THE AUSTRALIAN ASPHALT MIX DESIGN PROCEDURE: AN OVERVIEW

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INTRODUCTION

Aim of This Paper

A new performance related method of asphalt mix design is currently being implemented in stages by Australian State Road Authorities (SRAs). The work on the design procedure began in the late 1980s and the procedure and associated test methods have undergone a number of changes since initial conception. The purpose of this paper is to trace the history of the design procedure and describe some of the experimental work on which it is based. It is hoped that this will assist future users in their operation of the new procedure and interpretation of its outputs.

The Need for Change

Until recent times, Australia relied on the Marshall and Hubbard Field methods of asphalt mix design. Essentially, the two procedures involve compacting a specimen of the candidate asphalt and testing the resulting cylinder to determine stability and flow values. While the Marshall and Hubbard Field procedures have given good service for many years, the mechanical properties which are measured in the tests (and the conditions of measurement) are not related directly to road conditions and do not reliably predict performance under traffic. Perhaps the main reason the methods have produced satisfactory mixes is that they have allowed mix designers to produce mixes similar to ones which were known, through experience, to provide good service.

Where the two methods fall down, however, is in the design of mixes where the composition is outside the limits of local experience, or where asphalt is subject to more severe traffic stressing than was previously the case. As traffic loads have increased in recent years, and tyre inflation pressures have risen, rutting of asphalt has become a serious, world-wide problem. Attempts to develop Marshall and Hubbard Field designed mixes to overcome this do not appear to have been particularly successful.

Stages in Development of the Australian Mix Design Procedure

Research around the world has focused in recent years on developing performance relationships for pavements and on producing an asphalt mix design procedure based upon them. This is a very difficult task. The U.S. Strategic Highway Research Program (SHRP) which ran from 1988 until 1992 had this as one of its main aims. Despite the concentrated effort and a later follow-up program, no working asphalt design procedure has yet been produced by SHRP (or its implementation successor the Federal Highways Administration [FHWA]) which goes beyond assessing the volumetric properties of asphalt.

Concurrent research in Australia by the SRAs (represented by Austroads), the asphalt industry (represented by the Australian Asphalt Pavement Association) and ARRB Transport Research was based on a practical, cost effective approach and has resulted in an asphalt mix design procedure which takes into account the relative performance of mixes in terms of rutting, fatigue and moisture sensitivity. The Australian procedure, like the SHRP Superpave design procedure, uses a gyratory compactor to prepare cylindrical specimens for initial volumetric assessment.

Rutting is the critical distress mode in Australia, and work on the new mix design procedure commenced with examination of a simple laboratory test (dynamic creep) to predict the rutting resistance of a mix. A considerable effort went into improving the precision of the creep test. Following this work, an initial version of the new design procedure was developed and a full scale Accelerated Loading Facility (ALF) trial was arranged to validate the new procedure. However, it was found that the relative rate of rut formation of a series of mixes under a full scale wheel load in the ALF trial was different from their the ranking using the laboratory creep test.

Efforts were made to modify the creep test to improve the correlation but these have not yet been successful. The mix design procedure was therefore modified to include a wheel tracking test and a refusal density test as key measures to control rutting. Supporting information on this process and on the selection of gyratory compaction for cylindrical sample preparation is given in the following sections. The information presented in this paper represents only a small proportion of the total work associated with development of the design procedure.

GYRATORY COMPACTION

Selection of Compactor and Design Cycles

One of the tasks undertaken by the National Asphalt Research Coordination (NARC) group was the development of a laboratory based sample preparation method to produce specimens that more closely simulated the performance of asphalt placed in-situ than the Marshall compaction method. After a survey of overseas developments the gyratory method of compaction was selected as the most appropriate technology for Australia. Industrial Process Controls (IPC), an Australian company, developed a device (the Gyropac) to the specifications of a NARC working group. The compactor was capable of manufacturing specimens of either 100 or 150 mm diameter.

