Laboratory versus Field Assessment of Full Depth Asphalt Mixes in New Zealand.

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ABSTRACT

In a major project in New Zealand which included the use of RAP aggregates it was determined that RAP handling and preparation in mix design affected the compaction in the field of both High fatigue and structural layers. This was shown to be harshness or tenderness depending on the total effective fines. This was associated with the concept of "available fines" in the RAP and breakdown of RAP in mixing. A simple test was developed to determine how this was likely to affect field application and allowed mix adjustments. Laboratory assessment of production mixes was also compared with respect to Matta resilient modulus, wheel tracking and voids. It was found that laboratory compacted samples were similar in wheel tracking (slab compactor) to field cores but the laboratory compacted samples did not correlate well with field cores. It is concluded that performance assessment of mixes is better determined by analysis of field cores than laboratory compacted blocks. Permeability testing on larger stone (AC20) mixes showed air voids was not a good indicator of the transmission of water under load. This is of concern as water ingress can lead to a higher potential for top down cracking. Higher water ingress can also increase moisture damage over time, even with complying mixes.

1. INTRODUCTION

The performance of asphalt pavements is influenced by several primary factors, mix design, material consistency plant production and field compaction. Compaction is a key issue in design and the relationship between design and the field is not a simple task. Mohammed (1) found low correlation between laboratory measurements and field measurements for a range of properties. Where pavement design uses laboratory design measurements and quality is judged by volumetric measurements this is a matter of some concern. He states that there is no relationship between a mixtures laboratory properties and its field performance. However some properties can be ranked. Field voids to laboratory voids has been reported as correlating however how this affects performance is more problematic given that these are aggregate voids and make no reference to size shape or distribution.

The relationship between design compaction and field compaction is important to maintaining consistency and judging success. The use of repeated hammer load compaction such as Marshall Hammers has been discontinued or reduced in many parts of the world due to its lack of relationship to field results. In USA Superpave (TM) and in the Australian APRG18 methodology a gyratory method is preferred (2,3 4,5, 6,7). This is basically because the Marshall method does not simulate aggregate orientation in field compaction obtained by vibratory static rollers and kneading rollers (7,8,9,10,11,12,13,14,15,16,17). Indeed in some studies Marshall was shown to change gradation of some softer recovered aggregates whereas gyratory did not (7). Up until the early 2000's Caltrans was still using a kneading Hveem compaction method in an attempt to better simulate field compaction in design (18).

Density is a significant contributor to mix performance but the detail of the microstructure of the mix and both air voids shape and distribution have been shown to be different between laboratory and field (1, 19, 20, 21, 27). Air voids levels are important with respect to the test of the mix microstructure although and their interconnectivity i.e. distribution is likely to have a significant effect on properties such as permeability and aging. Moisture damage is related to this effect. Recently scanning and imaging technology has been used to attempt to quantify some of these effects. It has been found in some work by the authors that mixes with air voids as measured in the laboratory that met mix requirements still showed significant permeability in falling head tests (21, 22).

Oliver and work during the SHRP program (7,10) found that gyratory compaction more closely simulated field compacted orientation than Marshall and other methods but did not match field compaction. The reason for this is associated with the vertical inhomogeneity of void structure. (20) It was found that in laboratory compacted gyratory samples, air voids became concentrated at the top and bottom of the samples whereas in field compaction the air void are concentrated at the bottom of the layer (23, 24). The gyratory matched the field cores for air voids at lower gyrations and the orientation aggregate of field cores at higher gyrations(25) . Azari (20) found that the distribution was not well correlated with simple performance tests for permanent axial deformation. Masad (21) found that air void distributions were related to mixture properties using the Hamburg wheel tracking tests for gyratory specimens. In most studies wheel compaction has been shown to produce better field correlation with void distribution and particle orientation (7, 13, 26, 27). Uniformity is related in the field to roller patterns and sequencing of different equipment (21).

Laboratory compacted samples using gyration have been found to be scattered but relatively homogenous (19), wheel compaction is most simulative. Some work has indicated that gyratory compacted samples produce superior properties to field cores. These effects were evident in higher stiffness values and lower shear strain in Superpave testing (13).

Volumetric properties are important as they describe the potential structure of the mix and hence its potential mechanical properties and permeability to both air and water. VMA for example describes the inter-granular space occupied by bitumen and air, thus it is an indicator of potential movement of aggregates under shear and as it forces a level of bitumen content it is an indicator of durability. (29-34), Anderson (29) found however that VMA does not always correlate with performance testing and that this is a function of gradation (fine Vs coarse gradations). Clearly aggregate shape angularity and packing play an important role. This means performance testing plays a significant role in determining mix suitability (35).

Mix design is the process of determining the proportions of binder to aggregate the initial steps are to establish a grading and then to determine the volumetrics. The volumetric calculations are dependent on the density of the samples prepared and so the compaction is a key element. Consistency is a key issue and so the methodology needs to be repeatable. Gyratory compaction is a convenient way of optimising the volumetrics but the caveats above must be kept in mind. Increasingly, field compliance has been based on meeting mix design criteria in field cores; however as the laboratory test methods do not simulate they field with gyratory compaction this appears to be of limited value. This is not to say consistency of mixes cannot be measured however this will not relate to field cores. In the 90s Mobil/ Emoleum laboratory used cores from wheel compacted slabs and found that reproducibility was good along with field correlation.

It is understood that the 120 cycles gyratory compaction and the 250 cycles refusal compaction seeks to indicate the compaction potential over traffic and time. Several studies (9, 10) noted that refusal density and voids are not a good indication rutting potential, however, the field testing needs to determine the mix consistency along with the other design parameters. Field compaction shows the state of the pavement with respect to its traffic loading when new- the worst case scenario in fact. Wheel tracking and initial field cores present a means of checking the likely real pavement response. Matta checks similarly though inherently variable. As none of these include ageing effects in the binder they become measures on consistency and binder rheological assessment using aged binders as in "Superpave ™ " should be considered. It has been usually found that field samples do not match gyratory design for rheological parameters such as Complex Modulus (G*) (36).

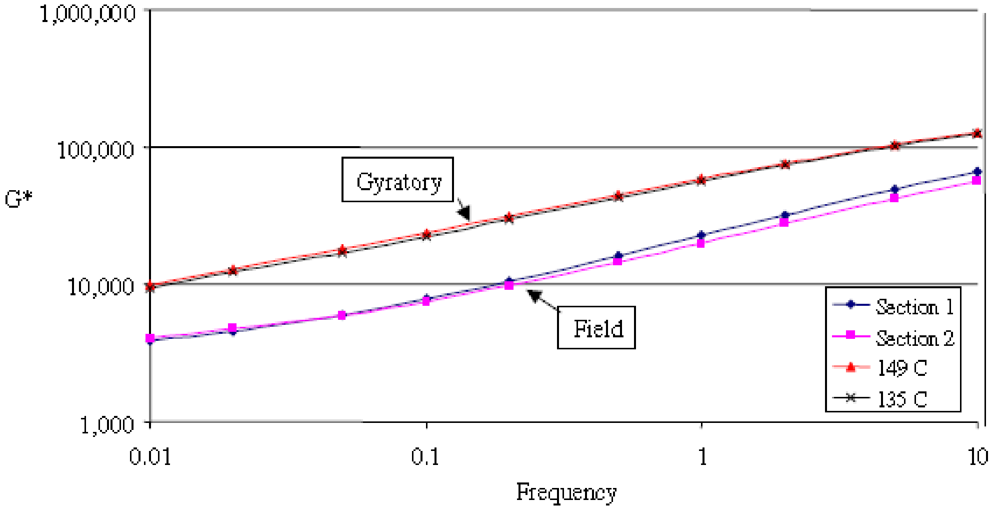


Figure 1 Resilient Modulus (36)

2. RAP Use

A complication in this project was the use of RAP in all structural layers- including the high fatigue layer. The use of RAP in this project has presented its own issues with respect to achieving design parameters and consistent manufactured product. The main issues with RAP have been associated with:

- Design allowance for RAP binder
- Specific Gravity (SG) calculation
- Treatment of RAP in the design process – heating
- Grading for design - accessible fines
- RAP Consistency - Preparation

Design Allowance

How is the binder allowed for in the RAP? It has been shown that the degree of mixing is variable depending on the binder condition in the RAP. Various methods have been used to allow for this (37, 38, and 39). In this work extraction was used to examine binder contribution. Volumetric calculations needed to take into account the whole amount of binder but projected binder properties for purposes of durability assessment required an assessment of rheological properties. Figures 2-4 show the Dynamic Shear Rheometer

(DSR) results on recovered binder from RAP and virgin binder. Also blended binders from these are compared. 40/50 binder is shown as a comparison.

