

RESEARCH FINDINGS ON THE SUCCESSFUL TREATMENT OF MARGINAL AGGREGATES

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Transit New Zealand recently issued draft specifications that allow the use of marginal aggregates, stabilisation and alternative construction methodologies. They are performance based and rely on a complete understanding of a material's properties and the way it performs. Transit New Zealand recently suggested companies would need to undertake R + D to develop a range of road base materials that will perform adequately for different applications and will cost less to produce.

KOBM Binder™ has been used extensively in the greater Auckland area, particularly the Rodney District Council as a binder to modify marginal aggregates in some 300 km of new and rehabilitation projects over the last 10 years. While enjoying unquestionable success in the treatment of marginal aggregates, its use and application rates have been based on an empirical method with limited laboratory testing. In late 1997 we identified a need to fully understand the reaction mechanisms and develop the use of KOBM Binder™ and the concept of modified marginal aggregates to provide product information and a level of confidence to specifiers that Transit N.Z. are now suggesting is essential to the performance based approach.

The research project that we undertook in association with Industrial Research Limited addressed these items and provided outcomes that clearly demonstrate the scope for use of the binders, and the properties achieved with typical aggregates which enables prospective specifiers and pavement designers to specify using KOBM Binder™ or Durabind™ easier, with more confidence and at appropriate application rates. The data will prove the pavement material has the necessary strength and durability for tender evaluation and will produce significant client benefits in a number of ways as not only are the products cheaper they are “environmentally friendly” and “people friendly”.

This comprehensive package of information on the binders and its uses gives specifiers the necessary manuals and specifications that can readily be adapted to any particular application and includes real life data for typical aggregates such as resilient modulus result which can be input into mechanistic analysis of pavements.

Pavements will now need less binder at less cost to achieve equivalent results.

1.0 THE PROJECT

KOBM (Kontinuous Oxygen Blast Maxiite) Binder™ is one of two slags produced in significant quantities during the steel making process at Glenbrook Steel Mill in South Auckland and has found use as a road stabilizing binder.

KOBM Binder™ has traditionally been used at dosage rates for any one soil type at any location by some empirical measurements. The dosage rate suitable for most soils has been about four percent by weight but because little was understood about the mechanism of the binder, application rates more than double this have been over specified by engineers to ensure adequate strength is achieved.

The objectives of our research project were:

- To gain more understanding of the chemistry of the binder and the mechanism of how it reacts with the roading aggregates to form a modified roading material so that some criteria could be placed on its use.
- To identify a substitute material or chemical that could be used as an initiator for KOBM Binder™ instead of hydrated lime or Portland cement so that its performance was optimised.
- To conduct a series of road stabilisation trials to test the effectiveness of the new binder formulation.
- To develop material handling, quality control and recommended practice procedures for specifiers and customers.

All scientific analysis and product characterization was undertaken by Industrial Research Limited. (I R L)

1.1 TERMS

- KOBM Binder™ - The refined material from weathered KOBM Slag.
- Durabind™ - Mixture developed from the research which is KOBM Binder™ and Various pre-blended initiators.
- Stabitec Ltd - Stabilization Technologies Ltd the research and supply company providing the above products.

2.0 TECHNOLOGICAL DEVELOPMENTS

2.1 SAMPLING AND COMPOSITION OF KOBM BINDER™

A bulk sample of ready to use KOBM Binder™ was collected and used for all performance trials. Manufacturers assurances confirmed that the chemistry was typical of the slag which has been produced at Glenbrook for several years.

Calculations were undertaken from XRF results which concluded that the principal components of the ready to use KOBM Binder™ are:

- $\text{Ca}(\text{OH})_2$ Calcium Hydroxide
- C_2F (substituted) Dicalcium Ferrite
- Glassy material

It is believed that much of the lime component of fresh solidified KOBM Binder™ is chemically bound and not available for reaction.

KOBM Binder™ stored in the open air loses reactive quality as the calcium hydroxide carbonates to calcium carbonate. Traditionally the slag has been stored uncovered in a stockpile open to the weather. Continued carbonation will occur as shown by the reducing $\text{Ca}(\text{OH})_2$ content of the various stockpiles with time. However, a crust of carbonate on the outside of the pile will protect the interior of the pile. This was demonstrated by XRF of a sample from the interior of an 8 year old pile which had the same $\text{Ca}(\text{OH})_2$ as the fresh sample.