To use the compactor in the mix design procedure then under development, information was needed on the number of Gyropac cycles equivalent to light, medium and heavy traffic compaction of asphalt in the field. SRAs were contacted and asked to carry out Gyropac testing of typical mixes and calculate the Gyropac cycles required to achieve the density which the mixes normally achieved in the field. However, due to resource constraints, not all SRAs were able to provide information and the data received was insufficient to draw reliable conclusions.

It was therefore decided to obtain an estimate of these numbers by determining the Gyropac cycles required to produce the same density as Marshall compacted specimens. Generally, 75 blow Marshall compaction is considered to be equivalent to heavy traffic compaction in the field, 50 blow Marshall to medium traffic, and 35 blow Marshall to light traffic.

It was originally planned to "correct" mensuration densities (calculated from the piston height of the Gyropac) to bulk (water displacement) densities by use of a correction factor. Testing indicated, however, that this correction factor varied with number of cycles of compaction and mix type, and that use of the procedure could introduce a substantial error.

Road Authorities were therefore requested to compact specimens of three typical mixes using 35, 50 and 75 blow Marshall and also to manufacture identical samples of these mixes in the Gyropac over a range of cycles. The density of both sets of samples was measured by the conventional water displacement procedure.

Good agreement between the number of Gyropac cycles equivalent to 35, 50 and 75 blow Marshall was obtained in the case of two laboratories. The results from a third laboratory suggested that one of the mixes it tested was either unlikely to be useable in the field or that there was an equipment problem. A fourth laboratory experienced considerable variability in its results, and an extensive investigation failed to resolve the problem.

In determining a Gyropac versus Marshall relationship, emphasis was placed on the results obtained by the first two laboratories. The relationship found is shown Table I. Further information on testing is given in a report by Oliver (1993).

Table I Proposed Gyropac Cycles Equivalents

Marshall blows	Gyropac cycles
35	50
50	80
75	120

Homogeneity of Compacted Cylinders

In order to obtain an indication of the homogeneity of specimens compacted in the Gyropac, two dense graded asphalt mixes were selected and compacted in a Gyropac over a range of compactive efforts, bitumen contents and compaction temperatures. The compacted specimens were tested to determine their resilient modulus and bulk density.

Repeatablity of resilient modulus for 100 mm diameter specimens manufactured in the Gyropac was less than 700 MPa and less than 0.04 t/m^3 for bulk density. Compactive effort, compacting temperature and bitumen content significantly affected the properties of the compacted asphalt specimens, as expected.

The homogeneity of the compacted asphalt specimens was assessed both along the length of the specimens and with respect to radial position. The outer portion of the specimens were found to be about 0.035 t/m^3 less dense than the inner portions. However, the inner core of the specimen was homogeneous. The density gradient down the axis of the specimens was more marked than the density gradient across the radius of the specimens. On average, the top and bottom thirds of the samples were equal and about 0.05 t/m^3 less dense than the middle third. Further information on the work is given in a report by Oliver and Alderson (1993).

Aggregate Particle Arrangement in Compacted Cylinders

A study was undertaken to determine whether there were differences in aggregate particle orientation between field asphalt, and laboratory compacted samples manufactured using Marshall and Gyropac equipment (Oliver et al. 1995). Samples of one particular mix composition were obtained from the Accelerated Loading Facility (ALF) asphalt deformation trial in Queensland. Field mix and laboratory compacted samples were sectioned and the orientation angle of exposed aggregate particles determined by visual inspection of the cut faces.

Statistical analysis indicated that, in most cases, there was evidence of aggregate particles having a preferred orientation (as opposed to being randomly orientated). Two quantitative measures of orientation direction were developed: (a) the mean orientation angle, calculated by vector addition of the resolved vertical and horizontal components of the orientation angles, and (b) the proportion of particles oriented within 22.5° of the horizontal.

Comparison of the orientation angle of aggregate particles in specimens cut from the ALF pavement with Marshall-compacted specimens and gyratory-compacted specimens suggested that the aggregate packing in Marshall- and gyratory-compacted specimens was different to that in field compacted mix. There was some indication that the gyratory compacted specimens were closer to the field situation than Marshall specimens but the data was insufficient to verify this.

