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Original Research Article

Concrete Latex Asphalt for Waste Prevention on Flood-Prone Niger Delta Roads: Performance and SDGs

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Abstract

A 6% concrete-latex addition raised the Marshall stability of submerged asphalt wearing course by 37% and its elastic modulus by 35% on average, and a simple life-cycle scenario shows how that can prevent road waste. Pavements in the flood-prone Niger Delta are repeatedly saturated, fail early, and are then milled and replaced, generating asphalt waste and consuming virgin aggregate and bitumen. This article takes the waste-management view of a laboratory study in which asphalt concrete was modified with 0–10% concrete latex and immersed for 0–7 days. The 6% mix retained higher stiffness at every immersion time (for example, 5,119 MPa after 7 days against 3,629 MPa unmodified), and, using the Asphalt Institute fatigue criterion, its estimated fatigue life was 1.20–1.31 times that of the unmodified mix. In a transparent scenario for a 7.3 m wide, 50 mm wearing course, a life-extension ratio in that range avoids about 200–800 t of milled asphalt waste per kilometre over 24 years, after counting the extra latex used, with a break-even at about 1.06. The latex is found at the top of the waste hierarchy (prevention) and is used in conjunction with the waste-based modifiers (polythene, polystyrene, ashes and recycled dust) discussed at Rivers State University. The results support SDG 9, 11, 12 (especially target 12.5) and 13.

Keywords: Waste prevention; asphalt pavement; concrete latex; moisture damage; flooding; circular economy; Sustainable Development Goals; Niger Delta.

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1. INTRODUCTION

The world produces approximately 2.01 billion tonnes of municipal solid waste (MSW) per year, which will grow to 3.40 billion tonnes by 2050 (Kaza *et al.,* 2018). The UNEP and ISWA 2024 vision is that prevention is better than treatment. Road construction and maintenance is another less noisemaker that causes the same set of problems. When every pavement layer fails too early, a volume of asphalt has to be milled off and disposed of or recycled and an equal volume of virgin aggregate, binder and energy has to be used to replace it. One of the most common causes of early wear of wearing courses is moisture damage. The presence of water displaces binder from the surface of the aggregates and softens the mix, resulting in reduced stability and stiffness of the mix, and the surface raveling (Caro *et al.,* 2008; Hicks, 1991; Kiggundu & Roberts, 1988).

In the Niger Delta, high rainfall, poor drainage and recurrent floods leave pavements saturated for long periods; in 2022 Nigeria's national emergency agency recorded about 2.5 million people affected by flooding across 33 of 36 states (James & Ajimotokan, 2022), and further increases in flood hazard are projected for parts of Africa (Pörtner *et al.,* 2022). A pavement that keeps its stiffness when wet lasts longer, and a pavement that lasts longer is waste that is never produced.

Researchers at Rivers State University have tested many modifiers against submergence damage, most of them wastes: waste polythene, polystyrene, tyre chips, agricultural and shell ashes, candle wax, calcium carbide residue and recycled concrete dust (Section 2). This article examines a different route, a commercial concrete latex, and asks a waste-management question that earlier laboratory work did not: how much asphalt waste could a moisture-resistant mix prevent, and how does that compare with using wastes as modifiers?

The aim is to (i) summarise the performance of concrete-latex-modified asphalt concrete under 0–7 days of immersion; (ii) estimate, from that performance, the change in fatigue life and in retained properties; (iii) place the result in the waste hierarchy and quantify the

waste avoided in a stated scenario; and (iv) link the outcome to the Sustainable Development Goals (SDGs) (United Nations, 2015). A companion article treats the same data set statistically.

