EMOGPA Sustainability Investigation

Waka Kotahi New Zealand Transport Agency

23-Nov-2020

Epoxy Modified Open Graded Asphalt

Low Noise Pavement Investigation

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Client: Waka Kotahi New Zealand Transport Agency

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Executive Summary

Open Graded Porous Asphalt (OGPA) provides significant noise attenuation when compared to other surfaces such as Dense Graded Asphalt (DGA) and Chipseal. However, OGPA deteriorates very quickly, with resurfacing being required after 7 to 8 years on average. EMOGPA has been proven to be significantly more resilient, with studies suggesting a lifespan almost three times that of OGPA with only a very minor cost increase.

The New Zealand Transport Agency has commissioned AECOM to review the whole-of-life noise benefits of Epoxy Modified Open Graded Porous Asphalt (EMOGPA) over a 50-year period. This work forms part of a sustainability review of EMOGPA which covers the carbon footprint, resource requirements and whole-of-life costs.

Road / tyre noise is the dominant source of noise for road traffic travelling at over 15 to 20 km/h. The pavement is a driving factor on the amount of noise generated. The main factors that can be influenced in the pavement are:

- The aggregate size. 7 mm aggregate is effective for low noise pavements.
- Void spaces should be maximised with typical sizes of 15% to 20%. Void sizes greater than 20% typically do not show significant benefits.
- Pavements thickness should be maximised. The optimal depth of the running pavement is 40 mm.
- The stiffness of the road should be reduced.

There haven't been many studies on the noise attenuation of EMOGPA, with those that have been completed generally found to be inconclusive. The general finding is that there isn't much difference between OGPA and EMOGPA.

Physically EMOGPA and OGPA are very similar. While the epoxy binder in EMOGPA allows larger voids, studies have found that increasing from a 20% void to a 30% void size has little effect on noise. It is possible that the increased stiffness of EMOGPA would increase noise levels, however this effect is only minor and may not be relevant due to the small impact on overall noise levels.

A literature review identified that the EMOGPA has a significantly longer lifespan than OGPA. Studies have found a wide range of estimates from more than 30 years to well over 100 years. However, while further work needs to be completed to confirm, the noise reduction properties are unlikely to last for more than 20 years.

A cost benefit analysis has identified that although EMOGPA has a lifespan of more than 30 to 40 years, it is significantly more cost-effective (from a noise perspective) to replace the pavement at around 20 years, to ensure that a reduction in noise is experienced.

1.0 Introduction

1.1 Scope

The Waka Kotahi NZ Transport Agency has commissioned AECOM to review the whole of life noise benefits of Epoxy Modified Open Graded Porous Asphalt (EMOGPA) over a 50-year period.

This assessment has included:

- A description of the mechanisms of road/tyre noise;
- A comparison between Open Graded Porous Asphalt (OGPA) and EMOGPA from the perspective of noise;
- A literature review of previous noise assessments undertaken of EMOGPA both in New Zealand and Internationally;
- A high-level cost analysis comparing OGPA-10 to EMOGPA-10 and EMOGPA-7 over 50 years;
- Recommendations for further work;

This work forms part of a sustainability review of EMOGPA which covers the carbon footprint, resource requirements and whole-of-life costs.

1.2 Overview

The Waka Kotahi document *Guide to state highway road surface noise* identifies that Open Graded Porous Asphalt (OGPA) provides significant noise attenuation when compared to other surfaces such as Dense Graded Asphalt (DGA) and Chipseal. However, OGPA deteriorates very quickly, with resurfacing being required after seven to eight years on average. The noise benefits of the pavement when compared to other low noise pavements only last about five years.

EMOGPA has been proven to be significantly more resilient, with studies suggesting a lifespan almost three times that of OGPA with only a very minor cost increase (see Section 3.0 for further detail). It is likely that the increased durability would be considerably more cost-effective and may result in low noise pavements being chosen in more situations throughout New Zealand. There are also secondary benefits where lower pavement noise levels are also likely to result in less noise barriers being constructed in locations where EMOGPA is used in place of standard pavements.

2.0 Road traffic noise overview

2.1 Overview

There are four dominant sources which contribute to free flowing road traffic noise. These sources are:

- engine / drivetrain noise,
- exhaust noise,
- aerodynamic noise; and
- tyre / pavement noise.