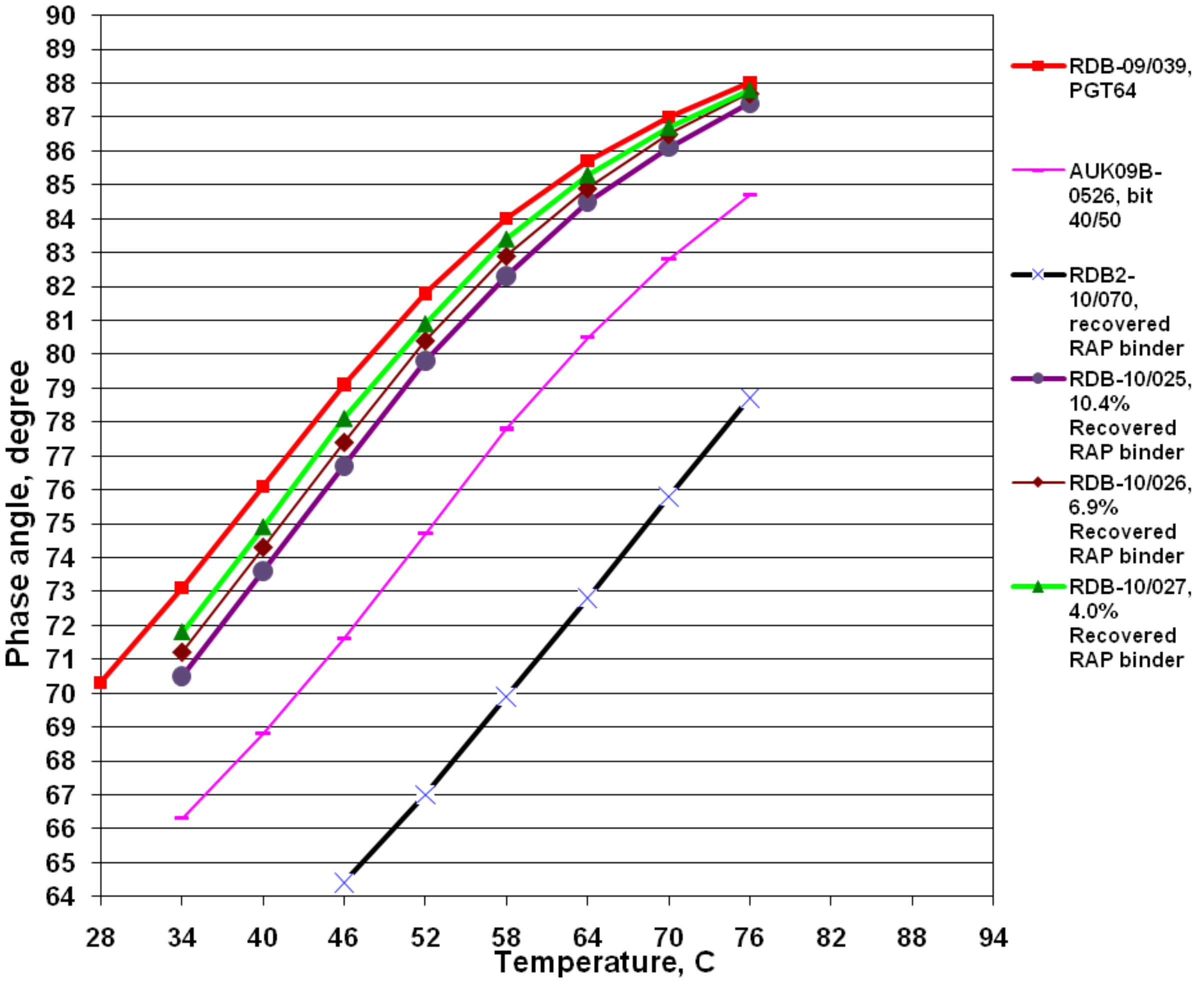


Figure 2 Phase angle Versus Temperature For Various Recovered/Virgin Bitumen Binders

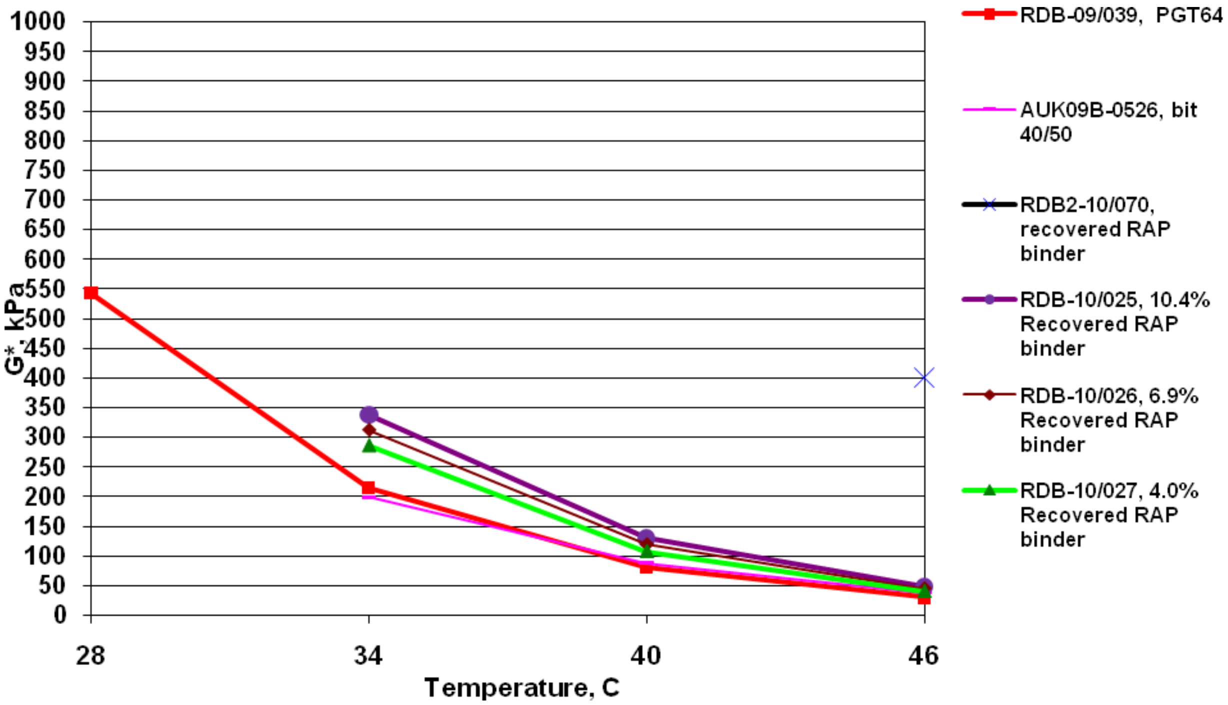


Figure 3 Complex Moduls Intermmediate Temperature Range For Various Recovered/Virgin Bitumen Binders