2.2 THE CHEMICAL MECHANISM OF THE KOBM BINDER™ INTERACTION

While the initial reaction of KOBM Binder™ is similar to that which occurs between $\text{Ca}(\text{OH})_2$ and the clay minerals in the aggregate, the development of strength appeared to be too great to be due to that mechanism alone. Scanning electron microscopes taken of the fresh KOBM Binder™ and of a sample after 2 days hydration show that a product forms on the surface of the grains as it hydrates.

It is believed there is an additional hydration mechanism formed from complex reactions with the Dicalcium Ferrite identified in the raw product and provides an ongoing increase in strength. This is similar to the findings of Little " Evaluation of Structural properties of Lime stabilised soils and aggregates " where it was demonstrated by extensive laboratory and field testing that a long term strength improvement results from the pozzolanic reactions

2.3 THE FUNCTION OF DICALCIUM FERRITE

The generation of further lime from the hydration of the dicalium ferrite was investigated by forming a synthetic version of the dicalcium ferrite.

Comparison of the X-ray diffraction pattern of the pure C_2F phase with the active material in KOBM Binder showed that the calcium ferrite phase in KOBM Binder was typical of a magnesium substituted compound.

Scanning electron microscopes was used to examine some of the phases and products of ferrite hydration. Thin sheets of $\text{Ca}(\text{OH})_2$ are present in the hydrated C_2F containing lime growing out from the ferrite mineral grains. However, there is no evidence of this in the lime free sample, which confirms that hydrating pure dicalcium ferrite does not produce more $\text{Ca}(\text{OH})_2$ although some hydration product is formed.

2.4 THE REACTION MECHANISM OF KOBM BINDER™ WITH AN AGGREGATE

Three quarry aggregates were chosen for the project; Flat Top (Basalt), Waitakere (Andersite) and Drury (Greywacke).

Flat Top is a volcanic rock that varies in composition and can be described as a highly weathered basalt with secondary minerals. The rock shows a significant crush zone component that accounts for the considerable quantity of fines. Drury's is a typical greywacke aggregate of high strength durable stone with clay fine seams that are sensitive to water and become plastic. Waitakere by contrast, is a much younger volcanic rock from the Miocene period. These all can be improved with the addition of KOBM Binder™ plus Cement as shown by recent California Bearing Ratio (CBR) values summarised in Table 1.

Table 1: Typical CBR Values for Aggregates

Aggregate	Dosage	7 day Soaked CBR
Flat Top	None	60-65
	3% KOBMBinder 0.5% cement	245-265
Drury	None	50-60
	3% KOBMBinder 0.5% cement	205-215
Waitakere	None	105
	3% KOBMBinder 0.5% cement	135-165

To understand the reaction mechanism between the aggregate and the KOBM Binder™ 50 ml pottles of each of the aggregate fines below 4.5 mm sieve was prepared with a standard addition of KOBM Binder™ alone, or initiating the aggregate/binder reaction with cement. The products were then analysed using X-ray diffraction and scanning electron microscopes of the hydration products from each aggregate/binder blend.

Submicron sized needles form a network between the very fine grained minerals in two of the aggregates. The needles are particularly abundant in the Flat Top and Drury blends which are already recognized as good performers with KOBM Binder™. By contrast, the abundance of needles in the Waitakere samples is relatively low and this perhaps accounts for its lower performance compared to Flat Top.

It is believed the formation of needles is a key to early strength development in the aggregate fines/binder reaction. The needles are extremely fine and their composition cannot be determined, but they are similar in structure to those formed in hydrated Portland cement. The needle patterns are also similar to those from hydrated C2F which suggests that they may originate from there.