For general traffic operating at more than 15 to 20km/h the dominant source of noise is tyre/pavement noise. This high-level review has focused on tyre / pavement noise.

There are three main mechanisms which generate tyre noise. The main noise generating mechanism at the road/tyre interface is tread impact. This is caused by the surfaces of the road and tyre impacting together as the tyre rolls. This impact results in vibration of the tyre carcass and generates noise.

Another form of noise generation is air pumping. Noise is generated between the contact patch of the tyre and the road surface. It occurs when air trapped in the gaps between the road and tyre is pumped in or out and put under compression. The rapid air movement creates a noise similar to clapping.

Slip-stick and stick-snap mechanisms also contribute to road/tyre noise. Slip-stick occurs due to distortion of rubber tyre treads which causes horizontal force at the tyre/road interface. In the case that this force exceeds frictional force between the two surfaces, the tread will slip rapidly and then re-stick. This results in high frequency noise and vibration generation. Stick-snap occurs when a vacuum is created between the road surface and tyre tread due to the pushing out of air. A noise is then generated when the vacuum is released.

Noise radiation from the road/tyre interface can be greatly enhanced by several mechanisms. A major mechanism is the acoustical horn effect which results from amplification of noise moving through the horn shape that forms between tyre and road. Noise is also amplified as a result of tyre tread forming shapes that enhance noise generation. These include 'pipe resonance' and 'Helmholtz resonance' mechanisms.

2.2 Pavement influences on noise

The noise generation and radiation mechanisms that occur at the road/tyre interface can be influenced by the type of road surface used. There are three main properties of the surface that will influence noise generation, with the most important being texture.

The bumps and troughs on a road surface make up its texture and can be categorised as microscopic or macroscopic. Macroscopic texture – which repeats itself every 10 to 100mm - is visible to the naked eye and has the greater effect on noise. Generally, macrotexture should be decreased to minimise noise, this can be achieved with use of finer aggregates. Typical aggregate sizes used in asphalt pavements are 7mm, 10mm, and 14mm, with 10mm being the most common in New Zealand.

Texture with dimensions of less than 10mm can be beneficial as air and water can escape from the spaces that form between the road and tyre surfaces. This in turn can minimise certain noise generation and amplification mechanisms, for example; by decreasing the occurrence of air pumping. Texture can be classified as positive or negative. Positive texture provides an unsmooth surface and so generally increases noise. Negative texture provides a relatively smooth surface whilst also reducing noise through absorption and minimisation of generation and amplification mechanisms.

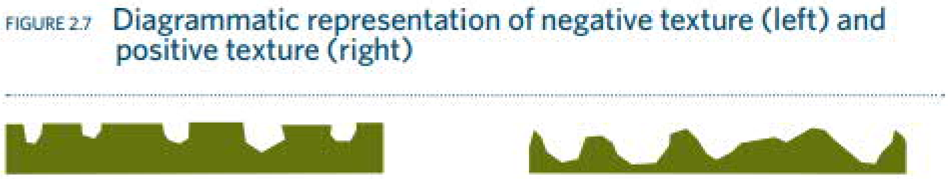

Figure 1 Road texture, from Guide to state highway road surface noise - Version 1.0, by NZTA, 2014

The porosity of the road surface has the second greatest effect on noise generation. Porosity is a measure of void spaces within a material. It is a fraction of the volume of voids of a material over its total volume. Most road surfaces are made up of materials with porosity of less than 5%. Noise reduction can occur when air flows through the material - generally when porosity is increased to greater than 20%.

Porosity of a road surface reduces occurrence of air compression at the road/tyre interface. This in turn decreases noise generation through the mechanism of air pumping. Noise is also reduced due to a reduction in the effect of enhancement mechanisms.

Porous materials also reduce noise through sound absorption. Noise generating mechanisms that occur at the road/tyre interface create soundwaves. When air is pushed by these soundwaves into the voids of the surface, a viscous loss occurs and heat energy is generated. This decreases the percentage of sound energy being reflected from the road back into the surroundings.

Recent studies have identified that thickness has the greatest impact on a material's sound absorbing performance with thicker materials providing improved sound absorbing qualities. A study conducted by Altissimo Consulting on behalf of NZTA in 2019 found a clear relationship between porous asphalt thickness and tyre/road noise. The overall thickness effect was found to be –2.4 dB Lcpx* per 10 mm increase in thickness. For OGPA, the optimal thickness is around 40mm for tyre- noise reduction. The pavement thickness is also the hardest to control because current construction practices don't measure the thickness of the layer.

