Research Report

Use of Reclaimed Tyre Rubber in Asphalt

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Executive Summary

This report was requested by Transit New Zealand to identify possible methods and any constraints on the use of waste tyre rubber in asphalt in New Zealand.

It is estimated that New Zealand generates around 3 million waste tyres per year.

There are two main methods of incorporating rubber into asphalt:

> **Wet Process –** The GTR is first combined with the asphalt binder and digested before this modified asphalt is used to create the HMA. There are two types of wet process, **terminal blend** (or ‘wet process no agitation’) and wet process **high viscosity.**
>
> **Dry Process –** the GTR is used to replace a fraction of the aggregate within the HMA.

The wet process can be used to produce asphalt with superior properties than conventional asphalt. However the equipment required for this process is expensive and there may be few asphalt projects within New Zealand that are sizeable enough to support its use.

Currently available, less expensive polymer modified binders offer similar performance to wet process binders.

In all cases the use of the dry method does not appear to offer any performance enhancement to the asphalt but does appear to add significant costs and risks to a project’s success.

The recyclability of AR HMA does not appear to be a barrier to its use within New Zealand, however local research would be required to confirm this.

Permission for the use of dry process rubber HMA is required from Transit on a case by case basis under the current specification.

Current air discharge limits enforced under the resource management act may also exclude the use of the wet process.

1.0 Introduction

This report was requested by Transit New Zealand's (Transit) Engineering Policy Section (EPS) to identify possible methods of using recycled rubber in asphalt and any constraints that currently exist that may hinder adoption of these methods.

To evaluate the possible methods for the use of rubber in asphalt in New Zealand, a literature review was undertaken, including past and current New Zealand research on this topic.

A review of Transit's current asphalt material specifications (M/10, P/11, NAS) was undertaken to identify constraints on the adoption of any of these methods. Members of the New Zealand asphalt industry were also consulted to identify other constraints on the adoption of rubber recycling methods using asphalt within the New Zealand industry.

Currently approximately 950,000 tonnes of all types of asphalt is laid each year in New Zealand.

The report provides recommendations to Transit regarding how the use of rubber in asphalt can be promoted within the New Zealand industry.

2.0 Treatment of Waste Tyre Rubber

It is reported that New Zealand produces around 3 million waste tyres per year, with estimates varying from 2.2 to 4 million waste tyres per year (Sweet 2004). However Sweet also reported that this number is expected to increase from an increase in vehicle fleet numbers, importing of used tyres and the reducing numbers of tyres retreaded.

Historically the majority of these were landfilled, however landfilling of whole tyres presents problems with tyres tending to 'float' to the top in landfills. Tyres also provide a good source of fuel and oxygen during landfill fires and can act as a breeding habitat for some disease carrying mosquitos. These problems can be addressed by first shredding the tyres however this adds to the cost of their disposal.

Another significant use was for weighing down silage covers however recently the increase in average size of dairy farms has lead to more use of silage baling systems that do not require tyres.

New Zealand does have some current waste tyre processors that shred tyres either to render them acceptable for landfilling or to provide tyre chips for such purposes as playground surface cover, drainage material, horse arena surfaces, embankment construction and land erosion control.

3.0 Literature Review

3.1 New Zealand Literature

Patrick and Logan prepared Transit New Zealand Research Report No.62 (1996) titled “Use of Tyre Rubber in Bituminous Pavements in New Zealand”. This report consisted of an international literature review to determine possible methods of incorporation of waste tyre rubber into road pavements.

The report identified that the waste tyres would need to be ground up to produce “Ground Tyre Rubber (GTR)”. Patrick and Logan found that

“..in 1993, two main processes were used to incorporate GTR into bituminous surfacings:

1. Wet process – where GTR is blended with hot bitumen and applied as a sealing binder or used in a hot asphalt mix;

2. Dry process – where GTR is added to the aggregate in the production of hot mix asphalts.”

A more detailed description of the wet and dry processes is contained in section 3 of this report.