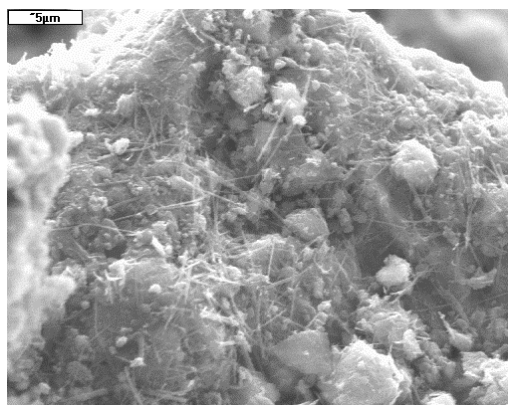


Fig 3(a): Hydrated Flat Top and KOBM Binder™ Blend

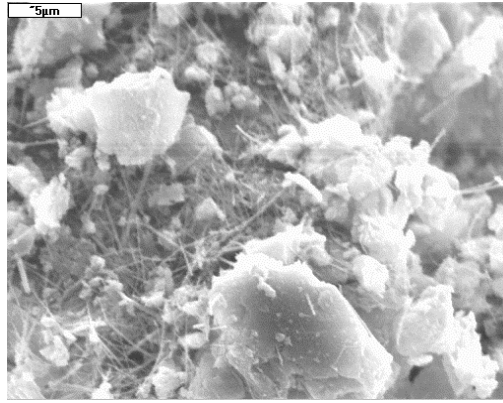


Fig 3(b): Hydrated Drury and KOBM Binder™ Blend

2.5 CHEMICAL INITIATORS FOR KOBM BINDER™

A major objective of the project was to investigate the use of an alternative binder to cement to act as an initiator for setting of the KOBM Binder™/clay reaction. A number of chemicals were screened as possible initiators by preparing small scale pottles and measuring the penetration strengths or whether setting occurred.

Durabind showed excellent results, in one test exceeding the early strength development for cement. Testing for longer periods up to seven days, while maintaining adequate moisture levels around the specimens, showed continued strength development.

Scanning electron microscopes of the aggregate/KOBM Binder™ and aggregate / Durabind showed a considerable amount of hydrated material that would have cementing properties, adhering to the outer surface of the particles.

3.0 ENVIRONMENTAL CONSIDERATIONS OF USING KOBM BINDER™

KOBM Binder™ contains measurable levels of heavy metals and it was critical to assess the possible leachability of these into the water table. Initially, a sample of KOBM Binder™ was exposed to neutral and slightly acid conditions using hydrochloric acid but this failed to show any leaching. A second environmental test was set up where a 5g sample of KOBM Binder™ sub-sampled from a bulk supply intended for immediate use on the road was leached in acetic acid for one week maintaining the pH <5. The leachate was filtered, concentrated and analysed using X-ray fluorescence.

The elemental analysis showed no evidence of heavy metal leaching, particularly for chromium and vanadium, which are present in the raw slag. These metals are retained by the alkaline binder matrix. It is believed that this test is considerably more aggressive than is likely to be found in nature and unless the KOBM Binder™ is extensively ground it is believed that there is little possibility of heavy metal leaching from a binder/fine aggregate matrix.

Other testing involved leaving Durabind™ exposed to the air. This test has shown satisfactory results provided the blend is well protected from the weather. It is believed at this stage that it should have a shelf life in excess of two weeks.

The work reported in the previous section showed that long term exposure of a KOBM Binder™ stock pile to weathering will lead to slow carbonation. However, provided the pile is left undisturbed, the carbonated layer protects the internal binder from carbonation.

4.0 FIELD TRIALS

4.1 BACKGROUND

The project undertook a roading trial with aggregate from Flattop Quarry which is a highly weathered basalt and showed good results in the laboratory phase to establish a formula that provides optimal performance of KOBM Binder™ plus cement and Durabind™ for a basecourse type.

Westhoe Road was an existing unsealed road, which connects the Upper area of Orewa in Rodney District. The trial pavement detailed below consists of a KOBM Binder™ plus Cement control section and a Durabind™ test section each 220 m long with 30 m buffers at each end to ensure consistency of each section.

Pavement design for the control and test section conforms to the basic pavement cross section in figure 1. Traffic commodity counts have been undertaken and record AADT of 211 with average HCV 14%. The road is currently being used on an access road for heavy equipment to the new Alpurh Motorway and so is a good test of the performance of the products.

Two Coat Chip Seal – Grade 2 & 4

<p>Basecourse 150mm Flattop GAP 65 modified with KOBM Binder 4 % plus cement 1 %</p>	<p>Basecourse 150mm Flattop GAP 65 modified with Durabind 3 %</p>
<p>Subgrade 250mm Insitu Clay stabilized with Lime Oxide 3 %</p>	<p>Subgrade 250mm Insitu Clay stabilized with Lime Oxide 3 %</p>

Figure 1 Pavement Design

4.2 PERFORMANCE MONITORING OF MODIFIED AGGREGATE

Work plan details for the field trial were formulated in consultation with a reputable pavement engineering consultancy, Manukau Consultants Ltd.

A comprehensive testing regime was developed that monitored the performance of the trial versus the control over an extended time period measuring both the changes in the material properties and the changes in the infield performance properties. This will be on going for a lengthy period to monitor durability and in field level of service from the different products.

