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Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

Re-use of High Skid Resistance Aggregates in Porous Asphalt

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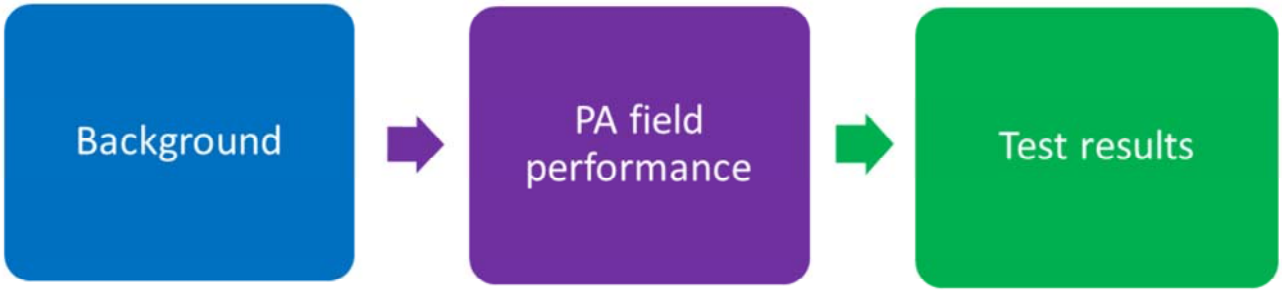
Outline



Why PA?

Benefits of PA:

- Safety
- Driving experience satisfaction
- Environment

Aggregates used in PA on Auckland Motorways:

- Greywacke
- Basalt
- Andesite
- EAF slag
- Melter slag

PA on Auckland Motorway

Porous asphalt (PA) is used in New Zealand (NZ) primarily as a surfacing for safety enhancement. However, PA is more than just about safety. It can help with environmental objectives such as cleaner storm water and reduction in impact of the Urban Heat Island effect. It can provide a more pleasant driving experience due to the reduction in noise as well minimizing splash and spray during rain events.

Auckland motorways is the biggest user of PA in NZ where over 90 % of all network is paved with PA. The rest is stone mix asphalt (SMA) and dense-graded mixes.

A wide range of aggregates have been used for the manufacture of PA mixes on this network. These include greywacke, basalt, andesite, electric arc furnace (EAF) slag and melter slag, a by-product from steel production.

Melter slag

- ≈12 years ago considered as waste
- Now considered a top quality aggregate
- High skid resistance properties (PSV≈ 60)
- A good field performer
- Demand > supply
- NZTA has taken control of more than 50% of this aggregate supply

"Honeycomb" vesicular structure of melter slag aggregate

Around 12 years ago, melter slag was considered to be a waste product in NZ. Furthermore, it didn't pass the crushing resistance specification criteria unlike other aggregates which were used in PA manufacture. This did not help to achieve acceptance of this aggregate in premium applications. The gradual introduction of PA in various asphalt mixes, especially in stone-on-stone mixes such as PA and SMA, demonstrated that this aggregate provides superior performance due to aggregate interlock in asphalt mixes and polishing resistance properties compared to many naturally occurring aggregates. SMAs made with melter slag aggregates, in fact, have excellent resistance to rutting and flushing.

Even though the Polished Stone Value (PSV) of meter slag is around 60, it outperforms natural high PSV aggregates in the long run in relation to skid resistance. This is due to its vesicular structure and inclusion of titanium in its structure.

Melter slag is now in high demand in NZ, even to the point where contractors bring this aggregate from Auckland to regions significant distances away. Demand is significantly higher than the supply, this has resulted in the New Zealand Transport Agency (NZTA) taking control of more than half of the melter slag aggregate distribution for used for safety enhancement in critical areas.

PA performance investigation.

- 30 sites were visited (at night) over 1.5 years
- Each site was photographed and information recorded
- Majority of sites visited had issues with base failures

To understand how to recycle PA into new PA, it is important to understand how PA currently performs in the field.
Field visits to around 30 sites over 1.5 years were carried out on the Auckland motorway network. Each site was photographed, failure modes recorded and site information collected. It was evident that the majority of PA sites visited had base failures, some to the point of significant pavement deterioration. However, it is important not to generalize. This observation about numerous base failures only relates to the sites visited. Despite this, it is important to note that the site selection was not specifically targeting sites with base failures. It was based on the suitability of site for visiting such as selecting sites where safe to visit during closures for maintenance work. These sites also cover a wide range of locations of Auckland motorways network.