Finally, stiffness of roading also has an impact on noise generation mechanisms. Lowering material stiffness of a road will decrease the difference in stiffnesses between the road and tyre. This results in lower impact forces and therefore less noise generation.

In summary to achieve the greatest benefits from a low noise pavement:

- The aggregate size should be minimised. An aggregate size of 7mm is effective at reducing noise.
- Void spaces should be maximised. Void sizes greater than 20% typically do not show significant benefits.
- Pavements thickness should be maximised. A depth of 40 mm should be targeted.
- The stiffness of the road should be reduced.

3.0 Understanding Epoxy Modified Open Graded Porous Asphalt

3.1 Open graded porous asphalt (OGPA)

Open graded porous asphalt (OGPA) is the most commonly used low noise road surface in New Zealand. It is made up of a mixture of coarse and fine aggregates, mineral filler, and a bituminous base binder. The aggregate consists of sand, crushed stone, and gravel, with the coarse material having a diameter of greater than 4.75mm and fine aggregate less than 4.75mm. The most common coarse aggregate size in New Zealand is 10 mm. The binder used in OGPA consists of penetration grade bitumen.

OGPA is considered a low noise road surface because:

- It is comprised of a negative texture and often includes aggregate 10mm or smaller.
- Includes interconnected voids, typically between 15% to 30%.

Over time, the voids in an OGPA surface can fill with particles which leads to a decrease in acoustic performance. On high speed roads this is less of an issue due to a pumping action caused by tyres cleaning the surface. Binder oxidation is the principal factor governing the ultimate life of the porous asphalt.

Oxidation of the binder eventually leads to embrittlement of the surface which results in ravelling and fretting of the road surface. Due to the open nature of the material, oxidation and binder embrittlement happens more rapidly when compared to denser mixes. Thus, OGPA has a relatively short average lifetime of approximately eight years within New Zealand.

3.2 Epoxy modified open graded porous asphalt

Epoxy modified OGPA (EMOGPA) is manufactured with the same mix designs as OGPA except for the bitumen component. This is replaced with epoxy bitumen which contains a reactive epoxy resin and curing agent. The modified binder used in EMOGPA improves the longevity of the surface by decreasing susceptibility to oxidation. The result is a road surface with a longer lifetime and an expected slower degradation of noise absorbing properties than basic OGPA.

Epoxy modification has also been shown to increase the tensile modulus of OGPA. The effect of this on road/tyre noise generation has not been studied. However, variation of road stiffness is known to effect noise generation caused by impact of tyres on the road. The stiffer road surface provided by EMOGPA therefore has the potential to increase impact noise at the road/tyre interface. When compared to other mechanisms such as the aggregate size, void size, and pavement thickness, the stiffness is a relatively minor contributor so the change due to stiffness may be negligible.

Like OGPA, EMOGPA acts as a porous sound absorber. In general, the thickness of a material impacts its sound absorbing properties with thicker materials providing greater noise attenuation.

The void concentration of a porous material also impacts its sound absorbing performance. Increasing the porosity of EMOGPA is therefore expected to decrease noise levels. However, in practise increase of porous asphalt void concentration has not been shown to decrease recorded noise levels. This is because increasing void content also increases macrotexture of porous asphalt. Road surface texture is the dominant variable for road/tyre noise generation. The benefit of further increasing porosity of EMOGPA appears to be insufficient to counteract the negative impact of increasing surface macrotexture.

Some studies have identified that pavements with higher viscosity have a greater likelihood of debris ingress. This has the potential to reduce the noise attenuation properties of the surface and increase the degradation of the surface. It is possible that the epoxy binder could prevent this occurring which would extend the acoustic life of the pavement. Further studies would be required to confirm or deny this hypothesis.

3.3 Literature studies

Epoxy Asphalt is not a new material and has demonstrated its ability to deliver 40 years of service life as a road surfacing on steel bridge decks. However, there is a distinct lack of previous studies available which documents the noise performance of EMOGPA over the life cycle and the comparison to OGPA, beyond the similarities of the base materials used, both within New Zealand and internationally.

