that if the test had continued the specimen would have expanded and approached the same ultimate locus as the asphalt specimens. It may also be noted that the asphalt binder resulted in more uniform deformations being observed in all the DAC specimens, which tended to bulge out despite their dense and dilative nature.

Because different confining stresses have been used in the drained tests for the asphalt specimens and the specimen without the bitumen, the test results cannot be directly compared. An alternative approach is to compare the stress ratio (q/p′) versus axial strain responses as presented in Figure 5. This shows that the specimen without the binder at an effective confining stress of 500 kPa is behaving very similarly to the asphalt specimen at 700 kPa. As discussed previously, and shown in Figure 4, the asphalt specimens are slightly denser and this can explain, at least part of, the difference in the behaviour with stress level. The similarity of the shape of the responses also suggests that the ultimate frictional resistance of the aggregate is similar to that of the asphalt specimens, and as expected the frictional resistance of the asphalt is controlled by the aggregate. The results presented in Figures 1 to 5 all suggest that the binder has only a minor effect on the stress-strain response of the DAC asphalt specimens. At the slow loading rates used in these tests the bitumen is simply acting as a viscous pore fluid, and it is viscosity is sufficiently low for it to flow out of the way of the aggregate to aggregate particle interactions.

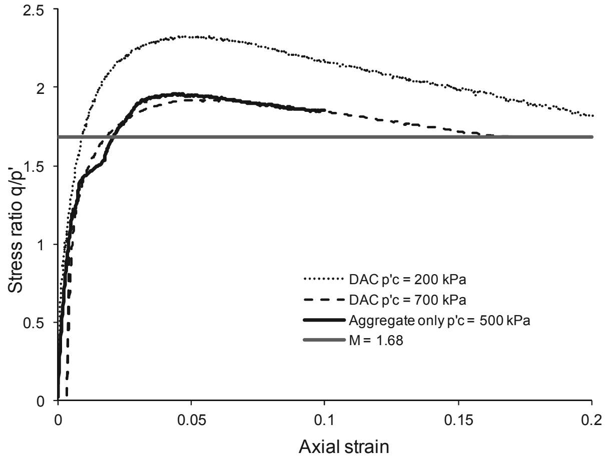

Figure 5. Stress ratio, strain responses in drained tests.

Tests have also been conducted on Stone Mastic Asphalt (SMA) specimens. SMA is used in pavements as it is reported to have better resistance to rutting, and this is believed to result from the greater contact between the larger particles of aggregate, which occurs because of the removal of some of the intermediate particle sizes in the grading.

Figure 6 shows a comparison between the stress-strain responses of the SMA and DAC specimens in drained tests. This shows that there are significant differences between the two asphalt materials. The SMA specimen has a peak deviator stress only half that of the DAC specimen even though both specimens have the same confining stress. This significant reduction is not the result of differences in the aggregate void ratio, which is essentially identical for the two materials, and neither can it be explained by differences in the frictional characteristics of the aggregate as the same aggregate is used for both types of asphalt. However, the SMA aggregate only specimen had a significantly higher void ratio, approximately 0.4, and this can explain why the SMA aggregate appears less stiff and more compressible than the DAC aggregate.

Figure 7 shows the volume strains measured during the drained tests shown in Figure 6. The DAC specimen is significantly more dilative than the SMA specimen even though the specimens are compacted with similar energies and with

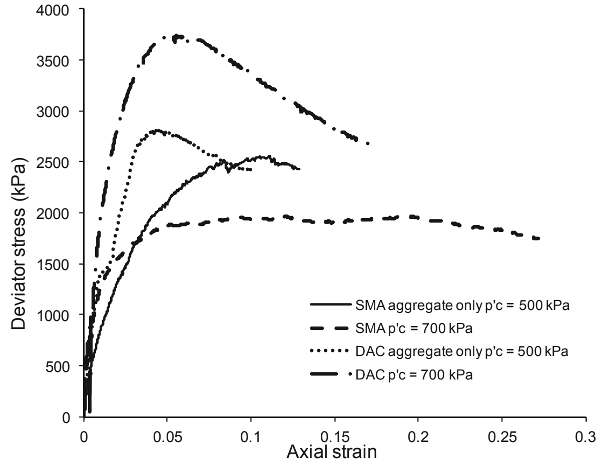

Figure 6. Comparison of SMA and DAC materials in drained tests.

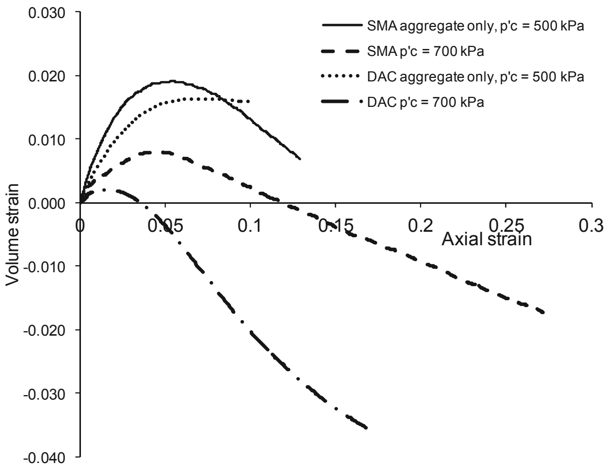

Figure 7. Comparison of volume changes for SMA and DAC.