ALF DEFORMATION TRIAL

Dynamic Creep Test

An ALF asphalt deformation trial was undertaken to assess the rut resistant properties of asphalt mixes and to provide information on the effectiveness of the dynamic creep test in predicting rutting.

The trial was undertaken in a number of stages and full details are given in papers by Oliver et al (1995) and (Jameson et al. 1994). Only a summary of two of the stages is given in this paper, these being:

- the Core Trial where seven mixes were trafficked at ambient temperature (assumed to average 35ºC), and

- the Phase One Follow Up trial where six mixes were trafficked at a controlled temperature of 50ºC.

Table II shows the main mixes used in the Core Trial. The same mixes were used in the temperature controlled Follow Up Trial, with the exception of mix C5 which was omitted. Mix C1 was a typical Queensland mix and was used as a control. Mixes C3, C4, C6 and C7 had the same grading as the control but different binders (to evaluate the effectiveness of polymer modified binders). Mixes C2 and C5 had different gradings to Mix C1.

Table II Mixes used in the Core trial

Code	Description
C1	Control mix - Class 320 bitumen
C2	AUSTROADS designed mix - Class 320 (C1 binder)
C3	Control mix (C1 grading) with SBS binder (SBS-1)
C4	Control mix (C1 grading) with EVA binder
C5	Stone Mastic Asphalt - Class 320 (C1 binder)
C6	Control mix (C1 grading) with multigrade binder
C7	Control mix (C1 grading) with Class 600 bitumen

Dynamic creep testing was performed on samples cored from untrafficked areas of the pavement. The minimum slope of the deformation vs number of cycles plot is the creep test parameter most widely used to indicate deformation resistance. Fig. 1 shows the correlation between ALF deformation rates and dynamic creep minimum slope (corrected to an air void content representative of ALF pavement conditions (Oliver 1994)).

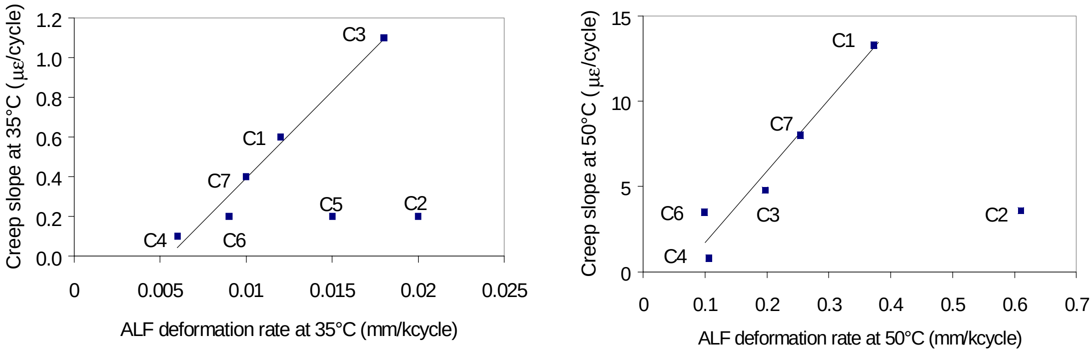

Fig. 1 Minimum creep slopes vs ALF deformation rate at: (a) 35°C, and (b) 50°C

The ALF data in Fig 1a were collected during the core trial experiments when the temperature of the pavement was uncontrolled. A temperature of 35°C has been assigned to the data as being close to the typical pavement temperature during ALF loading. Fig 1b shows the ALF data collected during trafficking of six sections at a controlled temperature of 50°C.

It can be seen that, particularly for the 35°C data, there was a good correlation for mixes with the same composition (aggregate grading and binder content) as the control mix, but with different binders (mixes C1, C3, C4, C6 and C7). The points for the two mixes with different compositions to the others (C2 and C5) did not appear to conform to the same relationship as the mixes with the control mix composition. There was no ALF deformation rate data for C5 at 50°C but it seems likely that the point for this mix would be separate from the main group of data, as was observed for the 35°C data.

The inability of the creep test to correctly rank the ALF deformation resistance of mixes with different aggregate gradings is considered to be a serious impediment to its use in a mix design procedure where the aim is to select an aggregate composition and binder content which will meet specified rut resistance (and other) requirements.