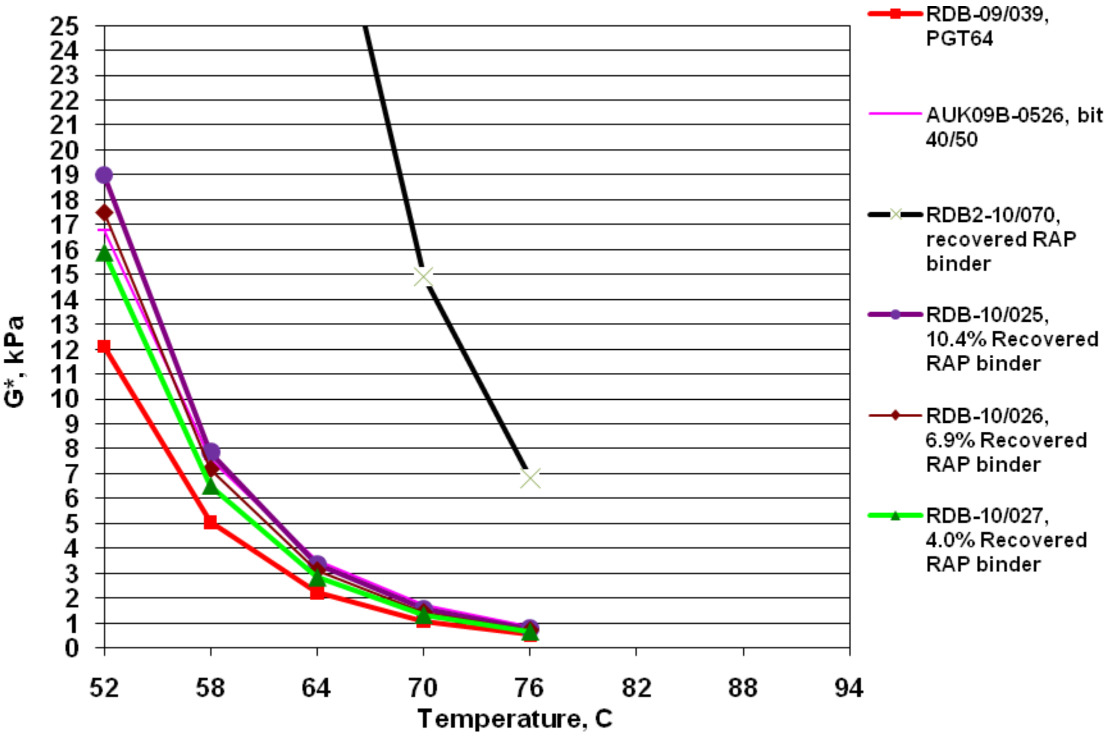


Figure 4 Complex Moduls High temperatutre range For Various Recovered/Virgin Bitumen Binders

The dramatic change in binder rheology with relatively small amounts of RAP binder indicates 100% mixing does not occur in manufacture. It might be expected that mixing would be a function of a number of variables and the degree will affect mechanical properties (Figure 5), these include*:*

- Temperature
- Mixing time
- Heat soak time – silo storage
- Degree of aging in the recovered binder

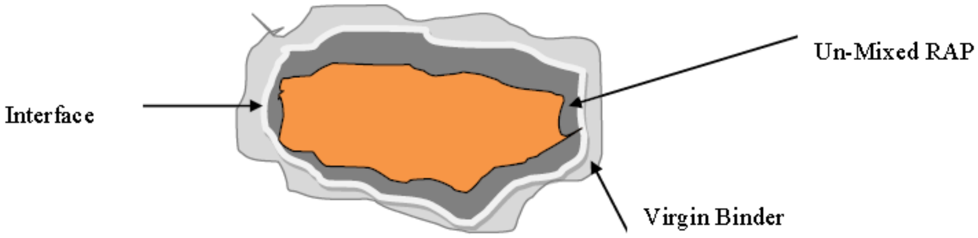


Figure 5 Schematic Representation of Mixing Extent

The idea of compensating for the hardness of the binder has been studied at length (37-43). This has included use of blending charts and lowering the grade of the added binder, however the conclusion is that performance testing and allowance for aging is necessary. Using a lower grade of binder added or rejuvenation agents may be guided by extraction testing but ultimately the design must include performance based testing.

In this work beam fatigue testing was used as a check as well as TSR. TSR results have shown that TSR is quite high (>85%) for such mixes, perhaps due to anchoring of water resistant binder on the aggregate. Fatigue was also satisfactory and the allowances were not used. This is in line with recent work by Swiertz et al (40) on using mechanical tests as well as extraction for determination of low temperature properties. The high temperature G* plot shows that the resistance to deformation should be enhanced by the RAP.

SG Calculation and Measurement

Calculation of SG is an important requirement for the RAP. SG is calculated for the recovered aggregate after extraction of the binder in the RAP. Accuracy is further enhanced by separate testing for fine and coarse aggregate. However the retention of binder on the aggregate will reduce the accuracy of this method and for higher RAP levels of addition may skew some volumetric calculations, for example VMA. As base mixes are more likely to have higher RAP contents and are larger stone this is probably not as much of an issue. This approach is in line with Asphalt institute recommendations (44).

Treatment of RAP in design

Some studies have shown that RAP handling can change the grade of the recovered binder by as much as two grades (45). This will affect the compactability and as such the volumetric calculations. As RAP levels are increased this is more important. In this work RAP was heated to the mix temperature and this time established for different amounts of RAP. This was added to dry aggregated at the same temperature for approximately 30 minutes before the samples were compacted. For larger mix amounts of mix the actual time needs to be established.

Grading- Accessible fines

In design sometimes agglomerates of fines with binder do not break up, overheating makes this situation worse. This can lead to difficulties in compacting samples. This might seem to be a laboratory phenomenon but compaction difficulties were also noted in the field, especially in relation to tenderness. Excess fines in RAP is sometimes noted as an issue in the literature however, in this work, the fines that extraction indicated were available in the RAP did not appear to be active in the field samples. That is reliance on the RAP for fines were NOT a good idea. Crushing was used as a means of regulating the RAP grading envelope- more as a way of breaking up agglomerates than fundamentally changing the RAP grading. Testing was carried out on a batch production basis for grading and binder and SG were re-measured monthly.

A simple wheel compaction test was developed to examine potential tenderness. This showed that fines expected from the extracted RAP were not reflected in the mix compactability that is, agglomerates of fines with hard RAP binder persisted in the mix. The test allowed grading to be adjusted to compensate for this effect. It also allowed for adjustments in the RAP processing methodology in liberating these agglomerated fines to be assessed.

Figure 6 Mix Shoving in Mould due to RAP Agglomerates- A tender mix with agglomerated fines causes shoving in the mould

RAP Treatment in Production

RAP in this project was treated as both an aggregate and a contributor to binder level. To ensure consistency was the main requirement. The RAP was treated in two ways, in the beginning of the project it was milled and then screened, then later it was crushed and screened as shown in Figure 7.

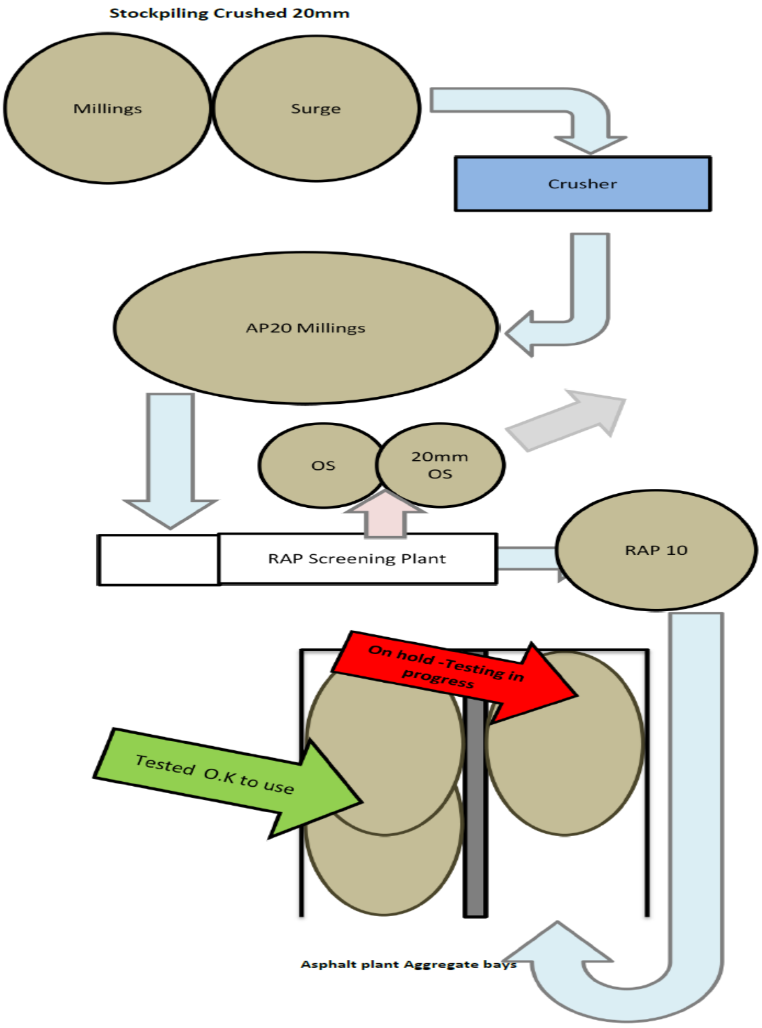


Figure 7 Processing RAP

It was found that crushing assisted significantly in ensuring both consistent grading and binder content.