In summary the Durabind™ is performing marginally better than the commonly used KOBM Binder™ plus cement combination and demonstrates in a live road situation that the new product is useable, effective and achieves the desired material properties in the pavement.

4.3 SITE WORKS AND SUBGRADE STABILISATION

The subgrade was stabilised with 14kg lime oxide to 250mm to provide a strong base on which to construct the aggregate layer and undertake the aggregate modification process so as to avoid any effect of a weaker, inconsistent subgrade.

The aggregate was then placed and compacted in preparation for the modification process. It was also sampled (ex quarry) and tested to determine properties of the aggregate used in the trial.

A 20m section of the aggregate was pulverised without binders and sampled for resilient modulus test to ensure the sample represented a post stabilised materials grading.

The 2 Binders were tested for Moisture Content, % CaO, % Ca(OH) and grading to characterise the Binders used in the trial. A volume of both Binders used in the trials were retained for the repeated load triaxials.

4.4 AGGREGATE STABILISATION

The 2 sections were stabilised with their respective products at the following rates: Control KOBM Binder™ 4%, cement 1% and Test Durabind™ 3%. Particular care was taken to ensure any variables were minimised by monitoring water application, roller effort and number of roller passes and ensuring they were the same on both sections.

The application of Durabind™ was undertaken via a standard belt spreader and found to be completely successful. The blended nature of the product had not visibly altered during transportation and the product was spread with ease.

Pulverisation and mixing with the stabiliser was undertaken followed with normal compaction and trimming operations. The prepared surface was maintained for 7 days to allow for the planned testing schedule during which time regular watering and drag brooming of the surface was undertaken to maintain the condition, followed by sealing with a chipseal. The pre-seal surface was no different between the sections indicating the Durabind™ section was able to be sealed in a normal manner.

During the construction of the trial sections the pavement structures and materials were subjected to numerous tests in order to demonstrate the changes in material properties and verify the improvement in the pavement performance.

The following tests were carried out by Manukau Consultants Ltd:

A. Aggregate Material Properties:

- Laboratory California bearing Ratio (CBR) tests on two samples of the modified GAP 65 recovered from behind the hoe after curing for 3 days and soaking for 4.
- Particle Size Distribution (PSD) of a sample from each section of the modified GAP 65 recovered from behind the hoe.

- Plasticity index, Clay index and Sand equivalent.
- Crushing resistance and Weathering resistance.

Source Property Test	Natural		Aggregate Modified with	
	Marginal Aggregate Flattop GAP 65	TNZ M4	KOBM Binder Plus Cement	Durabind
Crushing Resistance	3.9% @ 100kN	10% @ 130kN	-	-
Weathering Quality Index	CC	AA, AB, AC, BA, BB, OR CA	-	-
California Bearing Ratio	60	Not less than 80%	250	220
Sand Equivalent	26	Not less than 40	44	43
Clay Index	6.3	Not > than 3	2.1	2.0
Plasticity Index	5	Not > than 5	-	-
Particle Size Distribution	No comparison as two different size materials GAP 65 vs AP 40		Grading to produce a dense durable pavement -	

B. Pavement Performance:

- Laboratory California bearing ratio CBR. 1, 3, 7, 30, 60, 90 days.
- In situ density test using a nuclear densometer at 50 m centre alternate lanes.
- Clegg Impact Values with 20 kg Hammer and 4 kg Hammer at 20 m centres in all four wheel tracks.
- Benkleman Beam at 20 m centres, on all four wheel tracks 1, 3, 7, 30, 60, 90 days.
- Resilient Modulus (undertaken by University of Canterbury).
- Unconfined compressive strength 1, 3, 7, 30, 60, 90 days.

4.5 RESULTS

Detailed results of the tests can be found Appendix A, B, C and D.

(1) Benkleman Beam

The results of the Benkleman Beam survey appendix A confirmed that the pavement was of high strength. Readings were taken every 20 m both sides and the initial deflection of 1.4 m quickly came below 1.00 mm. Generally a pavement with a maximum deflection less than 1.0 mm is considered of high strength.

Durabind™ Day 1 was slightly higher than KOBM Binder™ plus cement with the 7 day result lower and the 30 day result for both below 1.0 mm.

(2) Clegg Impact Value

The results of the Clegg Hammer tests are prepared in Appendix B. Analysis of the results using a rough method of conversion to CBR when $CBR = CIV^2 \times 0.07 = CBR 220$

The Durabind™ CIV are consistently higher than KOBM Binder™ plus Cement.