Previous work (Oliver 1994) had shown that the creep test results were greatly influenced by the air void content of the specimen. Further detailed study using mixes C1 and C2 provided more information on this dependence (Oliver et al. 1995). The results in Fig. 2 show that creep minimum slopes varied very considerably with air void content. For the mix C2 samples, which had air voids ranging from 1% to 7.5%, the creep slope changed by a factor of 800.

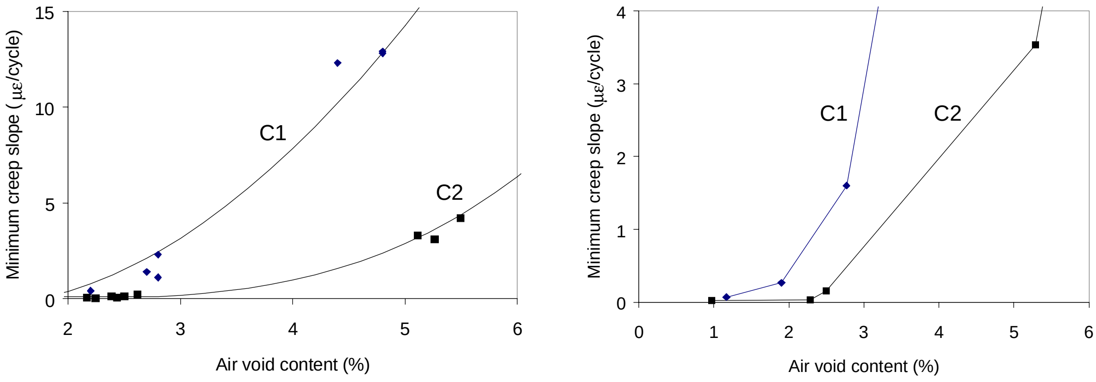

Fig. 2 Plots of air void content and creep slope for mixes C1 and C2: (a) full range, (b) magnified view of low creep slope region

It was concluded that the current version of the dynamic creep test appeared to have a number of serious deficiencies which compromised its use as a mix design tool.

It seemed likely that the poor correlation of the creep test with field performance was related to the lack of confinement of the specimen during laboratory testing. A limited study looked at the effect of confining pressure on creep test results (Oliver et al. 1995). Two methods of providing restraint for the creep specimens were used. These were:

1. testing 150 mm diameter specimens using a 75 mm upper loading platen, and
2. triaxial cell testing.

The first method involved use of an annulus of asphalt as a passive restraint, and the second method a triaxial cell with pulsed confining pressure to provide active restraint.

The annulus restraint method continued to rank the deformation resistance of the mixes differently to ALF testing. The results for the triaxial cell procedure suggested that the mix ranking might correspond to that of the ALF trial but there was a wide scatter in results and no firm conclusion could be drawn.

While efforts are made to improve the creep test, it has been left in the mix design procedure since it is believed that it may provide a coarse indication of rut resistance. However, other tests to control rut resistance have been also been included.

Wheel Tracking

In the absence of an acceptable correlation between creep test data and ALF deformation, an alternative test was investigated (Oliver et al. 1995). This was laboratory wheel tracking, using a machine based on the original TRL design. Wheel tracking had been used in mix design exercises previously in Australia (Oliver 1980).

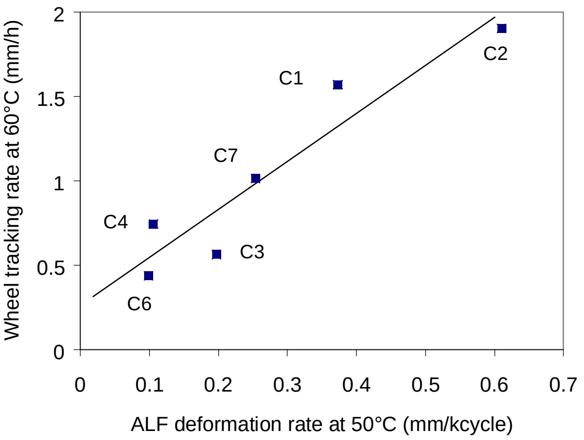

Fig. 3 Wheel tracking rate at 60°C plotted against ALF deformation rate at 50°C

Specimens cut from the ALF pavement were tested in a wheel tracking machine at 60°C (the Australian standard temperature). Fig. 3 compares the ALF deformation rates (during the Follow Up trial at 50°C) and the laboratory wheel tracking rates. It can be seen that an acceptable correlation (R = 0.95) was obtained.