Patrick and Logan (1996) went on to conclude that:

“1. *The wet process used currently is not expected to be cost competitive with the block copolymer rubber (SBS or styrene-butadiene styrene) binders used in 1993 because of:*

(a) Specialised mixing plant is required near the construction site as the blended bitumen rubber has a limited storage life.

(b) Specialised Distributors, that can cope with both the high viscosity and the rapid segregation of the bitumen and GTR, are required to spray the blended binder.

(c) Cost of GTR is expected to be at ;east NZ $ 1,000/tonne (as at 1993) as cost includes controlling the proportion of truck to car tyres (which differ in their natural rubber content) as well as grinding and sieving the tyres to a relatively narrow size grade range (of 3- 6 mm diam.).

(d) 20-25 % (five times more) of GTR is required to produce a binder with performance properties similar to those obtained by a binder containing only 4 % SBS.

2. GTR has a potential use in asphalt mixes produced by the dry process, only if the GTR can be easily included as part of the aggregate feed system in a drum mixing plant.

3. *If GTR is used in asphalt mixes, using concentrations and aggregate gradings similar to those used in other countries, the cost of the mix could be expected to increase by approximately 50 %.*

4. *The higher cost of GTR mixes would tend to restrict use of these mixes only to special situations where the enhanced performance would result in lower discounted costs than alternatives such as reconstruction."*

Patrick and Logan (1996) recommended that trials would need to be undertaken before the benefits and cost effectiveness of using GTR could be determined for New Zealand conditions.

The conclusions above are still considered to be valid at the time of writing this report.

Patrick and Reilly have since been granted funds from Land Transport New Zealand to investigate recycling of Reclaimed Asphalt (RAP) and crumb rubber in Hot Mix Asphalt (HMA). Their findings to date have been presented in a 2006 paper and at the time of writing this report, Patrick and Reilly's research report was under editorial review.

Patrick (2006) referred to his 1996 report and discussed the construction of three trials using the dry process in Manukau City. The size of the GTR added is not mentioned. Mixes were trialed with 1 % and 3 % GTR by weight of aggregate as well as a control mix with no GTR.

After one year the trials were inspected and Patrick (2006) reported the following observations:

" The first paver run is still performing well, but the two subsequent two paver runs have disintegrated and the site has been re-laid. It is unclear what the cause of this failure was, but quality control results indicate that mix variability especially in terms of compaction has contributed."

The trial also included testing fatigue beams prepared from plant samples, Patrick found:
"*..an unmodified mix had a fatigue life of approximately an eighth of the rubber modified mix tested under the same conditions."*

Patrick (2006) then concluded:
"*This should result in hotmix incorporating GTR being able to be used in areas that would now require pavement strengthening."*

3.2 International Literature

A lot of positive literature about the use of rubber in asphalts is available from several websites:

- www.asphaltrubber.com
- www.rubberpavements.org
- www.ces.clemson.edu/arts
- www.rubberisedasphalts.org
- www.scraptirenews.com
- www.rma.org

These organisations are promoting the use of waste tyre crumb rubber as an asphalt modifier and hence tend to contain reports from successful trials.

Most American literature refers to GTR as crumb rubber.
Most international literature refers to HMA containing some rubber modification as Asphalt Rubber (AR) HMA.

There is a large body of experience in America using rubber as a bitumen modifier. This is mainly related to the introduction of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. While this document was mainly concerned with funding of road maintenance and construction, section 1038 (d) of ISTEA required that all states use a certain percentage of rubber in their asphalt pavements, starting in 1994, or their funding would be reduced. While some states had already trialed using rubber as a modifier in asphalt, this act caused many more to conduct trials of the feasibility of using rubber in asphalt. These trials had mixed success, and the problems encountered lead to lobbying by many parties and the repeal of this section of the act. However some states still use large volumes of AR HMA and have developed special mixes and applications for their use as discussed below. The main reason stated in the literature for states not continuing to use AR is the high cost when compared to other methods of modifying binders.