2. LITERATURE REVIEW

Priorities for waste on roads. The waste hierarchy includes the hierarchy of waste prevention, preparing for re-use, recycling, other recovery (including energy) and disposal, with priority given to the waste prevention. The waste hierarchy includes the hierarchy of the waste prevention, preparation for re-use, the recycling, the other recovery (including the energy recovery) and disposal, with the highest priority for the waste prevention (European Parliament & Council, 2008). Prevention for asphalt pavements is to increase the lifespan of a pavement layer to reduce the amount of asphalt pavement material being milled, hauled and replaced. Other recycling/recovery methods rank lower: these are reusing reclaimed asphalt and using other wastes as modifiers or fillers. In fact, a life-cycle study of pavement maintenance, repair and rehabilitation (MaaS) conducted revealed higher life-cycle impacts for the milling-and-overlay and full reconstruction methods when compared to partial and full depth reclamation, indicating that the choice and frequency of maintenance interventions is important from an environmental perspective (Salem & Ghorai, 2015). Moisture damage as a cause of road wastes. Early failure is a major cause of failure for stripper, as cited by Airey & Choi (2002), Caro *et al.,* (2008), Hicks (1991), and Kiggundu & Roberts (1988). The studies at Rivers State University focus on the impact of submersion on the stiffness of Nigeria's roads in the delta region and how the road can be made stiffer again by using modifiers (Igwe, 2017; Igwe *et al.,* 2016a). Wastes as modifiers. There is a high percentage of wastes and/or by-products in Rivers State University work (Table 1). It is well known that waste plastics can be used as additives in the asphalt industry internationally (Ahmadinia *et al.,* 2011) and it is reported in the local studies that for every asphalt, an optimum concentration for the incorporation of waste plastics lies within a range from 2–4% by weight, beyond which the benefits decrease. The modifiers cannot be ranked directly as the studies involve different waste diversion targets and different measures and tests of success, but are worthy of recycling and recovery.

Table 1: Selected moisture-resistance results from Rivers State University studies

Modifier	Optimum reported	Reported result	Study
Rubber latex	1.5%	Tensile strength +113% (split cylinder) and +133% (double punch)	Igwe *et al.,* (2016b)
Polystyrene	2.5%	Swell reduced 60.6–66.9%; loss of stability reduced 24.1–50.4% over 1–5 days	Igwe & Amadi-Oparaeli (2018)
Bamboo ash filler	Filler replacement	Improved resistance to moisture damage of asphalt concrete	George *et al.,* (2021)
Candle wax	4%	Fatigue performance improved under submergence	Otto & Akpila (2020)
Waste polythene + quarry dust (laterite mix)	2% + 2%	Stability +34.9% over unmodified laterite mix	Inyang *et al.,* (2026)
Palm-kernel-shell + oyster-shell ash	Blend-specific	Improved elastic stiffness and indirect tensile strength ratio under full moisture conditioning	Enyi *et al.,* (2026)
Recycled concrete dust + granite dust	4% + 4%	14-day retained stability 63.1% vs 50.7%; swell index 5.15 vs 7.91	Otto & Agi (2026)

Other work in the series studied mineral fillers and mix-design properties (Igwe *et al.,* 2020), the modulus of waxed mixes (Igwe & Fun-Akpo, 2020) and correlations between tensile tests on rubberised asphalt (Igwe *et al.,* 2016c). Latex-modified binders have also been studied internationally (Mohd Hasan *et al.,* 2022).

Gap. None of these studies translates its performance gain into avoided road waste, and none places a manufactured polymer alongside the waste-derived modifiers in terms of the waste hierarchy. This article does both for concrete latex.

3. MATERIALS AND METHODS

3.1 Laboratory programme

The experimental data come from a laboratory programme at Rivers State University. The binder was a 60/70 penetration-grade asphalt cement; the aggregate was gravel and sand blended to ASTM limits; Marshall specimens (100 mm × 64 mm, 75 blows per face) were made at an optimum asphalt content of 5% following Roberts et al. (1996). Concrete latex, a commercial polymer emulsion whose exact formulation was not characterised, was added at 0, 2, 4, 6, 8 and 10% by weight of mix. Specimens were soaked for 0, 1, 2, 3, 4 and 7 days. Marshall stability, flow, density, air voids and VMA were measured, and tensile and compressive strains and strengths from indirect tensile tests were used to compute elastic, rigidity and bulk moduli. One reported value was available for each of the 36 latexes × immersion combinations.