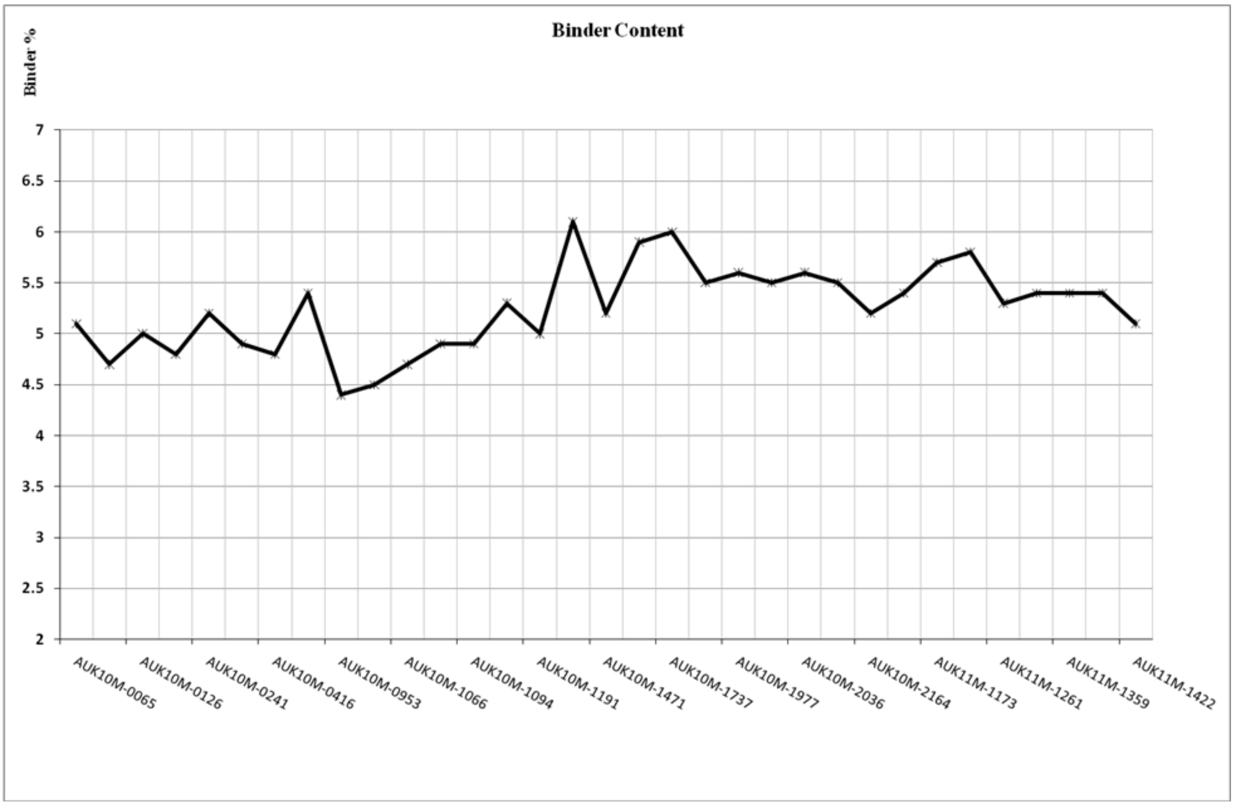


Figure 8 Variations in Binder Content

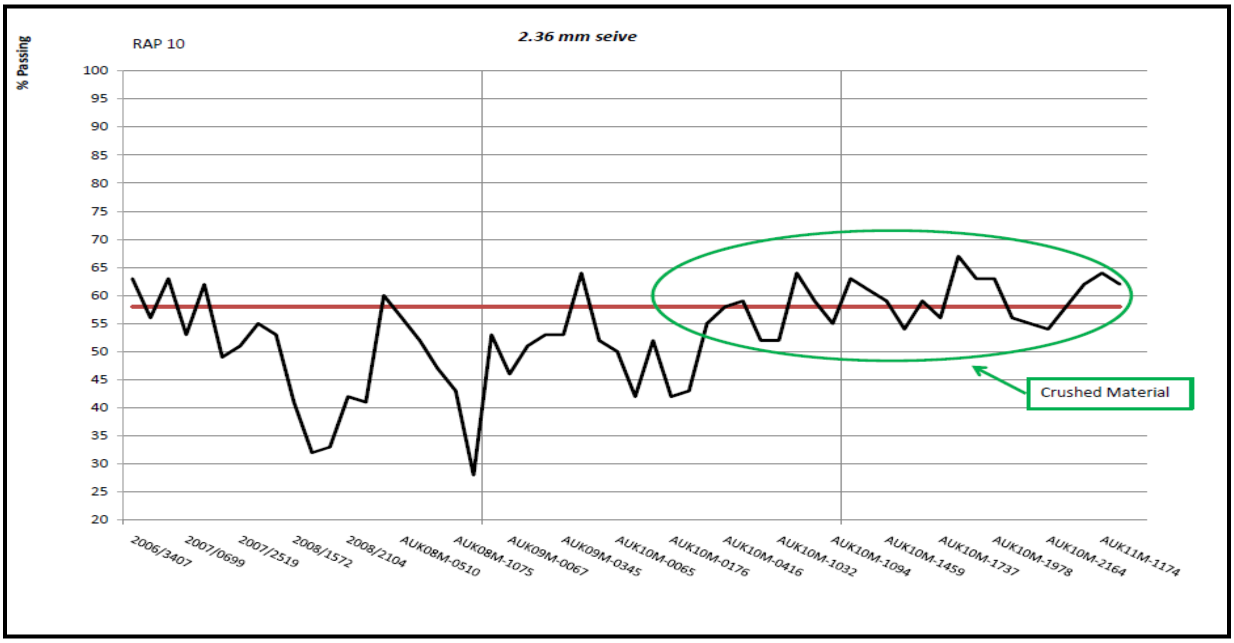
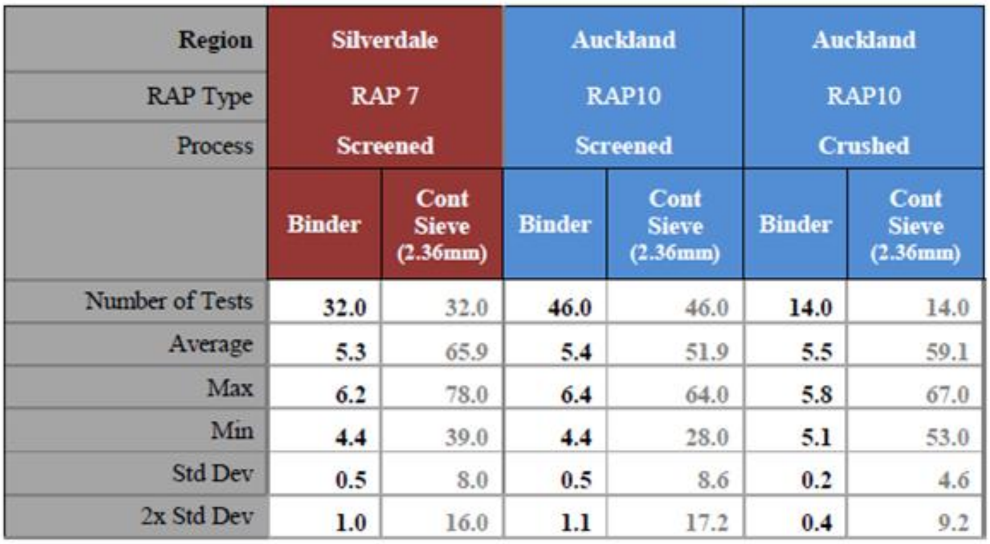


Figure 9 Variations in Control Sieve with Crushing



Region	Silverdale		Auckland		Auckland	
RAP Type	RAP 7		RAP10		RAP10	
Process	Screened		Screened		Crushed	
	Binder	Cont Sieve (2.36mm)	Binder	Cont Sieve (2.36mm)	Binder	Cont Sieve (2.36mm)
Number of Tests	**32.0**	32.0	**46.0**	46.0	**14.0**	14.0
Average	**5.3**	65.9	**5.4**	51.9	**5.5**	59.1
Max	**6.2**	78.0	**6.4**	64.0	**5.8**	67.0
Min	**4.4**	39.0	**4.4**	28.0	**5.1**	53.0
Std Dev	**0.5**	8.0	**0.5**	8.6	**0.2**	4.6
2x Std Dev	**1.0**	16.0	**1.1**	17.2	**0.4**	9.2

Table 1 Variability Reduction with Crushing

3. Results Field and Laboratory

The project involved about 200,000 tonnes of asphalt in a full depth pavement system. The project is a major diversion in Auckland. The main issues were involved with ensuring high modulus structural mix on top of a high fatigue layer. The surfacing is a polymer modified OGPA and SMA in high stress areas. The OGPA was designed for many areas to be a high PSV aggregate mix.