REFUSAL DENSITY TESTING

A second measure to control rutting introduced into the mix design procedure was the refusal density test. In this test, a sample of the candidate mix is compacted in a gyratory compactor for 350 cycles (after this number of cycles the mix is considered to be close to its maximum compaction i.e. it is at "refusal") and its density measured. There are two interpretations of the refusal density result.

The first interpretation is that a mix which has greater than about 3% air voids in the laboratory refusal test will not rut in practice because even if heavy traffic compacts it more than expected it will not attain less than 3% air voids in the field. It is thought that mixes below 3% air voids are the ones which fail rapidly because there is insufficient voids space to hold the binder and it then forces aggregate particles apart when the pavement is loaded by traffic (pore pressure effect).

The second interpretation of refusal density is based on the fact that, because the gyratory compaction temperatures are high relative to service temperatures, the resistance to compaction of the mix is controlled by the aggregate properties, since the binder is too fluid to provide much resistance. Thus the resistance to rearrangement of the aggregate structure (i.e. the aggregate contribution to rutting resistance) can be determined from the rate at which it compacts beyond the 120 gyratory cycle condition (120 cycles is believed equivalent to the state of a heavily trafficked mix in the road). A mix which compacts rapidly after 120 gyratory cycles is likely to have a poor aggregate skeleton and be liable to rut. In the Australian design procedure an aggregate skeleton which will resist rutting is assured by requiring that the reduction in air void content between 120 and 350 cycles is less than 2% for very heavily trafficked mixes.

Since rutting is regarded as the predominant distress mode for asphalt in most of Australia, a multi-faceted approach is adopted in the new mix design procedure by requiring mixes to:

- reduce in air void content less than 2% between 120 and 350 cycles (this requirement is being reviewed),
- have greater than 2.5% voids at 350 cycles, and
- have a wheel tracking rate less than a maximum (currently being decided) value (for heavily trafficked mixes). Because the wheel tracking test is conducted at 60°C it takes into account both the contribution of the aggregate and the contribution of the binder (important for polymer modified binders).

THE NEW AUSTRALIAN MIX DESIGN PROCEDURE

Introduction

The new Australian mix design procedure has been published under the title “Selection and Design of Asphalt Mixes: Australian Provisional Guide (APRG 1997). The title illustrates two aspects of the design procedure:

- selection of the appropriate mix type is of key importance to obtaining satisfactory field performance
- a number of the test methods have yet to be finalised based on the feedback which will be provided following extensive user experience (hence provisional).

The Provisional Guide was originally published in May 1997 and updates were issued in July 1998 and March 1999. Further updates are expected following the implementation process currently under way and the term “provisional” will then be dropped from the title.

The manual covers dense graded mixes, open graded asphalt, stone mastic asphalt and fine gap graded asphalt mix types. However, dense graded asphalt remains the mix of choice in Australia and the following section summarises the main components of the design process for this mix type.

Summary of Dense Graded Mix Procedure

The new Australian mix design procedure is arranged in three levels (see Fig 4). During **level one** testing, a composition with suitable volumetric proportions is identified by selecting a target grading and materials combination, and then preparing a series of mixes at binder contents that span the expected binder range.