3.2 Derived performance indices

Improvement was expressed as the percentage change of the 6% mix against the unmodified mix at the same immersion time, signed so that positive is beneficial. Retained-property ratios divided the day-7 value by the day-0 value for the same mix. Relative fatigue life was estimated from the Asphalt Institute fatigue criterion, in which cycles to failure scale with tensile strain and stiffness as (Asphalt Institute, 1982)

$$N_f \propto \varepsilon_t^{-3.291} E^{-0.854} \quad (1)$$

so that, for a latex mix compared with the unmodified mix at the same immersion time,

$$\frac{N_{f,\text{latex}}}{N_{f,0\%}} = \left(\frac{\varepsilon_{t,\text{latex}}}{\varepsilon_{t,0\%}}\right)^{-3.291} \left(\frac{E_{\text{latex}}}{E_{0\%}}\right)^{-0.854} \quad (2)$$

This is a screening index built from measured strain and modulus, not a fatigue test, and it assumes the Asphalt Institute exponents hold for these mixes.

3.3 Waste scenario

The mass of wearing course per kilometre was M = length × width × thickness × density = 1,000 m × 7.3 m × 0.05 m × 2.382 t/m³ = 869 t, with density the mean of the measured dry densities of the unmodified and 6% mixes. Over an analysis period of P = 24 years, an unmodified wearing course resurfaced every T_0 years needs $N_0 = P/T_0$ interventions, each producing M tonnes of milled asphalt waste. If latex extends service life by a ratio r, interventions fall to $N_1 = P/(r \cdot T_0)$. Because latex itself is an added virgin material, it was counted against the benefit at 6% of the mix mass per intervention (an upper bound, because the solids content of the product is unknown):

$$W_{\text{net}} = (N_0 - N_1)\, M - N_1 \cdot 0.06\, M \quad (3)$$

The baseline interval T_0 was varied over 5, 8 and 12 years, and r was varied from 1.0 to 1.5, bracketing the 1.20–1.31 obtained from the fatigue index. Service life was assumed proportional to fatigue life. These are scenario inputs, not field data. All other assumptions are stated in Table 4.

4. RESULTS

4.1 Performance gains from 6% latex

Averaged over the six immersion times, the 6% latex mix outperformed the unmodified mix on all twelve properties (Figure 1, Table 2). The largest gains were in Marshall stability (+37.2%) and the stiffness moduli (elastic +34.6%, rigidity +35.0%, bulk +28.1%). All twelve differences remained significant after Benjamini–Hochberg adjustment (adjusted $p \leq 0.003$).