Previous research has been carried out under the auspices of the OECD/ECMT (European Conference of Ministers of Transport) Joint Transport Research Centre, which is focused on the economic evaluation of long-life pavements. Their aim was to investigate the potential of epoxy-modified asphalt as a low maintenance long-life surfacing material with a focus from New Zealand on EMOGPA.

In 2007, laboratory investigations into the cohesive properties of OGPA manufactured using epoxy modified bitumen and associated accelerated load testing was carried out and results published (Herrington et al 2007). The outcome of the study indicated the early life cohesive properties of cured epoxy OGPA are comparable to that of standard OGPA. The epoxy material provided superior oxidation resistance compared to the standard asphalt which suggested a significant improved field life for EMOGPA.

OECD 2008 research confirmed EMOGPA can be expected to increase the long life / durability of conventional OGPA but at the time of the study there was no evidence that improvements to noise levels would be achieved. The physical properties of epoxy modified bitumens and curing behaviour have also been previously reported by other investigations (Cubek et al 2009, Herrington and Alabaster 2008).

Further investigations were subsequently carried out on the curing behaviour and durability properties of EMOGPA with a full scale road trial constructed in Christchurch 2007 (Herrington et al 2010). Monitoring carried out on the performance of the road for the initial two years after construction included rutting, skid resistance, permeability and noise measurements. Whilst the parameter on which the noise measurements was carried out are unclear, the noise levels recorded indicate similar levels of tyre noise for OGPA and EMOGPA providing no additional noise reduction benefits. Furthermore, the different air void sizes tested for the EMOGPA indicated minimal noise reduction changes between the percentages of air voids, however it was identified that further measurements would be required for properly assessing trends due to various factors affecting the trial results.

Based on the 2010 research, it was estimated the lifetime of 100% EMOGPA mix could be over 25 times that of conventional OGPA. Whilst, the costs could be approximately 2.3 times higher than a comparable OGPA surfacing which is based on 100% EMOGPA at the time of study. Using lower percentages of epoxy bitumen would result in lower costs.

From these studies it is possible to assume that EMOGPA would likely have very similar noise reduction properties to those of conventional OGPA. While OGPA noise-reduction performance has been well documented (CEDR, 2017-01) and there are also recent measurements taken in NZ with results detailed (Opus Research, 2014), there is still uncertainty of the actual reduction in noise.

The CEDR report identified that noise performance deterioration of porous surfaces could be as much as 4 dB(A) over a four to five-year period under high speed conditions.

A more recent study undertaken in Christchurch (NZTA, 2017) had inconclusive results. The final results indicated that some locations had a reduction in noise, while other locations had negligible change. The approach used a sample of 150 surfaces from four different regions, and averaged the results across the surfaces. A direct comparison of locations was not taken over time, meaning it cannot be conclusively determined that newer sections of OGPA will age and continue to perform similarly to the older section considered in the study. The study relied on an average across pavements rather than a detailed analysis of each location. The measurements also did not follow the applicable standard which adds further uncertainty to the results.

Two recent Australian studies (S Samuels 2006 and McIntosh 2019) found that reductions of 1.3 dB over 3 years and 2 dB reduction over four years. These studies found a noticeable increase in the first year, some levelling off for two to 3 years, and then a noticeable increase after that.

While OGPAs unlikely acoustic performance over time is clearly uncertain, each of the studies reviewed here suggests there is some ongoing reduction in performance. Further work would need to be undertaken to determine if the cause of the change in noise is due to traffic flows or age. The studies it appears that there are a range of variations with the increase in noise anywhere between 0 dB and 0.5 dB per year.

The noise reduction benefit over a standard pavement such as dense graded asphalt is theorised to be approximately 20 years.

4.0 Discussion

Based on the data currently available, a high-level cost benefit analysis comparing the cumulative cost and noise reduction over a 50 year period for OGPA and EMOGPA has been carried out. The data used in this analysis would need to be confirmed in future work.

The cost of road traffic noise against number of households affected has not been considered at this stage due to the lack of reliable data, and further investigation will be required to carry out an in-depth cost benefit analysis.

4.1 Cost benefit analysis

Waka Kotahi have defined the costs of noise mitigation in the document Impacts of noise, monetised benefits and cost manual. Presented below is the applicable formula for determining the cost impact from road noise

$495(2020) per year x dB change x number of households affected

In reference to the study being undertaken as part of this work, this formula has limited benefit. There is no cost differential for different pavements and the number of households affected is a constant. So the difference in impact is just the change in noise.