The High fatigue layer was factored in as a structural element. Design used resilient modulus (MATTA) as a major parameter. Fulton Hogan mixes used level three design. Layer thickness varied through the job based on design parameters provided by the consultant.

The design for the HF layer had a maximum stiffness of around 3000 MPa (Vb of about 12%) and the AC20 of around 5000 MPa. There were in fact four mixes, two for each type. This was because mix was sourced from two plants geographically separated and different quarry sources were used. A performance graded bitumen binder (PGT64) was used that complied with TNZ M/1 specifications but also was blended to optimize rheology.

Mix was laid using a standard paver with tamping.

The rolling patterns were established to optimize density using a calibrated nuclear densitometer. The first passes were carried out with a 10T vibratory roller with vibration in one direction only. This was always 2-3 passes. The static roller was used to intermediate roll and a pneumatic tyred roller used to finish roll followed by static for smoothness.

The roller patterns were changed in the coldest months but mostly in terms of time interval between laying and breakdown rolling.

This job achieved NAASRA counts of less than 25 (after OGPA was laid on the top).

QA included plant samples binder grading, volumetrics of laboratory compacted mixes and field cores.

Extra testing carried out by Fulton Hogan included resilient modulus, check on binder grading on cores as well as density and maximum theoretical density from melted field cores.

Wheel tracking was carried out on laboratory prepared slabs and compared to 200mm field core results.

Volumetrics based on NAS 2004 with NZTA New Zealand Supplement.

These were compliant in all mixes laid.

Resilient Modulus (MATTA)

Resilient modulus measured using MATTA testing has been shown to often have poor reproducibility between laboratories (46). Fulton Hogan, by rigorously complying with the test method requirements (AS. 2891.13.1-1995) particularly in terms of sample geometry and conditioning were able improve repeatability of testing to well within the test precision.

The results were measured over a year of production with two mixes from two plants but with the same mix requirements. The results for AC20 represent two layers of about 70-90mm laid. These represent some 919 points. The AC14 High Fatigue mix testing added a further 450 points. These are shown in figures 10-17.

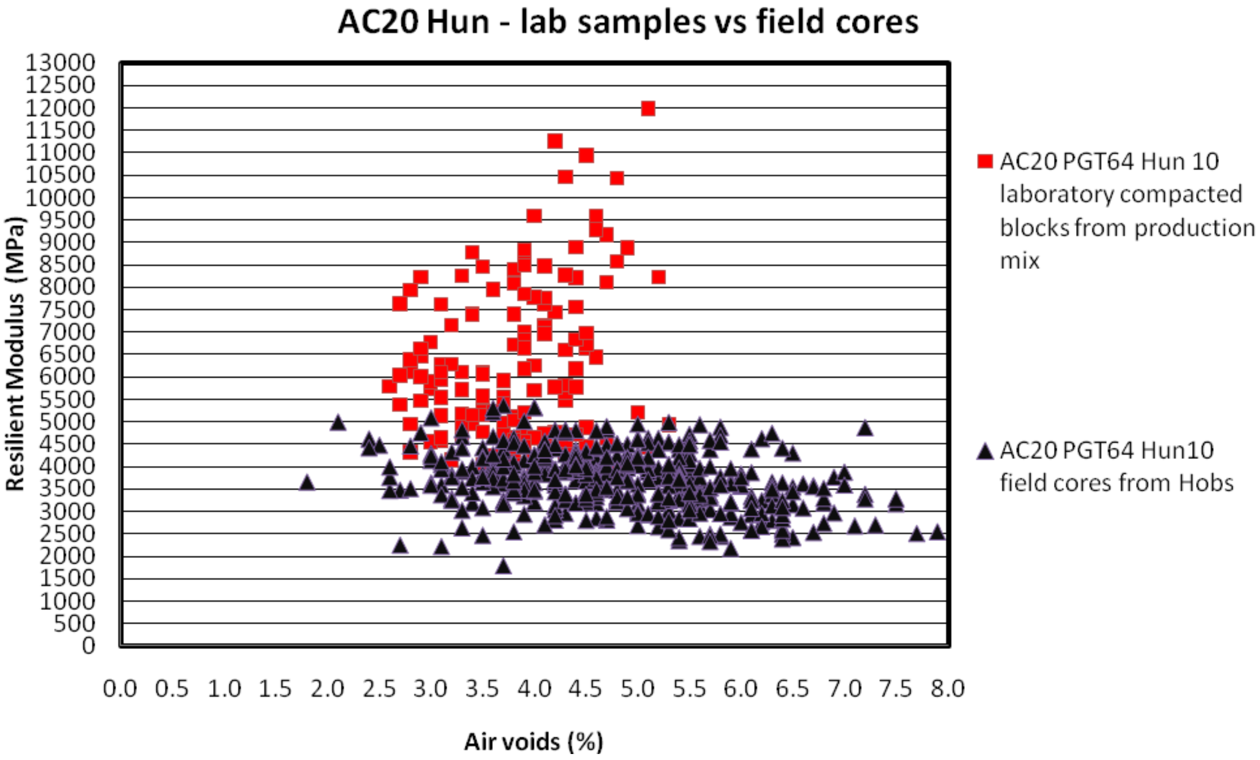


Figure 10 Comparison Laboratory Production Versus Field Air Voids and Resilient Modulus for AC20 Structural Mix ex Mt Wellington Plant

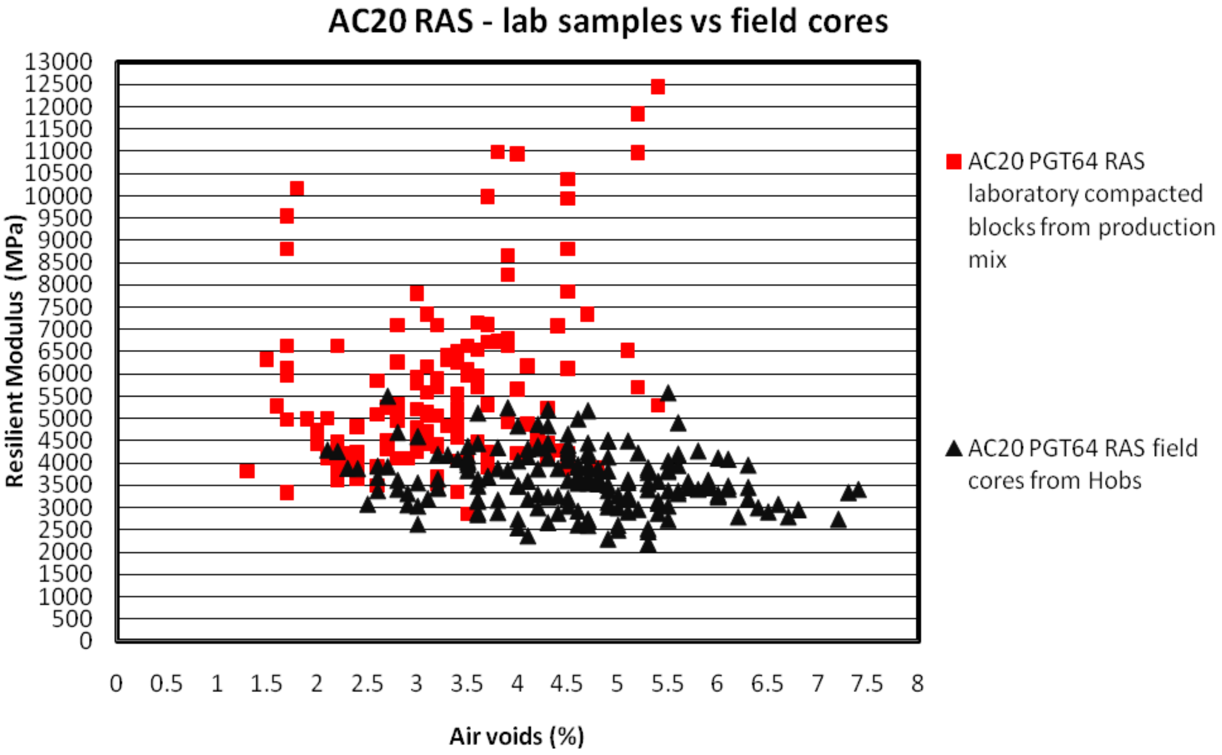


Figure 11 Comparison Laboratory Production Versus Field Air Voids and Resilient Modulus for AC20 Structural Mix ex Silverdale Plant