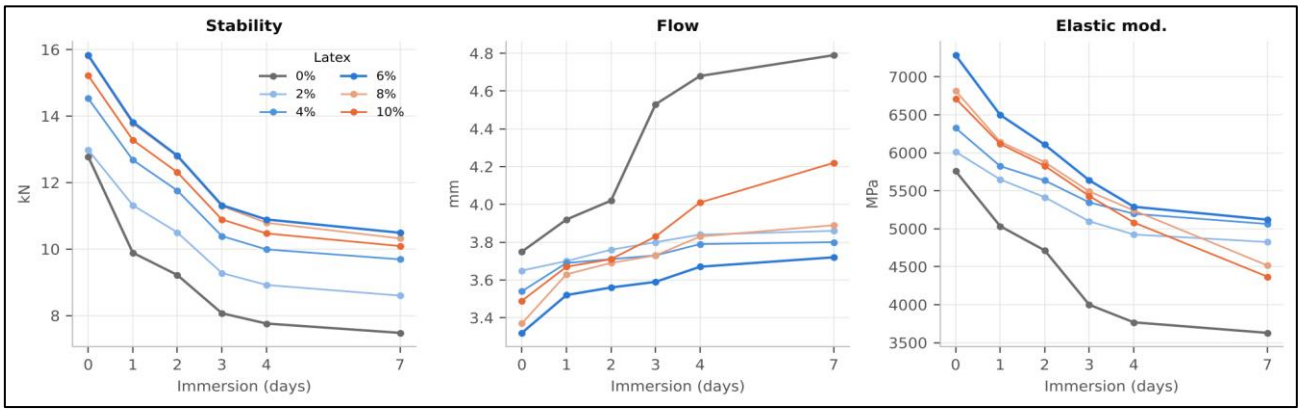


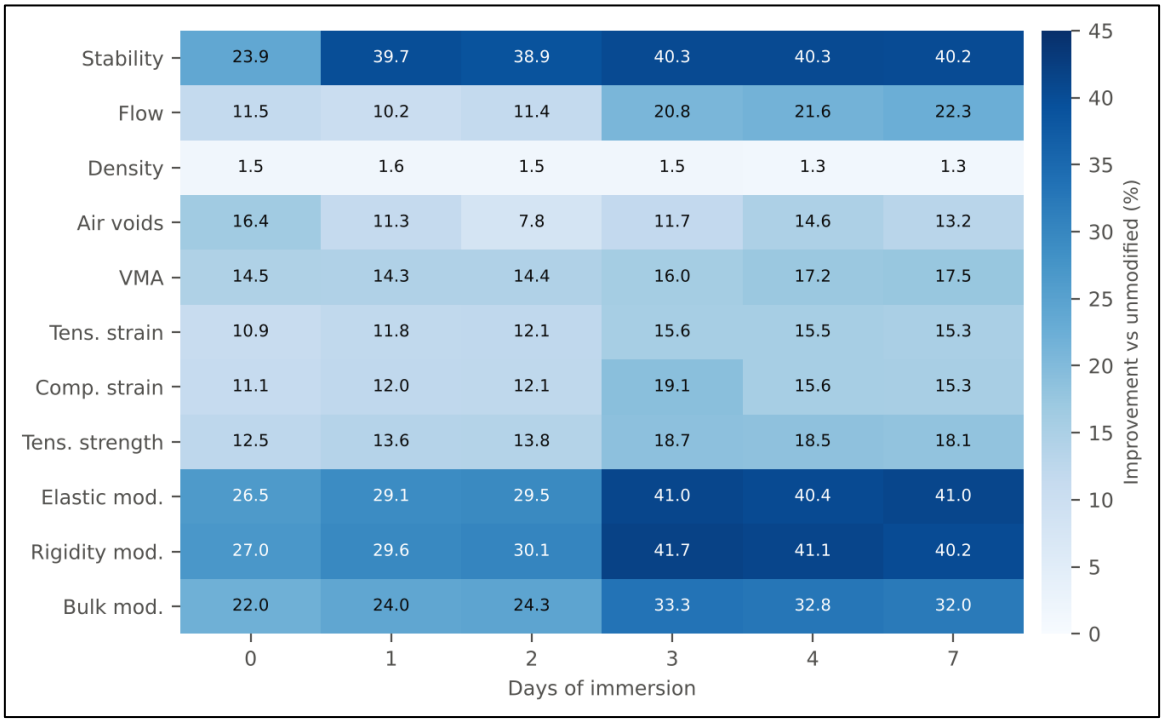
Table 2: Mean improvement of the 6% latex mix over the unmodified mix, days 0–7 (positive = beneficial direction)

Property	Mean improvement (%)
Marshall stability	37.2
Elastic modulus	34.6
Rigidity modulus	35.0
Bulk modulus	28.1
Tensile and compressive strength	15.9
Tensile and compressive strain	13.5 to 14.2
Flow	16.3
Voids in mineral aggregate	15.6
Air voids	12.5
Density	1.4