PA performance investigation..

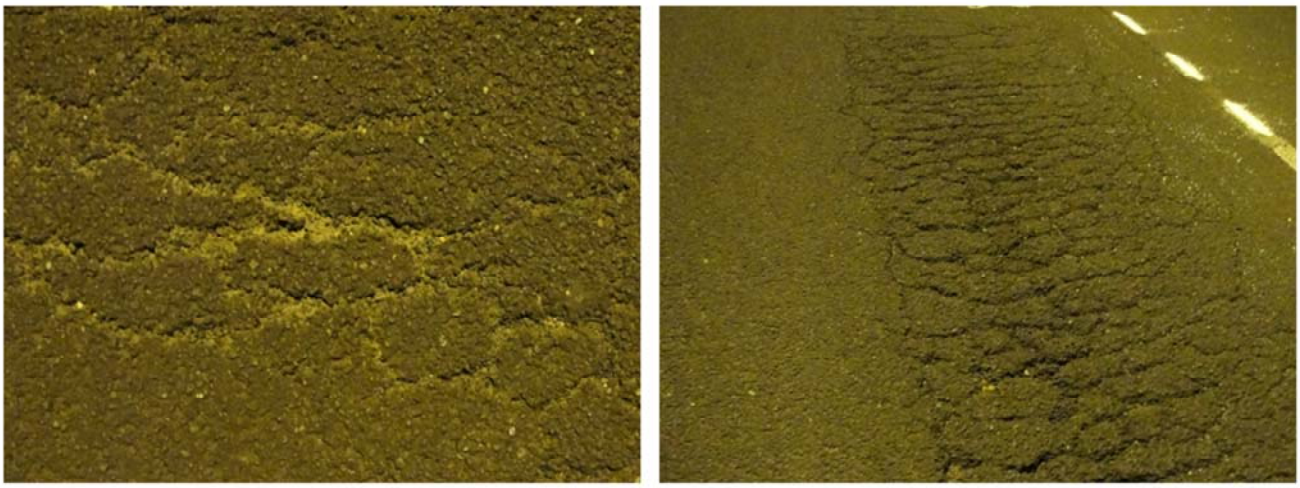
Based on the data collected, sites as young as 4 years old were milled and replaced due to the issues with bases. PA itself on such sites was in excellent condition.
The majority of the sites milled were around 7 years old. However, in the most cases the issue was base failures, not PA itself.
Cracking, fines pumping, pavement sinking, potholing and corrugation were amongst the commonly observed issues during the site visits. Some sites had aggregate disintegration in the PA mat.

PA performance investigation…

Examples of the most common base failures observed on Auckland motorways

These are the most common failures observed on PA sites. Especially regular interval cracks in a form of the fork with two prongs were present.

Melter slag in PA



PA with melter slag. 6 years old. PA mix itself was in a good condition

On this site, the melter slag aggregate was utilized. It was only 6 years old site, but it has severe cracking and fatigue failure. The PA itself was in a good condition. This meant that the valuable melter slag aggregate was not able to provide the long term benefits to the PA possible.

PA milling

Milling of PA sites was done using:
1) full milling at nominal depth of 25 mm
2) full depth milling at nominal depth of 35 mm
3) key milling by doing profiling to link new areas with old areas.
Some cracks were significantly deeper than the milling depth. This slide also demonstrates how much crack sealer gets incorporated into the millings, so it becomes a part of reclaimed asphalt pavement (RAP). The amount of crack sealer applied on each site would vary, so it is one of variable which needs to be understood for recycling of PA RAP. This crack sealer is mostly recycled tyre rubber based sealer.