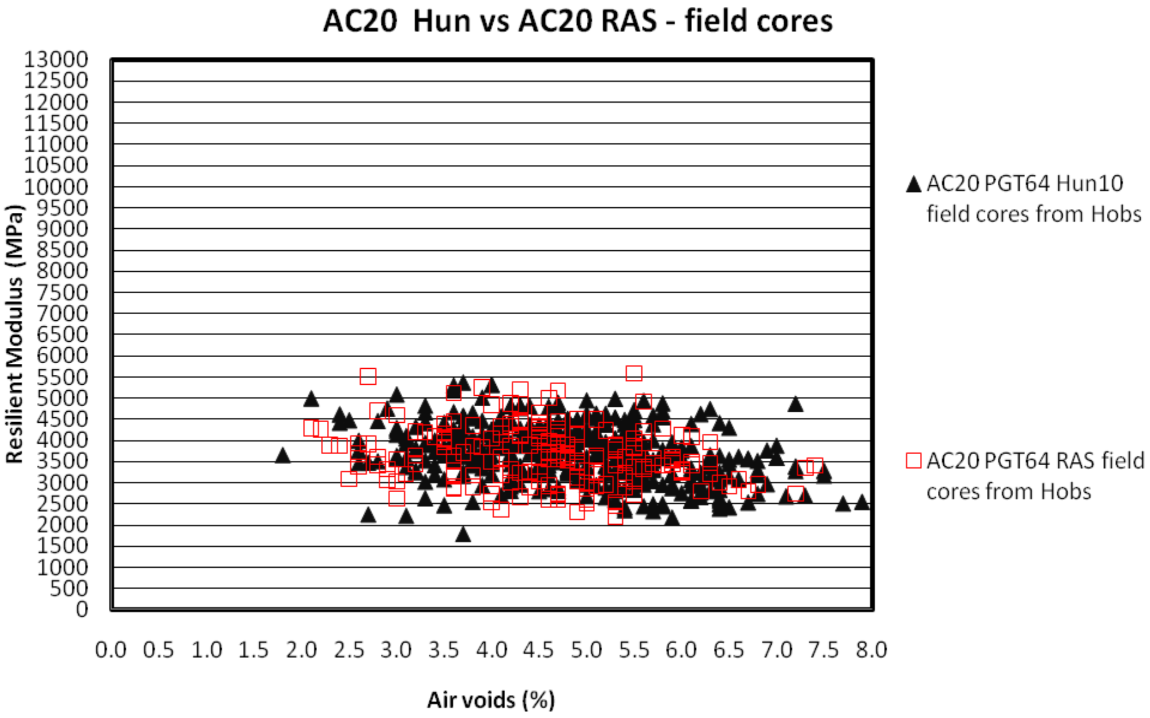


Figure 12 Comparison Field Airvoids and Resilient Modulus for AC20 Structural Mix ex Both Plants

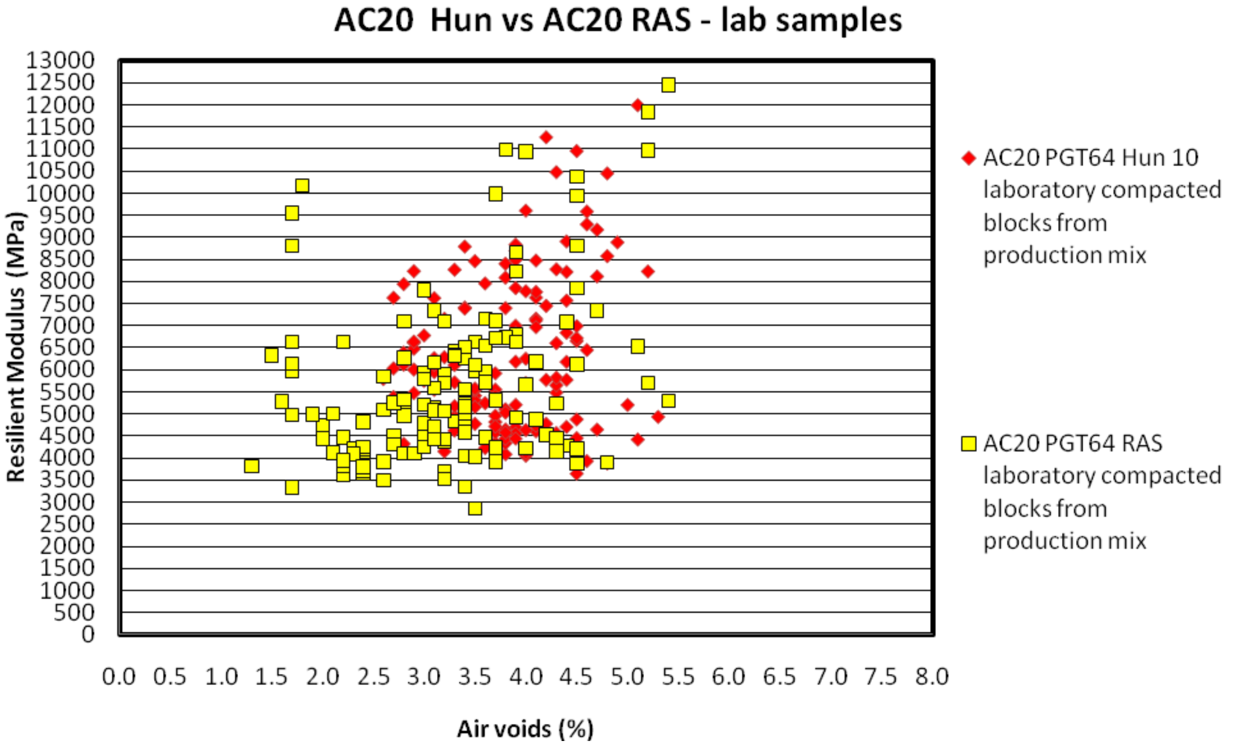


Figure 13 Comparison Laboratory Air Voids and Resilient Modulus for AC20 Structural Mix ex Both Plants