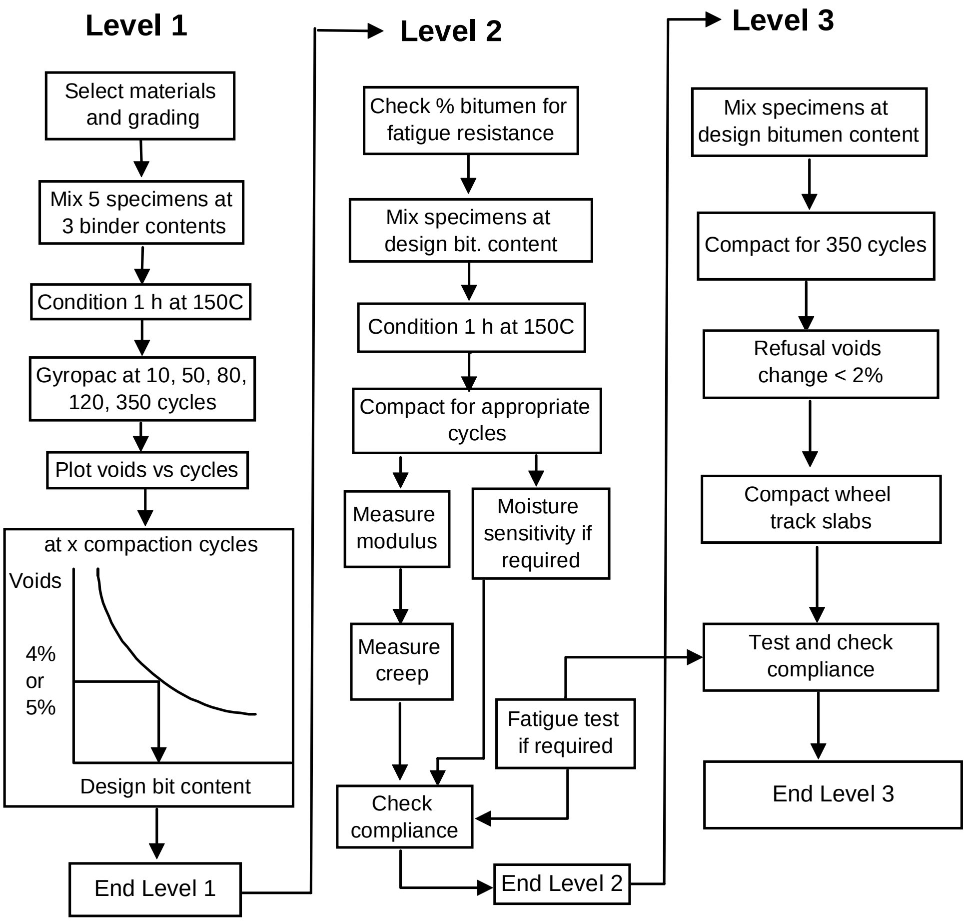

Fig. 4 Diagram of the asphalt mix design procedure

At each binder content, five samples of mix are compacted in a gyratory compactor, each sample being compacted for a different number of cycles. Prior to compaction, the mixture is conditioned in an oven to simulate the binder hardening which occurs during manufacture and placement of a mix and the first year or two of field service (Oliver et al. 1995; Oliver 1997). Compacted samples are tested for density and the results plotted as air void content against number of gyratory cycles.

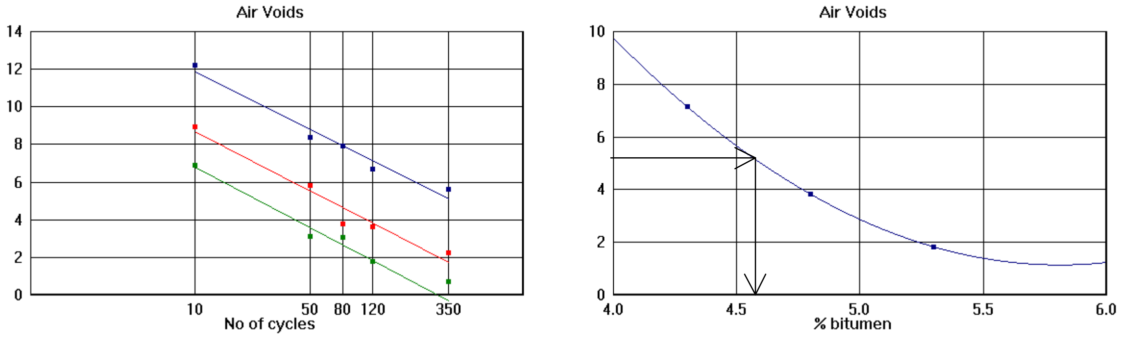

Fig. 5 Example of mix design plots of air voids vs (a) compaction cycles and (b) % binder