4.2 Improvement with immersion time

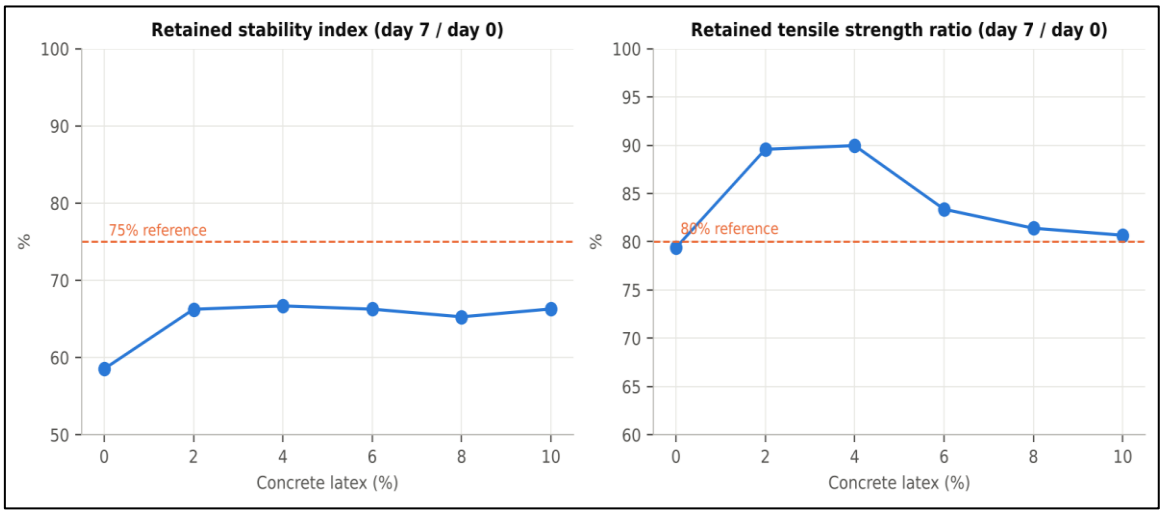
Figure 2 shows the improvement at each latex content and immersion time. The percentage gain over the unmodified mix grows with soaking time. This should not be read as latex becoming more effective in wet conditions: much of the growth arises because the

unmodified reference falls faster, so the same absolute value represents a larger relative gain. Tests of the latex × immersion interaction found no evidence that latex changes the rate of loss in stability, strength or the moduli (interaction p = 0.69–0.98); latex raised the level of these properties rather than slowing their decline. Flow and VMA were the exceptions and did show slower change.



4.3 Retained properties after seven days

The seven-day retained stability index was 58.5% for the unmodified mix and about 66% for the latex mixes. Retained tensile strength was 79.4% for the unmodified mix, 83.4% at 6% latex and 89.6–90.0% at 2–4% latex (Figure 3). On a retained-ratio basis, therefore, the moderate doses perform best, while on an absolute-value basis 6% is best. These two criteria answer different questions: how little is lost, and how much remains.



4.4 Estimated fatigue-life ratio

The screening index of Section 3.2 gives a fatigue-life ratio above 1 for all latex mixes at every immersion time except where the reference is the dry unmodified mix (Table 3, Figure 4). Against the unmodified mix soaked for the same time, the 6% mix ranges from 1.20 at day 0 to 1.31 at day 4 and 1.29 at day 7. The 4% mix is slightly higher at day 7 (1.33). Against the dry unmodified mix, however, the 6% mix falls from 1.20 to 0.89 by day 7: a soaked latex mix does not outlast the dry control.

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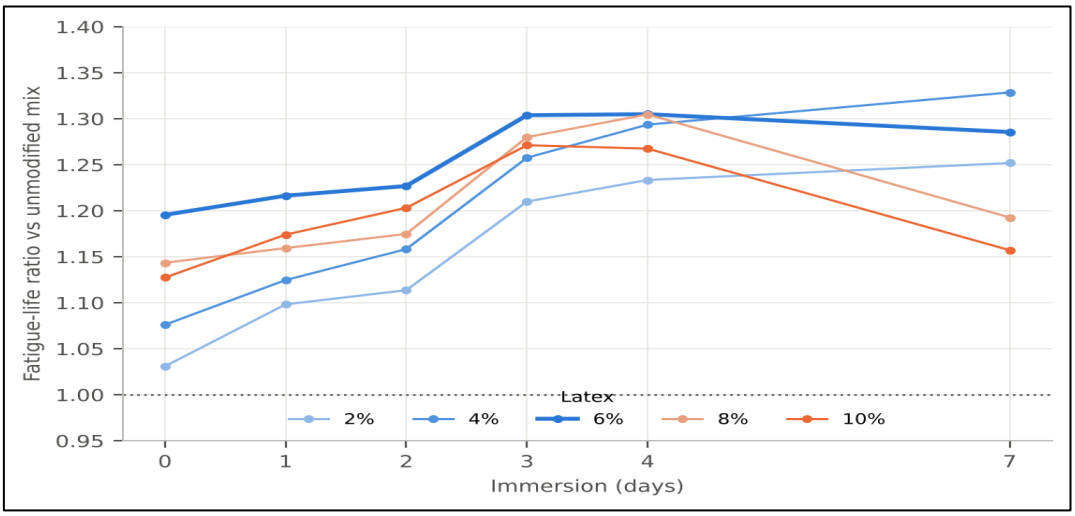
Table 3: Estimated fatigue-life ratio of latex mixes relative to the unmodified mix at the same immersion time, and (last row) the 6% mix relative to the dry unmodified mix.