To ensure that the cost of the different pavements is accounted for, an alternate approach has been incorporated in this assessment. Over a 50-year period the cost each time the period has been accounted for and the noise difference between the reference pavement (OGPA10) and the target pavement (EMOGPA7).

The following assumptions have been used for cost analysis are presented in Table 1below. These assumptions would need further refinement in future studies.

Table 1 Cost benefit and noise reduction assumptions

Assumption	OGPA10	EMOGPA10	EMOGPA7
Aggregate size	10 mm	10 mm	7 mm
Cost	$25.00 per m^2	$32.50 per m^2	$32.50 per m^2
Lifetime	8 years	40 years	40 years
Initial Attenuation Benefit	4dB	4dB	5dB[1]
Yearly Reduction in Attenuation	-0.5 dB/year	-0.2 dB/year	-0.2 dB/year

Note 1 The benefits of using 7 mm aggregate over 10 mm aggregate have been assumed based on experience with other pavements such as stone-mastic asphalt (SMA). Further studies would be required to confirm this assumption

4.1.1 Results

Provided below in Figure 2 is the cumulative cost for OGPA and EMOGPA surfaces over a 40-year period, assuming OGPA is resurfaced every 8 years and EMOGPA is resurfaced every 40 years, and every 20 years. Resurfacing has been considered every 20 years because after 20 years the pavement would no longer be a low noise pavement and would result in higher noise levels than DGA.

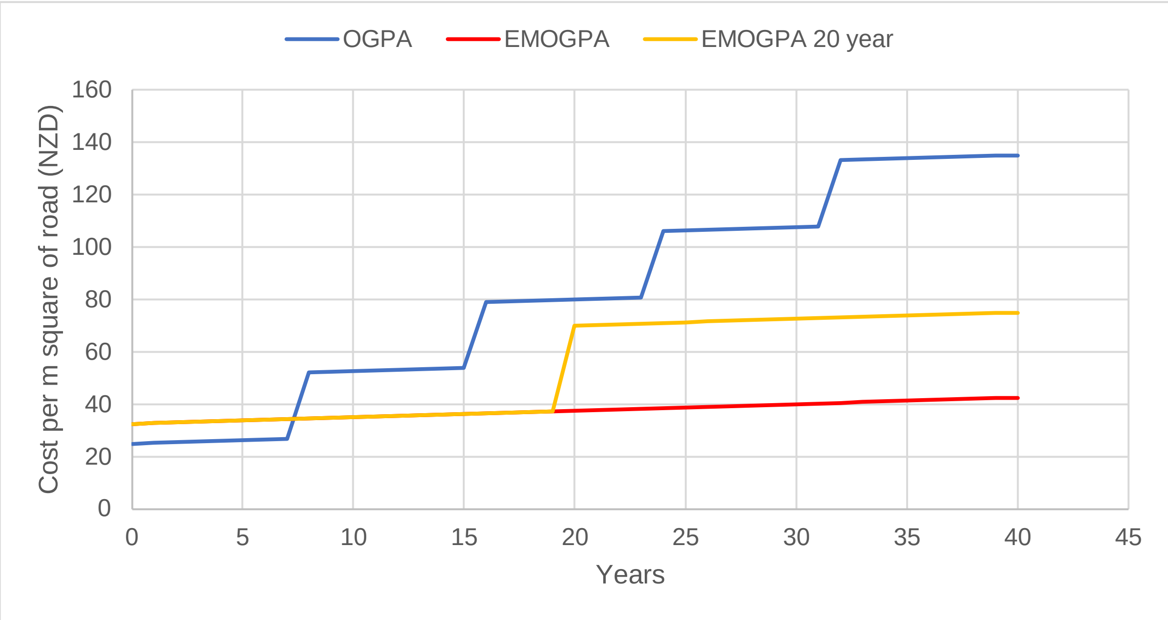

Figure 2 Cumulative cost analysis against 50-year timeframe

Predictions show EMOGPA has a lower cumulative cost over the 40 years. It becomes cheaper than OGPA after eight years due to its greatly increased lifetime.