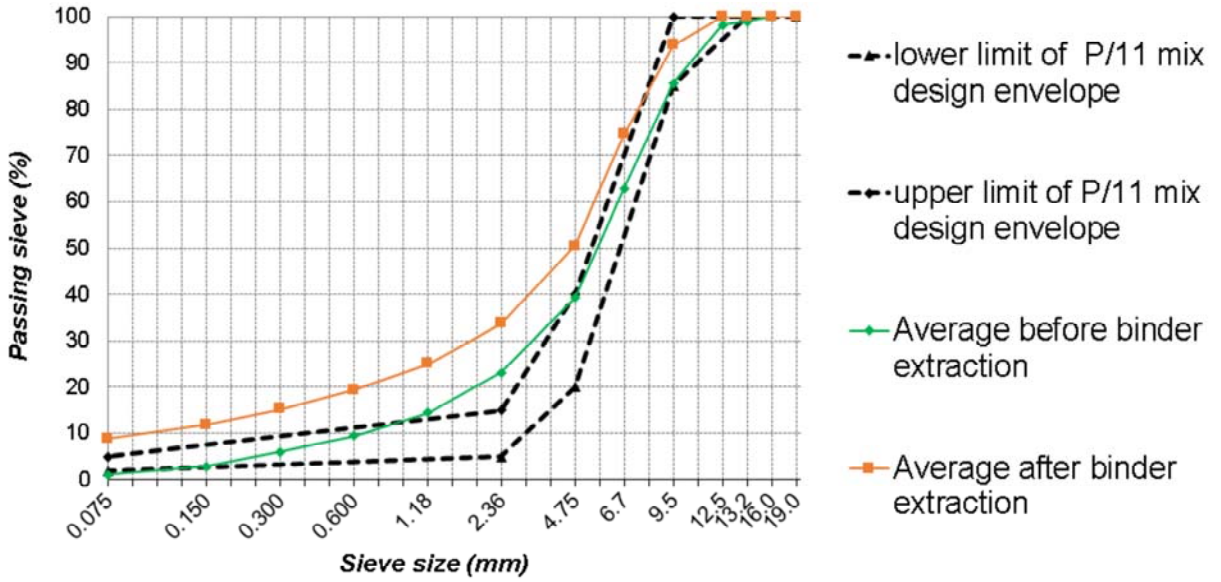
RAP contamination

Contamination in RAP:

- crack filler
- cold applied plastic (CAP)
- retro reflective pavement marker (RRPM, cat eyes)
- road shoulder materials

RAP can have various contaminants which can affect recyclability of this material. This includes crack filler, cold applied plastic (CAP), retro reflective pavement marker (RRPM, cat eyes) and road shoulder materials.