Another factor in the use of AR in America is that many states ban the practice of placing whole tyres in landfills. This has lead to a mature waste tyre processing industry. However the rubber manufacturers association reported in 2003 that of the 233.3 million tyres recycled, only 10.0 million were processed into AR, compared to 129.7 million used for tyre derived fuel.

States that make extensive use of AR in asphalt also use similar binders for chipseals and membranes.

Florida Department of Transport (FDOT) uses a binder modified with 12 % Crumb Rubber Modifier (CRM) passing the 600 μm sieve in its open graded wearing courses and 5 % CRM passing the 300 μm sieve in dense graded friction wearing courses. They do not require CRM in Dense Graded Asphalt (DGA) due to the lack of space within the mix for the CRM to occupy.

Arizona Department of Transport (ADOT) incorporates CRM into three types of HMA using wet process high viscosity binders. They do not use dry process HMA.

ADOT uses thin layers of AR OGPA over existing and new pavements to provide good frictional characteristics and low tyre noise. The high viscosity of the AR results in binder contents of 9 to 9.5 % by weight (typical NZ OGPA binder contents are 5.5 to 6.0 % by weight). Initially the AR OGPA was trialed as the high binder films and highly modified binder offered excellent crack resistance when surfacing aged concrete pavements. A side effect of lower noise emissions has lead to a demand from the public that this surfacing is used on all freeways within metropolitan Phoenix. ADOT normally lays this AR OGPA in very thin lifts, half to three quarters of an inch thick (12 to 18 mm), although this is increased to one inch (25 mm) for very highly trafficked areas.

ADOT also use a gap graded asphalt rubber asphaltic concrete (GG - ARAC) for structural overlays. GG-ARAC contains 7.5 to 8 % wet process binder, this being approximately 2 % more than the level of normal binder that can be contained in this type of mix without significant draindown. ADOT have found this mix has excellent crack resistance and can be laid in thinner lifts than conventional DGA and exhibit similar performance in rehabilitation projects.

ADOT also allow the use of some terminal blend wet process binders, mainly for patching operations using gap graded type mixes where mobilisation of high viscosity binder production equipment is uneconomic. Binder contents are lower than when using high viscosity binders.

California Department of Transport (Caltrans) has been using CRM in asphalt since the 1980s. The main use is within a gap graded mix referred to as RAC-G. This is laid in 30 to 60 mm deep layers.

Caltrans also use AR in an OGPA type mix where the high binder viscosity allows higher binder contents resulting in better crack resistance than OGPAs using conventional binders.

The Caltrans Asphalt Rubber Usage Guide states:
"*Use of asphalt rubber is not recommended in dense graded mixes because there is insufficient void space to accommodate enough modified binder to significantly improve performance of the resulting pavement*".

City of Los Angeles Bureau of Street Maintenance have also published a study where AR HMA was recycled. This project involved reconstruction of sections of Olympic Boulevard. Olympic Boulevard had been paved in 1982 with an HMA containing a wet process binder, resulting in the material having a rubber content up to 3 % by total weight. The existing pavement was milled from the site and added to mix produced from two plants – the normal plant used 15 % AR millings with 85 % virgin aggregate and it is reported that the Cyclean microwave plant used 100 % AR millings. As part of the study air pollutants produced during the milling and HMA production at the microwave plant were measured and found to be within the permissible exposure limits applicable at the time.

Caltrans (2005) reports on the feasibility of recycling rubber modified paving materials. It states that recycling of AR pavements by cold in place methods is acceptable providing a surface is applied to the material to prevent it ravelling.

The report also recommends further testing to confirm that up to 15 % RAP containing AR can be readily used during hot plant recycling. Some states experience suggests that higher concentrations are riskier as the rubber often reacts with the asphalt rejuvenating agents required when using RAP contents above 15 %. They recommend not to add further CRM by any method when incorporating AR RAP in DGA.

Texas Department of Transportation (TxDOT) use a wet process high viscosity binder in SMA and OGPA type mixes, particularly where reflective cracking is expected to be the main method of failure.