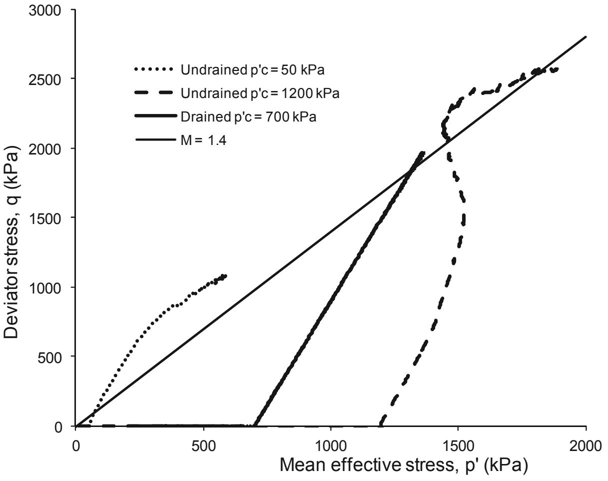

Figure 8. Effective stress paths of SMA specimens.

similar aggregate void ratios. Although the lower strength of the SMA specimen is consistent with the reduced dilation, this does not explain the very much lower mobilized frictional resistance of the SMA specimen, which can be seen from the plot of the effective stress paths of the drained test, and two undrained tests of SMA, shown in Figure 8. Figure 8 shows the mobilized stress ratio for the tests at the higher stress levels is 1.4, corresponding to a friction angle of 34.6°. This is significantly less than the friction angle of the aggregate which is expected to be 41°, similar to the DAC aggregate because the material is the same and the grading is not that different.

It can be seen that the SMA specimens mobilize a significantly lower resistance than the DAC specimens, even though they have mostly the same aggregate material with the same frictional characteristics. The differences between the two asphalt materials include: the gap grading of the SMA aggregate; the slightly higher bitumen content in the SMA; and the presence of a small amount of cellulose fibres in the SMA mix. The presence of fibres would be expected to provide some additional strength to the asphalt mix, and there was no evidence that they had a significant effect on the aggregate only mixture, so the fibres do not appear to be responsible for the difference in behaviour. It thus appears that in SMA the bitumen is interacting with the fine particles and acting to minimize the frictional interaction of the larger aggregate. In contrast in the well graded DAC there appears to be sufficient interaction between the larger aggregate particles so that the bitumen acts independently of the particle structure.

The results also suggest that SMA has a lower residual strength than DAC once the aggregate structure is disturbed at slow rates of loading. This is in direct contradiction to how the SMA product is supposed to perform at high rates of loading, which is to have better resistance to permanent deformation. This difference in behaviour at higher loading rates could be related to the much greater sensitivity of the SMA to changes in loading rate which has been observed in the triaxial tests. This is also consistent with the greater influence of the bitumen in the SMA tests than for the DAC.

3 CONCLUSION

Conventional soil mechanics triaxial tests have been conducted on saturated asphalt specimens. These have shown that the behaviour of the asphalt can be very sensitive to details of the aggregate grading. For dense asphaltic concrete, which has a well-graded aggregate and 5% bitumen, the behaviour in slow triaxial tests is controlled by the aggregate particles, and the bitumen appears to have little effect. For the stone mastic asphalt, which has a gap-graded aggregate and 6% bitumen, the bitumen has a significant effect on the stress-strain-strength behaviour.

The sensitivity of the asphalt to relatively minor changes in grading and bitumen content is a surprising result, and further tests are in progress to help understand the mechanisms responsible for this behaviour.

4 ACKNOWLEDGEMENTS

The authors are grateful to the Roads and Maritime Services (NSW) for supplying the asphalt specimens and materials used in this study.

5 REFERENCES

Antes, PW, Van Dommelen, AE, Houben, LJM, Molenaar, AA and Parajuli, U (2003) Stress dependent behaviour of asphalt mixtures at high temperatures, *Proceedings of the Technical Sessions*, v 72, p 173-195, *Asphalt Paving Technology*.

Li, P, Liu, J and Saboundjian, S. (2010) Materials and temperature effects on the resilient response of asphalt-treated Alaskan base course materials, *Journal of Materials in Civil Engineering*, 23, 2, p. 161-168.

Muraya, PM, Molenaar AAA and van de Ven MFC (2012) Contribution of the bituminous mortar and stone skeleton to the resistance to permanent deformation in Asphalt mixtures, Journal of Testing and Evaluation, 37, 5, 1-7.

Roads and Maritime Services(RMS) (2010), R121. QA Specifications, Stone Mastic Asphalt, Ver. 2.1 NSW , Australia.

Roads and Maritime Services(RMS) (2012) R116. QA Specifications, Dense GradedAsphalt, Ver. 8.2 NSW, Australia.