Latex content	Day 0	Day 1	Day 2	Day 3	Day 4	Day 7
2%	1.03	1.10	1.11	1.21	1.23	1.25
4%	1.08	1.12	1.16	1.26	1.29	1.33
6%	1.20	1.22	1.23	1.30	1.31	1.29
6% vs dry unmodified	1.20	1.09	1.04	0.98	0.93	0.89



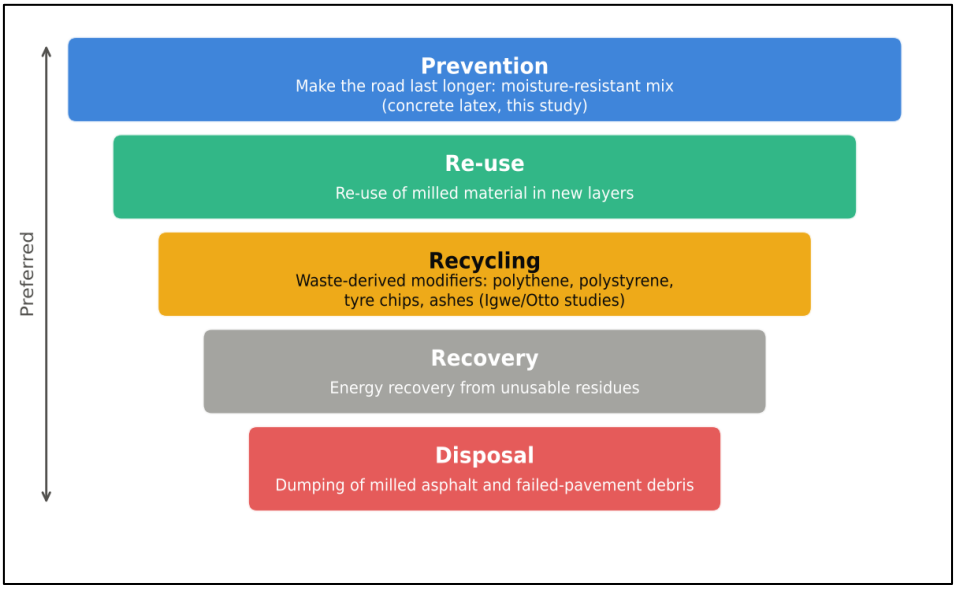
4.5 Optimum latex content

Quadratic models with day effects place the stationary latex content at about 6.4–6.7% for most responses (95% bootstrap interval 6.0–7.3%), with stability peaking later (7.8%) and flow earlier (6.1%). A composite desirability analysis gives 6.5% overall: 7.2% for dry specimens, falling to 5.7% after seven days of soaking. Thus, the dose for a wet weather design would be somewhat lower than a dry weather design. The mixes also performed well for the five volumetric requirements specified in the source study, within the 2–6% range, until day 7, while the unmodified mix was not satisfactory on flow requirement from day 2.

5. Waste-management implications

5.1 Where latex sits in the waste hierarchy

Latex would be on the highest level: the goal is to avoid wastefulness in terms of the frequency of resurfacing. Waste derived modifiers work lower level, reusing/recovering materials that would be discarded (Figure 5). These two approaches are complementary and not mutually exclusive, but have different risk profiles. The production of latex is a manufactured polymer and thus it involves its own production cost that will offset the benefit, which is not quantified in this article, but requires a life cycle assessment (Salem & Ghorai, 2015).