Better Roads (2005) reported that recycling of AR RAP is possible as the ignition point of bitumen is lower than that of rubber, hence it concludes that any smoke problems are from bitumen combustion and not rubber. Similar 'blue smoke' problems were encountered with early RAP trials, before the introduction of RAP collars to keep RAP away from burner flames in drum plants.

The same article also attributes additional stack emissions during CRM asphalt production as a result of the elevated temperature required along with higher binder contents, when producing CRM asphalt, rather than it being a function of the addition of rubber.

Hicks and Epps (2000) conducted a life cycle cost analysis on the use of asphalt rubber paving materials. They concluded that the use of these products was cost effective if the rubber asphalts were thinner or had a longer life than conventional products. They also noted that the analysis was based on information from interviews and engineering judgement.

Colucci (1998) reported that wet process mixing plants start at US $ 250,000 and estimated the cost of importing one to Puerto Rico would result in a " 67 % increase in costs for CRM HMA as compared to current dense graded asphalt unit prices". Colucci then suggested that a full life cycle cost analysis should be carried out as the wet process binders are expected to offer better performance than standard bitumens.

Over a period of four years from 1994 to 1997 the American National Institute for Occupational Safety and Health (NIOSH) investigated the Occupational Exposures and acute health effects associated with Crumb rubber modified asphalt paving (Burr et al l 2001). During this study, air samples from workers personal breathing zone were taken during paving operations for both CRM asphalt and conventional asphalt. Each of seven sites studied were reported individually, with a summary being reported in 2001.

Generally CRM asphalt paving operations were found to have higher emissions but these were still within NIOSH limits. Worker interviews also reported more irritation during CRM paving than conventional paving.

European experience to date has been mainly limited to various trial sections, except for Portugal and Spain where wet process mixes similar to those described above are in use (Way and Evans 2006). However recently European Union legislation has banned the practice of landfilling whole tyres from 2003 and shredded tyres from 2006. This has lead to many European projects investigating ways to use waste tyres, however the American experience is far wider in this field.

4.0 Detailed Description of Asphalt Modification Using Rubber.

4.1 Tyre Processing

Waste tyres must first be processed before they can be added to any asphalt.

First the tyres are coarsely shred so the steel belts and fibres can be separated from the rubber. The coarse rubber shreds are then shredded again to a smaller size.

For use in asphalt the rubber shreds must then be ground up to produce crumb rubber. The finer the crumb rubber is ground, the more it will react with bitumen, however additional grinding adds to the cost of the crumb rubber.

There are also two main types of grinding, ambient temperature and cryogenic. Cryogenic grinding uses liquid nitrogen to freeze and shatter the rubber into smaller particles. However the particles generally have a smooth surface texture which is less reactive. Ambient grinding uses mechanical grinding to reduce the rubber particle size and produces a very rough particle surface texture.

The tyre source also affects the type of rubber present, with truck tyres containing a greater proportion of natural latex than car tyres. Natural latex is more reactive with bitumen than ground tyre rubber. Early AR specifications called for reject tennis balls to be added to the ground rubber to increase the natural latex content of the crumb rubber to be mixed with bitumen.

Some AR specifications also control the ratio of car tyre rubber to truck tyre rubber so as to ensure an adequate amount of natural rubber is incorporated into the AR.

4.2 Asphalt Modification Methods

There are three methods used to incorporate GTR into asphalt, two ‘wet’ processes and the ‘dry’ process as described below.

> **Wet Process –** The GTR is first combined with the asphalt binder and digested before the binder is used to create the HMA. There are two types of wet process, **terminal blend** (or ‘wet process no agitation’) and **wet process high viscosity.**
>
> **Dry Process –** the GTR is used to replace a fraction of the aggregate within the HMA.

4.2.1 Terminal blends are produced by blending crumb rubber and other additives with bitumen at the bitumen supply terminal. The rubber has to be finely ground ($\leq$ 300 μm) so that it can be easily absorbed by the binder and can be kept in suspension by the limited mixing available from tank circulation. Generally these binders contain less than 10 % by weight of rubber, as higher concentrations are more prone to rubber particles separating from the bitumen, although Caltrans does report some of these products are available with rubber concentrations up to 15 %. Terminal Blends offer improved performance over normal bitumens, but the literature reports that where available the higher viscosity binders provide better performance due to their higher level of binder modification.