While the noise benefits of EMOGPA may last for a comparatively long time, OGPA needs to be laid more regularly. This means that while EMOGPA gradually reduces in noise benefit, every time EMOGPA is resurfaced the full noise benefit is achieved again. The OGPA would more regularly result in lower noise levels than EMOGPA over the 40 year period (because it is resurfaced more regularly), but at greater cost. The lower noise levels would occur every eight years for increasingly longer periods, until the EMOGPA was resurfaced.

The noise benefit-cost ratio of surface materials was found using the net present value of benefits based upon a 6 percent discount rate and relevant values presented in Table 1. Presented in Figure 3 below is the ratio of noise benefit to surface cost of OGPA10, EMOGPA7 resurfaced every 40 years, EMOGPA7 resurfaced every 20 years, and EMOGPA10 resurfaced every 20 years.

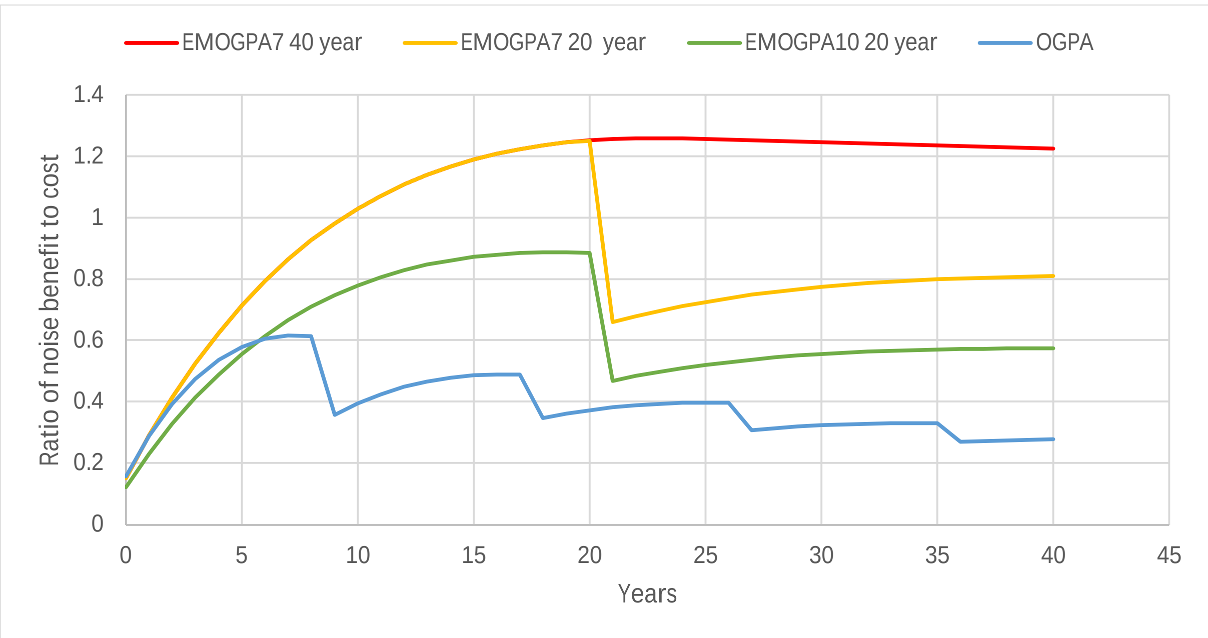

Figure 3 Cost benefit analysis – OGPA vs EMOGPA

For the stated assumptions EMOGPA7 has the highest benefit-cost ratio after a 40-year period. EMOGPA10 is shown to have a comparatively low value based on the assumption that it has a lower starting attenuation level than EMOGPA7. However, the degradation of EMOGPAs attenuation benefits are not well studied and values used in this analysis are estimations only.

No reduction in noise performance

Provided below is a comparison with no reduction in noise prior to the pavement being replaced.