(3) Unconfined Compressive Strength

Sampling was taken from behind the hoe and prepared in moulds on site appendix C. The first 21 days of the Durabind results indicate UCS values below the KOBM Binder™ plus cement indicating a slower setting binder, which is desirable to prevent cracking. However the 30 day results for Durabind™ UCS were above KOBM Binder plus Cement indicating the material is a modified lightly bound material. This is confirmed by RLT tests following.

Durabind 1000 KOBM Binder™ plus Cement 650. 30 day UCS

(4) California Bearing Ratio (CBR)

Sampling was taken from behind the hoe and prepared in moulds on site.

The CBR tests appendix D indicated a high soaked CBR value of the modified GAP65 in comparison to the minimum required CBR for an M/4 material of 80%. These values and the higher 30 day results may be outside the range of accurate measurement for this test equipment.

Durabind™ 220 KOBM Binder™ plus Cement 250. 7 day CBR

(5) Resilient Modulus

Repeated load Triaxials were undertaken on both options under basecourse and subbasecourse stress conditions and saturated.

E Durabind™ 700 E KOBM Binder™ plus Cement 1500

(6) Particle Size distribution (PSD)

The PSD of the modified GAP65 indicates a well graded material likely to form a dense stable layer.

5.0 FUTURE IMPLEMENTATION OF RESEARCH FINDINGS

The project confirmed KOBM Binder™ plus cement can be used successfully as a road stabilising binder in the form currently supplied by Stabitec to modify marginal aggregates to a modified product whose properties and infield performance exceed those of a traditional premium aggregate. The most desirable and recommended substitute for ordinary Portland cement as a reaction initiator, is the purpose designed Durabind which has generated performance results that exceed those of KOBM Binder™ plus cement with some aggregates.

While other industries are proactive and forward thinking in their R + D efforts, our experience indicates the roading industry is under investing in R + D work.

Is the industry inputting enough time and investment into R + D? In carrying out our KOBM Binder research what were the difficulties and barriers we faced? What improvements would we like to see within the industry in the areas of R + D to encourage innovation?

A recent research project by Bartley Consultants investigated areas of pavement engineering for roading authorities that were in need of further research. After a variety of stakeholders

within the industry were covered, the report noted that very few territorial authorities perform their own research or have involvement in state funded research. The report considered that this was to the detriment of the roading fraternity as a whole because territorial authorities are major users of pavement technology and would benefit from the research findings.

Our company evolved some 17 years ago when stabilising was a relatively new technology in New Zealand and we first started looking at the potential use of KOBM Binder as a highly specialised contractor we have had to adapt and embrace innovative practices and methods to retain our market position and ensure our long-term future. Innovation has and continues to be an integral feature of our company's philosophy providing the key to our businesses long-term future.

So you can see that innovation is not new to our company.

Innovation is needed to keep pace with the continual change occurring within our industry and has been largely driven by the following factors.

- Our roads are being subjected to increasing traffic volumes and loads.
- Recent adoption of Austroads design criteria and a mechanistic approach to pavement design.
- An increasing number of existing roads are reaching the end of their service life
- Road aggregate resources are diminishing, becoming scarcer and more expensive.
- Environmental issues have an increased priority.

As Roothing Innovation is therefore necessary and inevitable it must be better initiated and cultured through continuing R & D work.

5.1 RESEARCH AND DEVELOPMENT FUNDING

A major barrier in undertaking our KOBM Binder R & D was the lack of funding from within the roading industry. The industry needs to do more to assist with research applications, linking proposals with funding and having clearly defined guidelines for research applications.

Transfund has a total research budget for 1999 / 2000, amounting to less than \$ 2 million. This equates to less than 0.2 % of Transfunds total roading budget. At present there appears to be a huge discrepancy between the investment into R & D and the total dollar value committed to roading. We believe Transfund should see R & D funding as a "strategic investment" providing value engineering to the end user.

Technology New Zealand reports that "10 firms supported by Technology New Zealand turned \$2 million of products into earnings of more than \$200 million. Typically these firms invested more than \$7.00 to every \$1.00 of Government money. Direct taxation on that profit amounts to between \$6 million and \$9 million giving the New Zealand Government a direct return of more than 300%.

Our company has benefited from the support and funding provided by Rodney District Council and their network managers Manukau Consultants. This has culminated in several road trials of KOBM Binder and Durabind and testing of the pavement performances. The resulting data has been an integral part of our R + D programme.