4.2.2 Wet process high viscosity binders are produced adjacent to an HMA production facility using specialised equipment. Current best practice has crumb rubber added to the bitumen in a blending unit and then pumped into a reaction tank fitted with paddles to ensure the crumb rubber remains in suspension. During this process the bitumen is heated to a high temperature (176 to 226 °C) to facilitate reaction with the rubber and it is held at a temperature of 150 to 218 °C within the reaction tank. After a period of 45 to 60 minutes, the resulting binder is moved to a storage vessel, which also contains agitators top keep the rubber suspended. From there the modified binder is pumped into the HMA mixer for incorporation into asphalt. The rubber and bitumen continue to react within the storage tank, meaning this binder has a short storage life, hence the mixing takes place adjacent to the HMA plant. Special heavy duty binder pumps are also required to pump the high viscosity binder.

The chemical processes that produces wet process binders are considered to be swelling of the rubber particles from absorbing some of the more volatile compounds from the bitumen, followed by degradation of the rubber from devulcanising and polymersiation. The rate of reaction is affected by the following:

- temperature of the binder (higher temperatures provide a quicker reaction),
- the surface characteristics of the crumb rubber (rougher surface reacts quicker), the size of the crumb rubber particles (smaller particles swell quicker but to a lessor extent), and
- the period the rubber and bitumen are kept at the reaction temperature (longer time gives a greater reaction).

Most modern high viscosity mixing plants are mobile so they can be moved to any HMA plant. Using high viscosity binders to manufacture HMA requires the plant to operate at higher mixing temperatures. This generally results in a slightly lower production rate than when using conventional binders.

4.2.3 Dry Process involves replacing a portion of the aggregate of a HMA with rubber ground to a similar size. Care is required during the mix design to account for the significant density difference between aggregate and rubber. The rubber must also be introduced into the mixing zone clear of direct contact with any heating flames. It should be noted that while the asphalt in the dry process is considered to be unmodified, the rubber tends to absorb some of the lighter fractions from the bitumen. The designer must allow for this reaction by increasing the binder content slightly or there is a high risk of the mix ravelling. Colucci (1998) notes that a RAP ring would be a suitable device to manage this.

5.0 Review of Transit Specifications Regarding Barriers to using Rubber in Asphalt

Transit New Zealand has material specifications for dense graded asphalt (M/10 2005) Open Graded Porous Asphalt (OGPA) (P/11 2003) and a performance specification for asphalt (P/23 2005). Transit is also producing a New Zealand National Asphalt Specification (NAS) based on AAPA NAS 2004.

M/10 section 3.5 states “Unless specified in the specific contract requirements, binder is penetration grade bitumen complying with TNZ M/1 specification”. TNZ M/1 excludes “mineral matter other than that naturally occurring in the petroleum and shall be uniform in character”. This appears to exclude the use of crumb rubber using the ‘wet’ process.

However M/10 Notes contains an approval process for alternative asphalts where approved can be considered on a case by case basis. Hence a DGA containing a wet process binder could be approved for use by EPS.

M/10 section 4.2 for coarse aggregate states ‘Coarse aggregate shall consist of crushed stone or crushed gravel… …unless otherwise approved by Transit.’ This excludes the use of the dry process unless specific approval from Transit is provided. The wording for fine aggregate requirements is the same.

TNZ P/11 section 4.5 includes the statement “Synthetic aggregates may also be used provided they comply with all the requirements of this specification”. This statement will exclude dry process from OGPA production as CRM will not meet the aggregate performance criteria specified.

TNZ P/11 section 4.6 states that “the bitumen may be modified through the use of adhesion agents or polymers”. As rubber is a form of polymer the wet process is allowed by P/11.

NAS supplement section 2.3.1 regarding bitumen states”…alternative binders may be specified in the contract specification”. This will allow the wet process if this allowance is added to contract documentation.