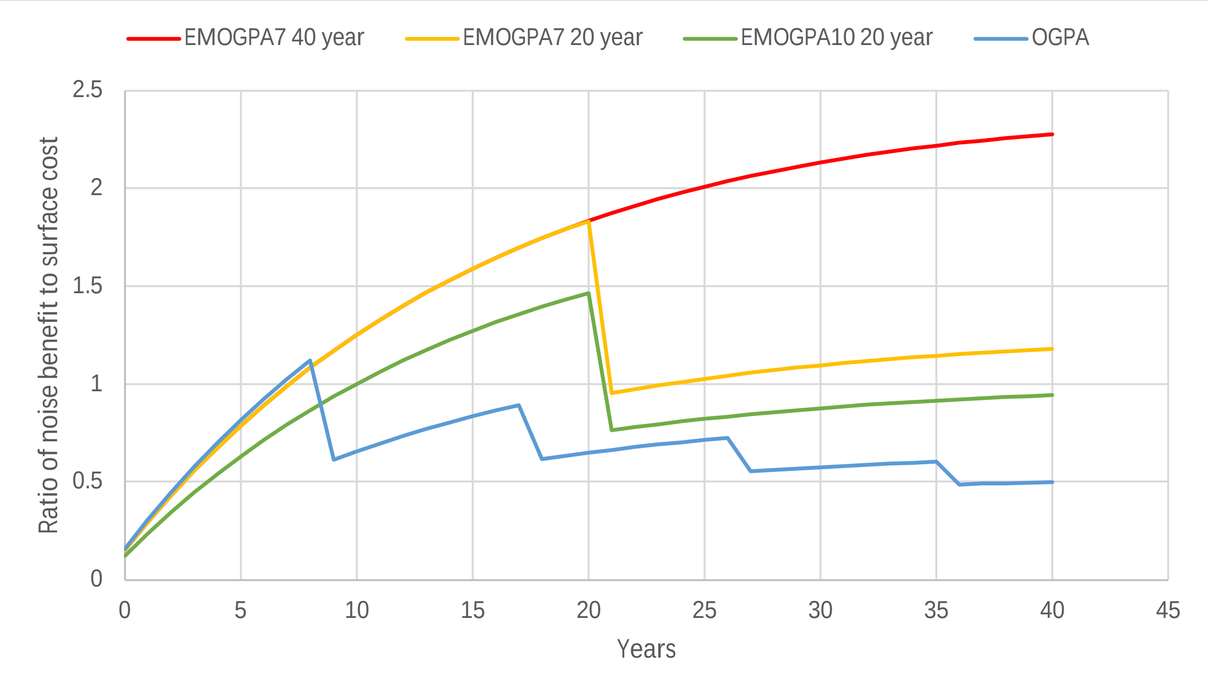

Figure 4 Cost benefit analysis – OGPA vs EMOGPA – No reduction in noise

The results in Figure 4 show that without a reduction in the acoustic performance a significantly improved cost benefit ratio is achieved.

4.2 Further work

There is still uncertainty about the noise reduction provided by EMOGPA, particularly over the life span of the surface. Further studies are required to provide more certainty about the acoustic performance over the life of the project, and particularly how it performs over extended periods of time.

Studies that will be required in the future include:

- Statistical passby measurements, controlled passby noise measurement and close proximity noise measurements to define the acoustical performance of the pavement
- The noise testing would need to be reviewed after 1, 2, 3 ,5, 10 and 15 years to clarify the acoustical performance over time.
- Costs associated with the pavement would need to be reviewed and the cost benefit analysis updated.
- This study has compared OGPA10 to EMOGPA7. However much more significant benefits could be achieved replacing other pavement types. Once the costs and approach are confirmed a review of the whole of Auckland would be completed based on AECOMs NZ Noise Model.

5.0 Conclusion

This report provides a high-level cost benefit of replacing 10mm OGPA with 7mm EMOGPA over a 50-year period.

Physically EMOGPA and OGPA are very similar. While the epoxy binder in EMOGPA allows larger voids, studies have found that increasing from a 20% void to a 30% void size has little difference. It is possible that the increased stiffness of EMOGPA would increase noise levels, however this effect is only minor and may not be relevant due to the small impact on overall noise levels.

A literature review identified that the EMOGPA has a significantly longer lifespan than OGPA. Studies have found a wide range of estimates from more than 30 years to well over 100 years. However, while further work needs to be completed to confirm, the noise reduction properties are unlikely to last for more than 20 years.

A cost benefit analysis has identified that although EMOGPA has a lifespan of more than 30 to 40 years, if a minor reduction in noise occurs it is significantly more cost-effective (from a noise perspective) to replace the pavement at around 20 years, to ensure that a reduction in noise is experienced. However if the acoustic performance is found not to degrade, the pavement should be replaced at the end of its effective life.

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