5.2 Scenario: avoided asphalt waste per kilometre

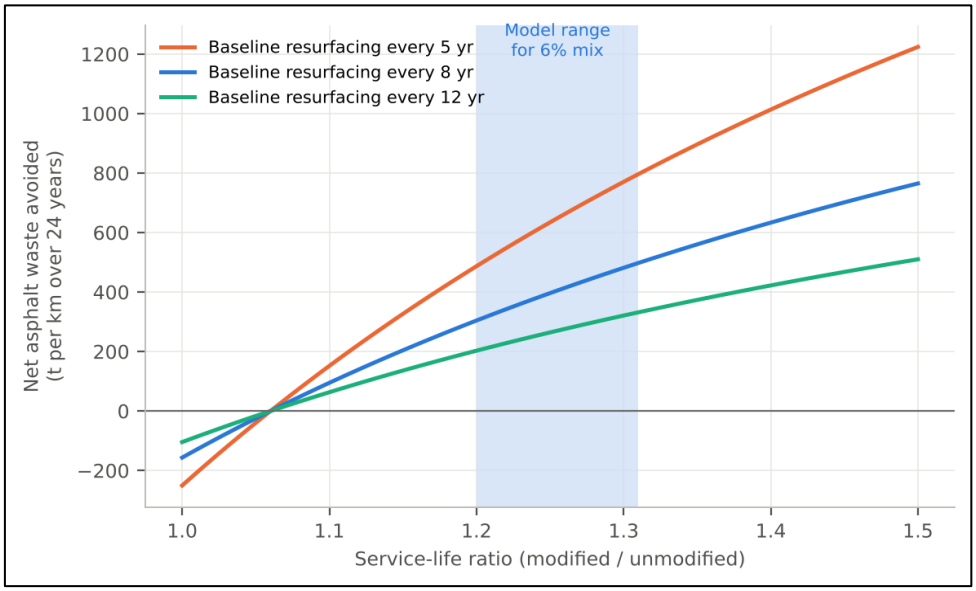
The assumptions of the scenarios are presented in Table 4 and the results in Table 5. For each intervention, 869 t of milled asphalt is produced on 1 km of wearing course. The break even life ratio is approximately 1.06, and it is independent of the basic interval. The fatigue index provides ratios of 1.20–1.31, comfortably over this break-even, but only if service life is truly based on fatigue life, which is to be verified by field trials.

Table 4: Scenario assumptions

Parameter	Value
Section length × width × thickness	1 km × 7.3 m × 50 mm
Mixture density	2.382 t/m³
Mass per intervention	869 t
Analysis period	24 years
Baseline resurfacing interval	5, 8 or 12 years
Life-extension ratio r	1.20, 1.29, 1.31
Latex charge counted as waste	6% of mix mass per modified intervention (upper bound)
Service life	Proportional to fatigue life

Table 5: Avoided asphalt waste per kilometre over 24 years (tonnes)

Baseline interval (years)	r	Interventions without latex	Interventions with latex	Gross avoided	Latex added	Net avoided	Net as % of baseline waste
5	1.20	4.8	4.00	696	209	487	12
5	1.29	4.8	3.72	938	194	744	18
5	1.31	4.8	3.66	988	191	796	19
8	1.20	3.0	2.50	435	130	304	12
8	1.29	3.0	2.33	586	121	465	18
8	1.31	3.0	2.29	617	119	498	19
12	1.20	2.0	1.67	290	87	203	12
12	1.29	2.0	1.55	391	81	310	18
12	1.31	2.0	1.53	411	80	332	19



The net saving is 12–19% of the baseline waste, from 203 t (12-year interval, r = 1.20) to 796 t (5-year interval, r = 1.31). Fractional interventions are an averaging device for a 24-year horizon, not a prediction of a particular maintenance schedule.