The NAS supplement contains the aggregate requirements from M/10 and P/11, which means that permission is required from Transit to use the dry process.

Under TNZ P/23, mechanical properties for the aggregates are specified so that use of the Dry process is excluded.

Modified Binder requirements under P/23 are to be included within each contract specification. These limits should be chosen to allow wet process binders to be used.

In summary the dry process is generally excluded from all specifications unless specific permission for the use of these types of mixes is granted by Transit on a case by case basis.

The use of the wet process is allowed under the allowances for the use of polymer modified binders within the various specifications, except within M/10.

6.0 Discussion

The experience of Patrick (2006) having early failure of parts of their initial trial of incorporating GTR using the dry process matches international experience. Most of these early failures are also blamed on construction processes, indicating that while conventional equipment can be used, conventional techniques may not be directly applicable.

All successful practitioners of the wet process are very strict on the temperatures at which the product can be laid and ensure that compaction starts immediately behind the paver. This often requires special release agents being used on the roller wheels to prevent pick-up of the GTR HMA.

The New Zealand asphalt industry already has polymer modifying experience using other types of modifiers that can offer similar performance to wet process AR, and that are cheaper to produce as the process of modification requires simpler plant. The modification plant is also in place within New Zealand.

Patrick (1996) reported that asphalt rubber pavements were 40 to 100 % more expensive than conventional pavements. Initial costs are likely to be at the higher end of this spectrum.

Current methods of heavy SBS modification increases the cost of the binder by up to 100 %, however this equates to approximately a 25 % increase in the cost of the asphalt.

The main concerns regarding AR HMA use within the New Zealand industry are:

- Higher air emissions from AR HMA (affecting worker health or resource consents for plant operation)
- Ability to recycle AR HMA into other asphalt mixes.
- Costs associated with using either the wet or dry process.

Caltrans also report that the ‘unit costs of CRM modification increased considerably for jobs using less than 2,250 tonnes of RAC’. Mainly due to the mixing plant mobilisation costs. The most likely use for wet process AR is in Open Graded Porous Asphalt (OGPA), normally laid at 25 mm depth on free flowing roads. A quantity of 2250 tonnes would cover approximately 8 km of two lane motorway carriageway. Jobs of this size may form part of large new alignment constructions or large motorway resurfacing projects.

Caltrans research showed that recycling AR within current standards of 15 % present no real obstacles although international research on this subject should be monitored. The current international view of not adding any further rubber to asphalt when already incorporating AR RAP should be followed.

While Patrick (2000) concluded that the dry process offers some material enhancement, most international field trials showed that these asphalts performed similarly to the control sections of normal asphalt, however there seemed to be many poorly explained early failures.

Approximately 9 kg of rubber can be produced from each scrap tyre. Current asphalt production is approximately 950, 000 tones. If 3 % GTR could be added to all of this asphalt, 28,500 tonnes of rubber would be consumed, equivalent to 3.15 million tyres, or approximately New Zealand's waste tyre generation. However not all asphalt is suitable for the addition of rubber.

The Resource Management Act is used by regional authorities to control emissions from HMA plants in New Zealand. The dry process is unlikely to result in emissions over that produced from conventional HMA. However the higher temperatures required for wet process AR production are likely to require an increase in the allowable emissions, as current limits are based on conventional asphalt production.

7.0 Conclusions

The wet process can be used to produce asphalt with superior properties than conventional asphalt. However the equipment required for this process to be used is expensive and there may be few asphalt projects within New Zealand that area sizeable enough to support its use.

Currently available, less expensive polymer modified binders offer similar performance to wet process binders.

In all cases the use of the dry method does not appear to offer any significant field performance enhancement to the asphalt but does appear to add significant costs and risks to a project's success.

The recyclability of AR HMA does not appear to be a barrier to its use within New Zealand, however local research would be required to confirm this.

Permission for the use of dry process rubber HMA is required from Transit on a case by case basis under the current specifications.

Current air discharge limits enforced under the resource management act may also exclude the use of the wet process.

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