For each compaction level of interest (different compaction levels are specified for different classes of mix), plots are constructed of voids, VMA and other volumetric properties against binder content. The design binder content is the binder content at which the compacted mix has a specified value of air voids. In the example shown in Fig. 5a the plots are for 4.3, 4.8 and 5.3% binder contents. 120 compaction cycle data from Fig. 5a has been used to construct the plot in Fig. 5b and select a binder content of 4.6% corresponding to an air void content of 5%. The required air void content depends on the class of mix and the traffic level.

The determination of volumetric properties during level one testing is considered by many mix designers to be the most important part of any design procedure and is the only step required for certain classes of mix. The approach adopted, of gathering information on volumetric properties at a range of compaction levels and binder contents, permits more than one mix type to be designed from the one set of laboratory volumetric data.

For mixes to be used on medium trafficked roads where there is slow moving traffic, or heavily trafficked roads, it is necessary to measure the mechanical properties of candidate mixes to ensure they meet agreed acceptance criteria. These acceptance criteria may be based on climate and the cost associated with failure of the pavement. Normally, resilient modulus and dynamic creep properties are measured, with moisture sensitivity being optional, and this testing constitutes **level two** of the design procedure. A check on binder film thickness is included to ensure that sufficient binder is present to provide acceptable fatigue resistance and durability.

For mixes to be used in heavily trafficked situations, where there is slow moving traffic, or in extra heavily trafficked situations, or where a high degree of confidence in the rutting performance of the mix is required, **level three** testing is performed. This is aimed at ensuring adequate rutting resistance is achieved. It involves compacting the design mix in the gyratory compactor for 350 cycles (refusal density) and checking that the air voids do not fall more than 2% below the design air void content. Slabs of mix, 300 mm square, are also prepared and tested at elevated temperature in a wheel tracking machine at 60°C to ensure that the mix has the necessary deformation resistance.

Fatigue testing may be specified for level two or level three mixes. The fatigue behaviour of an asphalt layer depends not only on the properties of the mix but also on the structural properties of the pavement in which the asphalt layer is placed, as well as traffic and climatic conditions. It is up to the specifying authority to determine when fatigue testing is required. The outcome of a fatigue test can be expressed in a number of ways. The procedure used in the Provisional Guide is based on loss of stiffness of specimens subject to continuous haversine loading at 20°C.

The same provisos apply to **moisture sensitivity testing** which may be required by a specifying authority, depending on site conditions, aggregate properties and previous experience with similar mixes.

Balancing Mix Properties

It is important that a mix designer does not concentrate on optimising only one property of a mix at the expense of others. It is comparatively easy to produce a very rut resistant mix by using a hard grade of binder, reducing the binder content and adding extra filler. Such a mix would, however, be liable to fail through fatigue and probably be prone to rapid oxidation hardening.

In the new mix design procedure a balance can be obtained between properties by requiring Level 2 and Level 3 mixes to be tested for both deformation resistance and fatigue resistance. These performance requirements normally place conflicting demands on a mix designer who must determine the optimum solution.

ACHIEVING QUALITY IN THE LAID MIX

While most emphasis in Australia recently has been on development of the new design procedure, it is clear that satisfactory field performance will only be achieved by ensuring that quality is built into each stage of the process: materials selection, mix design, mix manufacture and mix placement.

Recent papers have discussed process control of the mix manufacturing process (Mangan 1996, 1997; Crabb and Rebbechi 1998). Some key issues still need to be addressed on a national basis, however, and among these are:

- what properties of the mix after manufacture should be tested, and
- at what point should they be tested.

To conform with the performance-related philosophy of the mix design process, it might be supposed that testing of a performance property of the in-place asphalt would be the best approach. While this appears attractive, it does raise major difficulties in process control and in achievement of quality.

When asphalt that has already been placed on the road fails to meet specification requirements it is too late in the manufacturing process to alter matters to improve quality (apart from the drastic step of remove and replace). Only the amount of the deduction from payment is affected by the test result, not the quality of the asphalt.