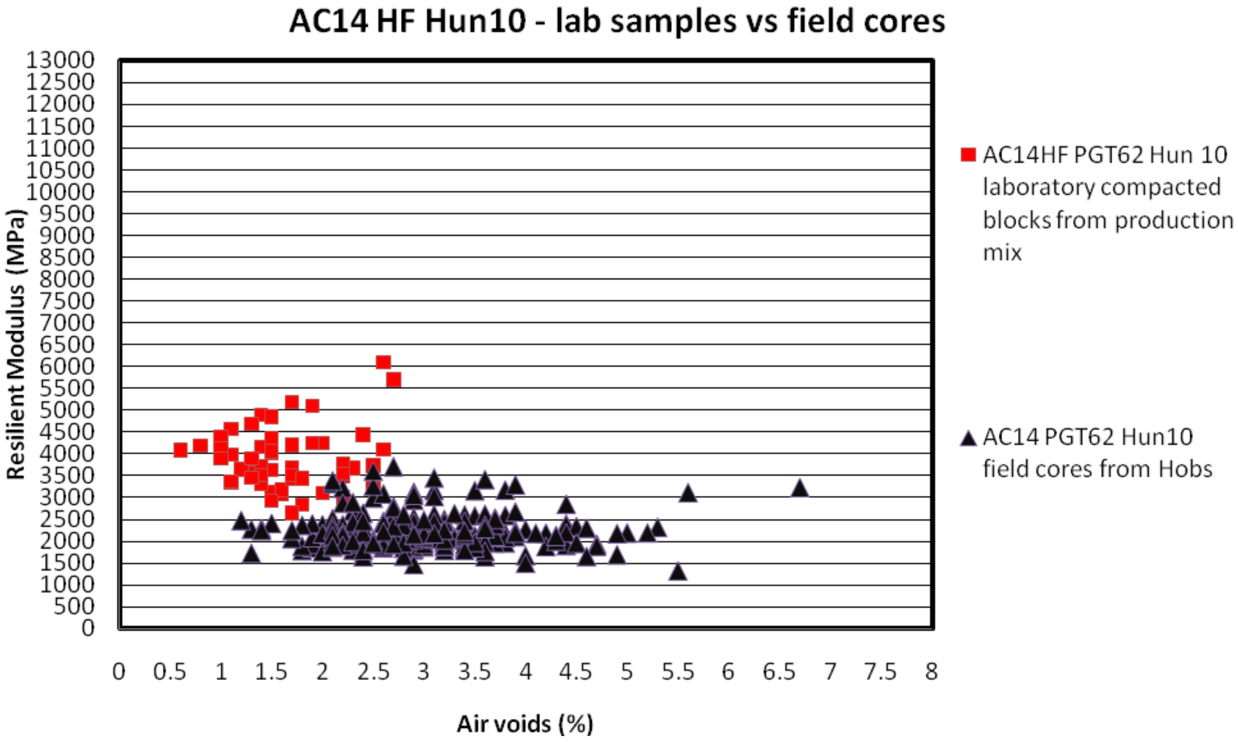


Figure 14 Comparison Laboratory Production Versus Field Air Voids and Resilient Modulus for AC14HF Mix ex Mt Wellington Plant

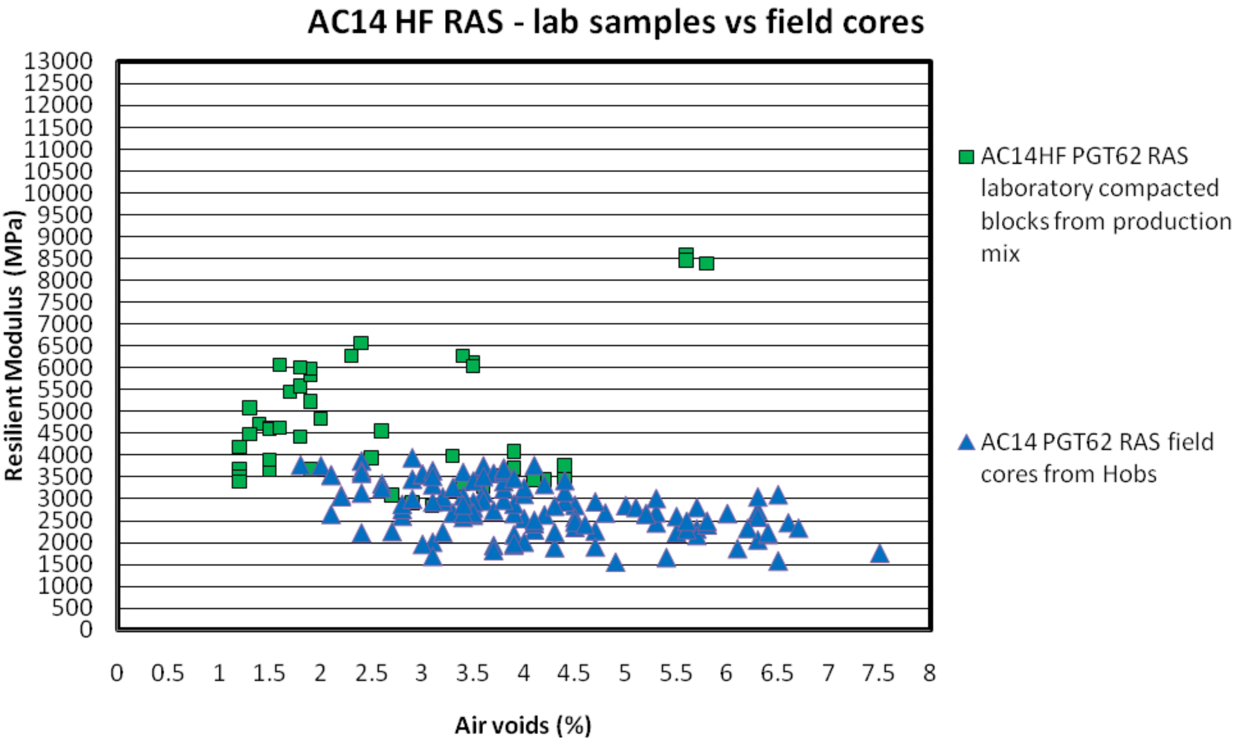


Figure 15 Comparison Laboratory Production Versus Field Air Voids and Resilient Modulus for AC14HF Mix ex Silverdale Plant

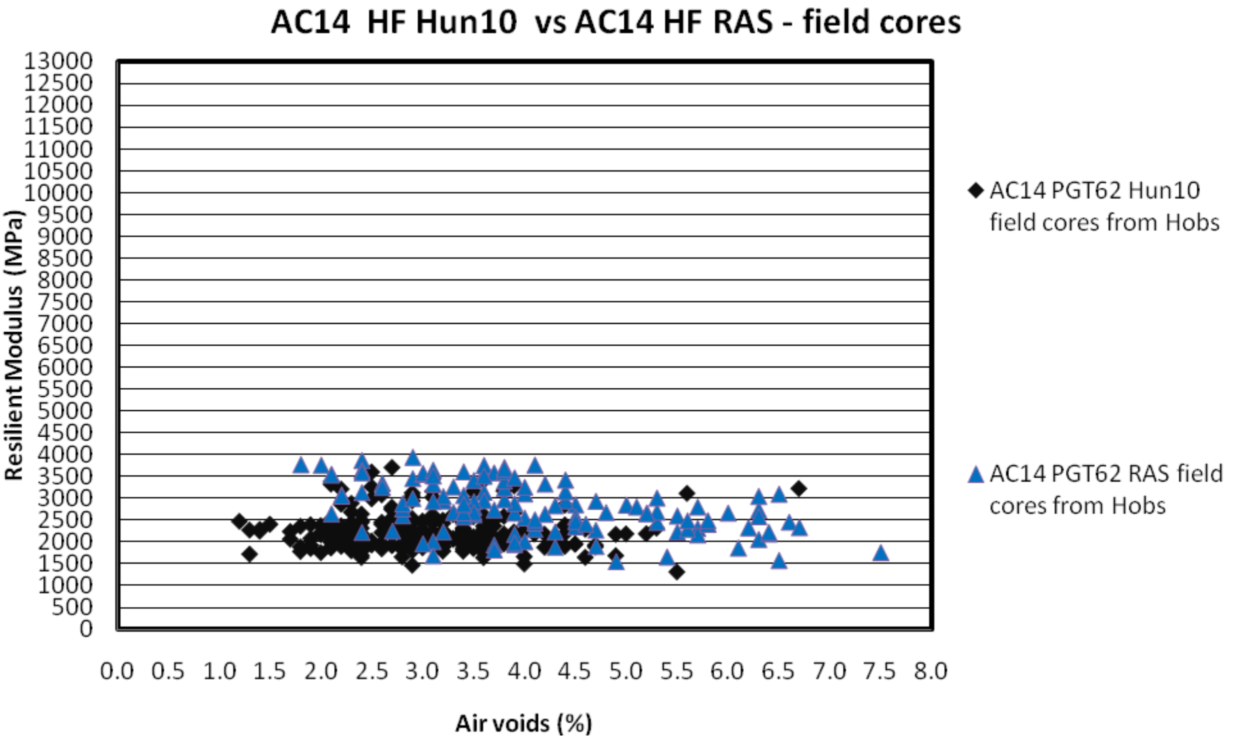


Figure 16 Comparison Field Air Voids and Resilient Modulus for AC14HF Mix ex Both Plants