The Rodney District Council and Manukau Consultants are committed to innovation and the benefits and advantages which innovation provides. However our experience shows this support and funding appears to be the exception rather than the rule if we are to look at the industry as a whole and this is further summarized in the Bartley Consultants report.

5.2 DISTRIBUTION OF RESEARCH FINDINGS

Upon publishing our KOBM Binder research, we have found inefficiencies with the current system of research distribution. The cost and time delays with the existing system create barriers, which restrict the benefits of research from reaching the wider industry. Given the investment by private companies and funding organisations into research, it is important that research information be accessible to the entire industry so we can collectively benefit.

The Rooding and Transport Authority in Australia have an excellent website for obtaining roading, testing and quality specifications and we believe the use of a dedicated website would give a more efficient and instantly available database provider than the current system.

Our company has been exclusively responsible for marketing and distributing our KOBM research information.

5.3 BENEFITS OF R + D FUNDING

KOBM Binder R + D has provided major economic cost benefits and savings to a number of roading authorities. Modification of marginal aggregate for use in pavement construction also provides major environmental advantages and provides a long-term solution to the dwindling availability of premium quality aggregates in the future.

Major benefits of public R+D funding include:

- More comprehensive testing within a quicker timeframe.
- Speedier implementation of proven technologies
- Published research information benefits a wider market
- Provides greater overall cost efficiencies to the industry.
- Gives contractors the opportunity for innovation
- Provides value and quality and return on investment to the fund provider.

5.4 PRIORITISING RESEARCH PROJECTS

Research projects must represent the real issues facing the industry.

In the past we had the National Roads Board pavements committee which was responsible for the allocation of industry related research funding. It appears that the current system lacks a coordinated strategic direction and may be too prone to subjectivity. We would like to see the contracting industry and other stakeholders have more input into the selection of research subjects to ensure that "core" roading issues at the forefront of research.

We must ensure that research topics represent the needs of the roading industry rather than creating research for the sake of it. Failure for this to happen will lead to a more bureaucratic and compliance driven research, which may loose touch with the real roading issues.

We would like to see funding allocations for hands on trial projects and performance monitoring for project such as foamed bitumen stabilisation, investigation and trialing of marginal aggregates, concrete roads construction, dust suppression and general material properties. It is important the industry collectively becomes more involved with research and trials. We need to see much more involvement from contractors, quarries, consultants and roading authorities working jointly on research projects and benefiting collectively.

5.5 CONTRACT DOCUMENTS ENCOURAGE INNOVATION.

The industry needs to encourage innovation through the tendering process, including performance-based specifications allowing the contractor to submit an alternative, which conforms to the tender document and RFT.

We need to see design ESA values, subgrade CBR strength, borelogs, and relevant project investigation and testing data included in the tender document to enable the assessment of alternatives. This information is already available with the consultant designer so why not include it in the document and allow a contractor the chance to evaluate and propose alternatives which benefit the end user.

TNZ performance specifications TNZ B3 and TNZ M22 are excellent moves towards innovation. We look forward to the proposed trial of B3 and M22 on the Alpurh motorway B2 which will give the opportunity for a semi- design build project.

Alternative pavements should be more widely encouraged and accepted within the industry through the use of semi design build and performance based specifications. Alternatives will continue to reflect innovation and quality.

6.0 CONCLUSIONS:

- Less binder is needed at a lower cost to achieve equivalent properties.
- Typical material properties for Flattop Gap 65 modified with Durabind or KOBM Binder™ plus cement are presented in section 4.5 and demonstrate the material is a strong and durable product producing a semi flexible pavement.
- Full material handling, quality control and recommended practice procedures for specifiers and customers have been developed for KOBM Binder™ and Durabind™.
- The purpose of this trial was to demonstrate that the modified aggregate was a suitable substitute for M4 quality material as a basecourse. The tests to date indicate that this is so, and observations over time, as the pavement is subjected to various traffic and climatic conditions, will provide the long-term confirmation that is required.
- More incentives and funding for research and development are required with Transfund to take a more initiating, co-coordinating and leadership role.
- Wider use of realistic and industry endorsed performance based specifications e.g. TNZ B3 and M22 specs with a greater use for semi - design build and performance based criteria specifications.
- Better inter industry sector communication and collective research focus.
- Greater involvement from roading authorities with funding research and development.

With a more pragmatic and active industry approach we should be able to collectively look forward to moving into the new millenium with confidence but it is essential the we all "walk the talk."

7.0 REFERENCES

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