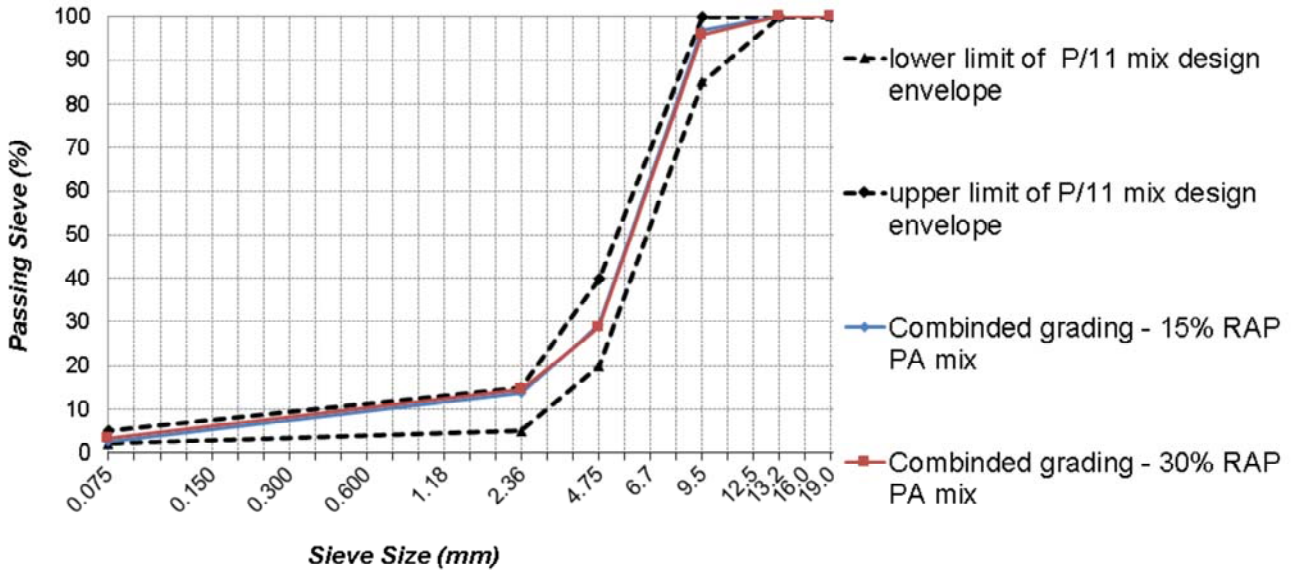
RAP gradation



RAP containing melter slag aggregate was tested for gradation before and after binder extraction. Gradation of PA before binder extraction was carried out to evaluate the agglomerations in this RAP. Results were compared with the P/11 mix design envelope used in NZ for PA mixes with nominal maximum aggregate size (NMAS) of 10 mm. The gradation of PA-derived RAP was significantly finer compared to the original mix design envelope. This can be due to several factors, individually or combined:

- possible disintegration of melter slag during service in PA mat under traffic and weather conditions,
- crushing of aggregate during the milling process,
- material from the clogging of PA accumulated through years in service.

RAP % in a new PA Mix



RAP was evaluated for inclusion into a new PA mix. 15% RAP can be incorporated without RAP fractionation. This would allow compliance with the minimum requirement of 85 % by mass of the coarse aggregate to be with the specified PSV value. Up to 30 % RAP can be incorporated into a new PA, but this means in this case, the requirement of 85% cannot be met.

Binder content in RAP millings

- Binder content in millings ≈ 4.9%
- Design binder content for PA ≈ 5.5%
- PA with PA-derived RAP:

- for 15 % RAP PA mixes ≈ 0.7% binder
- for 30 % RAP PA mixes ≈ 1.4% binder

Millings containing melter slag

Binder content in PA-derived RAP containing melter slag is around 4.9%, which is significantly lower than that of the virgin PA mix with the same aggregate at around 5.5%. If 15% RAP is to be incorporated in a new PA mix, this would mean that approximately 0.7% of binder would come comes from the RAP. If 30% RAP is used, this will give 1.4% binder from RAP.
The drop in the binder content in RAP compared to a virgin PA mix maybe associated with similar reasons as to why the RAP aggregate is significantly finer compared to the originally designed PA mix, as described earlier.

Micro-Deval (MD) testing

- Found to predict field performance in PA
- Performed under water
- Better simulates field conditions
- MD test - not a part of NZ PA specification
- LA abrasion – a poor performance predictor. Part of NZ specification. Impact test, not an abrasion test.

The Micro-Deval (MD) test was found to be a good predictor of field performance in dense graded and PA mixes. It is performed in a wet condition which better replicates field conditions compared to the Los Angeles (LA) Abrasion test which is performed dry. In pavements, especially in PA surfacing, aggregates are rarely dry. This is especially true in Auckland where rainfalls are common. The LA abrasion test also works as more of an impact test, not an abrasion test.
Currently, the LA Abrasion test is included in NZ specifications for virgin aggregate assessment, but MD is not. Furthermore, no limits are even set for LA Abrasion test, it is a record value only.

Virgin melter slag before MD testing

This is how virgin melter slag aggregate looked before MD testing was conducted. Highly angular aggregates with sharp distinctive texture and vesicular surface voids.

Virgin melter slag after MD testing

This slide shows how aggregate particles interact with the metal balls during the MD test. 5 kg of metal balls with 2 litres of water were used to abrade a specific fraction of the aggregate: 750g of the passing 9.5mm and retaining on the 6.7mm sieve plus 750g of the passing 6.7mm sieve and retaining on the 4.75mm sieve. MD test on the coarse fraction was performed in accordance with ASTM D 6928 standard test method.

Virgin melter slag after MD testing

The melter slag after MD test had a significantly smoother surface, however the vesicular structure of aggregate was still visible.