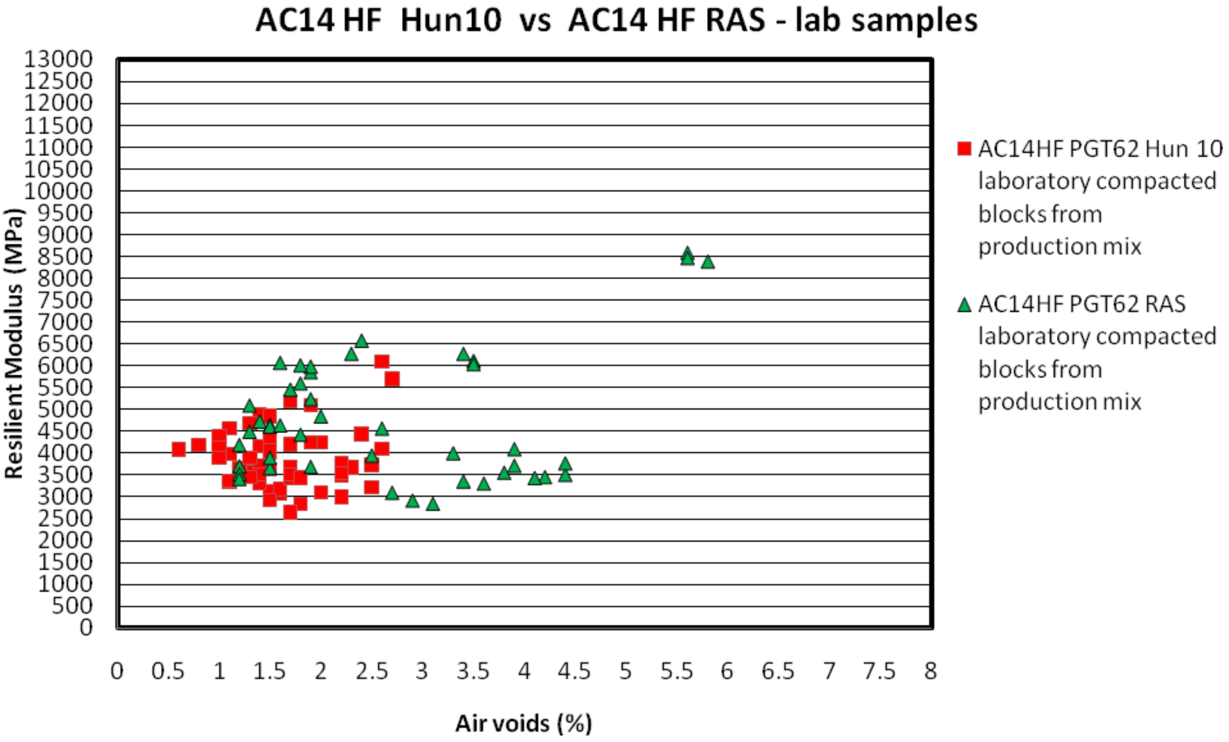


Figure 17 Comparison Laboratory Air Voids and Resilient Modulus for AC14HF Mix ex Both Plants

The Matta results were plotted against the voids content of the mixtures. Several points are evident:

- Actual Matta stiffness in field samples is lower than design. This is by about 25%. This is consistent with work by Mofreh (47). The laboratory moduli are much higher than the field for the same production lot.
- The modulus is remarkably stable for field laid mix over the whole project but quite variable in laboratory compacted mixes
- There is no relationship apparent for field or laboratory modulus and air voids
- The laboratory moduli for the same mixes has a significantly higher scatter than the field mix
- The voids levels were for laboratory compacted samples are in a narrower range and do not correlate well with field compaction
- The effects were not plant related or aggregate related
- The field voids do vary and this is likely due to several factors, these are:
  - Ambient conditions
  - Base conditions
  - Inherent variability due to transport
  - RAP binder variability

  - RAP grading variability

- The results were similar for both the High Fatigue and the AC20 mixes. Except the voids levels were much lower for the laboratory compacted mixes in AC14HF.

Wheel Tracking Results

The wheel tracker is used according to APRG protocols exactly. A minimum 6 day conditioning and 16 hour equilibration to test temperature has been used. This allowed excellent repeatability between slabs of less than 10%. It had been noted that some issues of tertiary creep were found at >10,000 cycles at 60^{0}C for some bitumens (48), and so all testing is done to 20,000 cycles or 15mm of rutting. No mixes reached failure level. Figure 18 shows the AC20 mixture slabs lab prepared and those from plant mix.

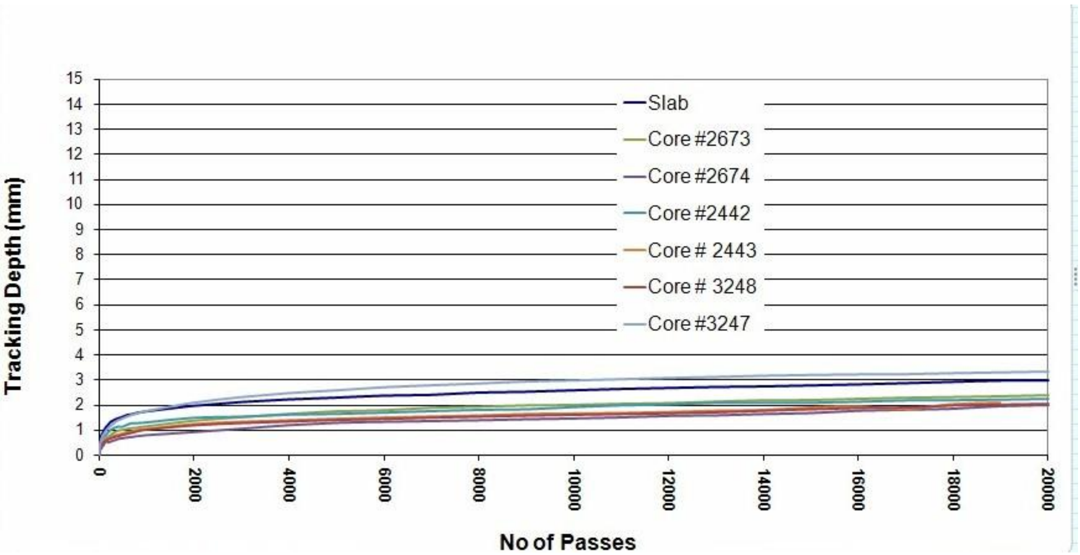


Figure 18 Wheel Tracking Results

The field mixes were sampled using 200mm cores as per Austroads specification and compared to the laboratory samples.

- It is clear that the deformation resistance of the cores and slabs are in the same population.
- No comparison was possible with gyratory cores but the literature indicates deformation resistance may be inferior (13).

Fatigue Testing

Beam fatigue testing was used to characterise the mixes and both were within the normal expected failure levels for AC20 mixes. See table 2. This was compacted by rolling wheel. Note that the tests were carried out on production mixes that had been reheated and hence may have had binder hardening- this would have increased flexural modulus and decreased fatigue life. Results show results within the scatter of the test.

Mix	15% RAP Mix Cycles to Fail	15% RAP Mix Flexural Strength (MPa)	Virgin Mix AC20 Cycles to Fail	Virgin Mix Flexural Strength (MPa)
AC20Hun	250,000	6560	315,000	6760
AC20RAS	319,480	4500	-	-

Table 2 Fatigue Results

*Fatigue Life of Compacted Bituminous Mixes Subject to Repeated AG:PT/T233 – 06 Flexural Bending 20^0C 400 μs.

Permeability Results

A falling head permeability test was developed base on Qld MRD devices. The major difference was that lateral flow of water was allowed. This device was used to test both laboratory compacted and field extracted cores. The AC20 showed moderate permeability in field, this was shown mostly in lateral movement of water as well as through the bottom of the layer. The gyratory compacted cores with voids at the top and the bottom of the cores showed lower permeability than the field cores at similar air void levels. This indicated that higher levels of interconnected voids are present in a field compacted sample. This means assessment for potential moisture damage may be better done on field cores.

4. **Conclusions**

- Matta stiffness is reproducible but from design gyratory samples should not be used in pavement design as the field result will be lower. It is dubious whether resilient modulus is acceptable as a substitute for flexural modulus in any case.
- Compaction method produces different structures in the mix including different void distribution. This produces different mechanical properties. Any assessment of performance properties should be done on cores.
- Laboratory compaction if rolling wheel is used may be a reasonable representation of field results.
- RAP mixes need special attention especially in heating and grading but present no problems when RAP is viewed as an aggregate and binder.
- Crushing may be used if the RAP is rescreened to desirable grading.
- Permeability is a potential issue with larger stone mixes, particularly those not to be trafficked for significant periods. Field cores give a better indication of this performance aspect than gyratory compacted laboratory samples.
- Wheel tracking of field cores gives a good correspondence with laboratory design slabs.

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