Specifying a performance property for a mix immediately after it leaves the pugmill or drum mixer also presents difficulties. If, for example, a refusal density voids requirement or a wheel tracking rate is not met, the plant operator cannot make a simple adjustment to the mix to correct the problem. This is because the operator can only control the proportions of components in the mix, and their influence on performance properties is often indirect and complex.

A preferred arrangement has been used by some SRAs for a number of years Rebbechi (1995). In essence, emphasis is placed on ensuring that the performance requirements of the mix are met during the design process. This is the stage at which high level expertise can be brought to bear on the process and all competing requirements can be taken into account.

The composition of the mix then becomes the property controlled from that point onwards. Thus, during manufacture, the grading and binder content is regularly measured and plant adjustments made if these properties fall outside specified limits about the design mix. This is a simple task which can be carried out by the plant operator

The only further test on the manufactured mix is for density, so as to ensure satisfactory compaction has been achieved during placing. Again, failure to meet density limits can be rectified by an (achievable) change in the compaction process.

CONCLUDING COMMENTS

While progress may at times have seemed to be slow, asphalt technology in Australia has advanced a long way since the late 1980s when efforts began to develop improved test methods. By working in partnership, SRAs (through Austroads), the asphalt industry (through AAPA) and ARRB Transport Research have produced a more fundamentally based and performance related mix design procedure.

The process is now entering its implementation phase. There is no doubt that fine tuning will be necessary based on more extensive user experience, and that some field validation work is needed. A final effort is now required to ensure that the new approach works well in practice and results in high quality asphalt on the road.

REFERENCES

APRG (1997). Selection and Design of Asphalt Mixes: Australian Provisional Guide. Austroads APRG Report No. 18 Published May 1997, Updated July 1998 and March 1999. ARRB Transport Research.

CRABB, R. and REBBECHI, J. (1998). Application of statistical process control to asphalt manufacture. Proc. AAPA Conference, Surfers Paradise, Qld. Session 7, 12 pp. Australian Asphalt Pavement Association.

JAMESON, G. W., OLIVER, J. W. H. and SHARP, K. G. (1994). Rut resistance of asphalt mixes under accelerated loading. Proc. 9th AAPA International Asphalt Conference, Surfers Paradise, Session 11 Paper 33, 9 pp. Australian Asphalt Pavement Association.

MANGAN, D. (1996). Asphalt process control. Proc. AAPA Pavements Industry Conference, Sydney, NSW. Session 4, 12 pp. Australian Asphalt Pavement Association.

MANGAN, D. (1997). Asphalt process control guide. Proc. 10th AAPA International Flexible Pavements Conference, Perth, WA. Vol. 2 Paper 47. Australian Asphalt Pavement Association.

OLIVER, J.W.H. (1980). The design of bituminous plant mix for specific operational conditions. 10th ARRB Conf. Sydney. Vol. 10 No. 3 pp 115-27. Australian Road Research Board.

OLIVER, J.W.H. (1993). The relationship between Marshall and Gyropac compaction. Working Document WD RI93/011.

OLIVER, J.W.H. (1994). Laboratory test results on asphalt specimens from the Accelerated Loading Facility (ALF) asphalt deformation trial. APRG Report No. 10. Australian Road Research Board.

OLIVER, J.W.H. (1997). Binder and asphalt hardening in early life. Contract Report, No: IC 6495BH. Australian Road Research Board.

OLIVER, J.W.H. and ALDERSON, A.J. (1993). Evaluation of the Gyropac gyratory compactor. ARRB Contract Report, No: ACR RI 93/03(k) 27p. Australian Road Research Board.

OLIVER, J.W.H., ALDERSON, A.J., TREDREA, P.F. and KARIM, M.R. (1995). Results of the laboratory program associated with the ALF asphalt deformation trial. APRG Report No. 12. Australian Road Research Board.

REBBECHI, J. (1995). Performance based specifications. Proc. AAPA Members' Conference, Glenelg, South Australia. Session 7, 10 pp. Australian Asphalt Pavement Association.