Micro-Deval testing on coarse fraction

Virgin

	Sample 1	Sample 2	Sample 3	Average	Stdev	COV
Abrasion loss (%)	6.3	6.1	6.3	**6.2**	0.14	2.28%

RAP

	Sample 1	Sample 2	Sample 3	Average	Stdev	COV
Abrasion loss (%)	7.8	8.4	8.2	**8.1**	0.31	3.76%

As it is important to understand how PA-derived RAP will perform in a long term, if it is to be incorporated into a new PA mix, virgin melter slag was tested for MD and compared with the PA-derived RAP containing slag.
The results showed that the virgin aggregates had lower MD loss compared to RAP. This is likely due to the fact that RAP aggregates were subjected to weather and traffic which has an effect on the durability properties.

Pollutant leaching from PA-RAP

- Clogging of PA. No PA cleaning in NZ
- Traffic is the main contributor to storm water pollution
- NZ fleet – the oldest in the developed world
- The second highest vehicle ownership level in developed world
- PA reduces pollutants in storm water:
  - Total suspended solids: 7-94%
  - Total lead: 55-99%
  - Total zinc: 67-90%
  - Total copper: 31-75%

Clogged PA in rain on Auckland Motorway

To be able to recycle PA-derived RAP, it is important to understand how polluted this RAP actually is.

PA get clogged over time. No cleaning of PA is carried out in NZ compared to, for example, the Netherlands or Japan, where PA is regularly vacuumed to maintain drainage properties and provide the maximum safety benefits.

It is known that traffic is the major source of pollutants. Taking into the account that NZ has the oldest vehicle fleet and the second highest vehicle ownership level in the developed world, as well as a very high level of second hand cars, our RAP is probably highly polluted. This is exacerbated as the RAP is not cleaned.

PA is known to significantly reduce pollutant concentrations in storm water compared to dense-graded mixes. This includes (but is not limited to) such pollutants as total suspended solids, lead, zinc and copper. Where do these pollutants go? As you have seen in the RAP gradation test results, it is significantly finer compared to the original mix gradation. How much of this RAP contains the clogging material including heavy metals and suspended solids which can contaminate the nearby soil and water?

To be able to handle this PA-derived RAP and process it, it is important to understand its properties in relation to pollutant leaching, especially if this RAP is stored outside, without cover, prior to processing. These questions need to be answered not only for environmental reasons but also for the safety of employees handling this RAP.

This year a number of experiments will be conducted to understand the risk of pollutant leaching from such RAP as a part of PhD on recycling PA into new PA mixes.

Summary & recommendations

- Melter slag is a valuable material which needs to be utilized in the most efficient way.
- The visited PA sites on Auckland motorways mainly failed due to base failure. This includes PA containing melter slag.
- PA-derived RAP contains various contaminants which is likely to affect the performance of new mix, if this RAP is incorporated into a new PA mix.
- Testing of PA-derived melter slag RAP shows that durability of this RAP maybe affected by traffic and weather. Also significant fining of RAP was observed compared to the original PA mix gradation.
- Understanding to what extend the PA-derived is polluted is important for RAP handling, processing, and storage to minimize a possible impact on environment and people.
- Where possible, PA-derived RAP should not be placed in one stockpile without checking the aggregate history prior to each site being milled.

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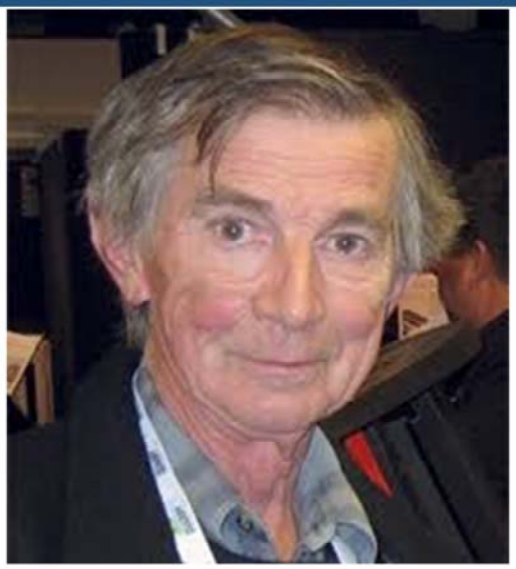

Bill Bourke, a visionary and a true gentlemen

THANK YOU!

Comments, Contributions, & Questions?