5.3 Comparison with waste-derived modifiers

The Rivers State University studies in Table 1 use modifiers at about 2–4% by weight. At the same 869 t per intervention, a 2–4% charge corresponds to roughly 17–35 t of material per intervention if dosing is by mix mass. So there are some waste-reduction modifiers that don't use dumps and can cost very little, but those studies don't mention that service-life gains would create the above avoided-waste calculation. Latex, by contrast, carries a larger charge (6%, about 52 t per intervention) of virgin material and reports a clear stiffness and strength benefit. Which route is preferable depends on

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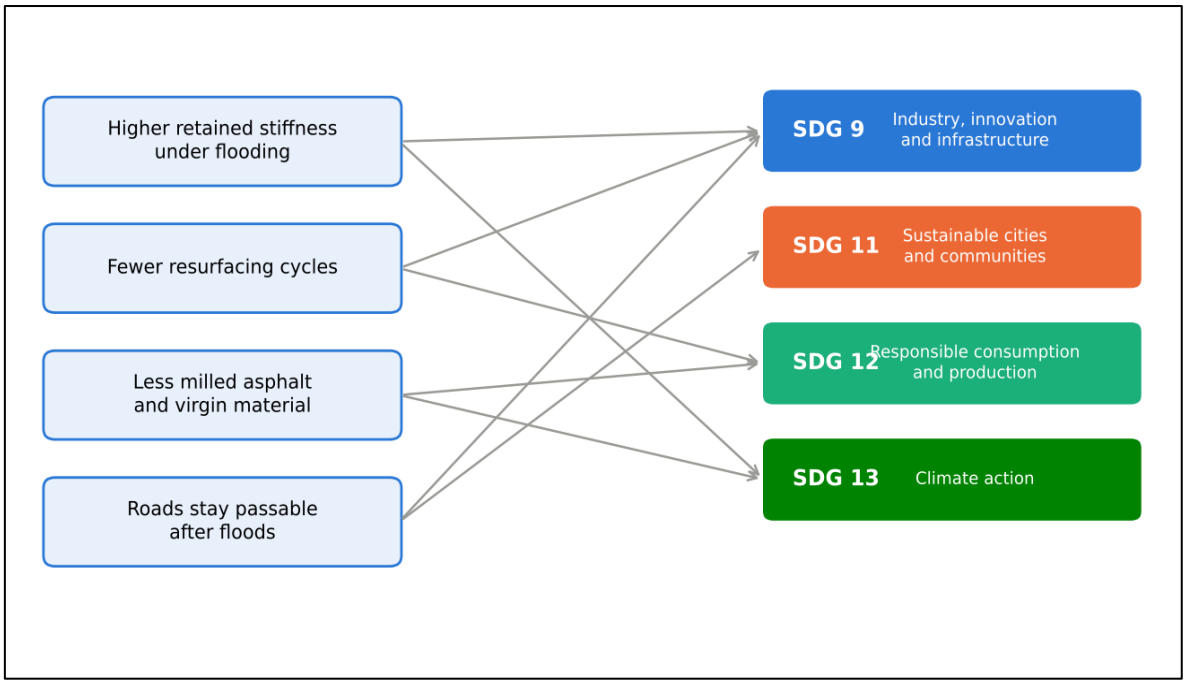
the unquantified life-cycle burden of latex and on the field performance of the waste-derived blends. A hybrid design, in which a lower latex dose is combined with a waste-derived filler, is a natural next experiment.

6. Contribution to the Sustainable Development Goals

The 2030 Agenda commits countries to resilient infrastructure and to sustainable consumption and production (United Nations, 2015). Table 6 links the findings of this article to the targets they bear on, and states how strong each link is. The links are potential contributions that depend on field confirmation; the laboratory data alone do not demonstrate them.

Table 6: Links between the findings and the Sustainable Development Goals

SDG and target	Evidence from this study	Strength of link
9.1 Quality, reliable, sustainable and resilient infrastructure	Stiffness and stability of the 6% mix were 28–37% higher than the unmodified mix when soaked; the 2–6% mixes met all five volumetric limits through day 7	Direct, laboratory scale
9.4 Infrastructure upgraded for resource-use efficiency	Estimated fatigue-life ratio 1.20–1.31 relative to the unmodified mix at the same immersion time	Direct, but model-based
11.2 Safe and sustainable transport systems	Wet-condition stiffness retained for longer implies fewer failures on flood-prone roads	Indirect
11.5 Reduced effects of water-related disasters	Stiffer wet pavement may recover sooner after flooding; not tested here	Indirect and untested
12.2 Efficient use of natural resources	Fewer resurfacing cycles mean less virgin aggregate and binder; net saving 12–19% of baseline waste in the scenario	Scenario-based
12.5 Reduced waste generation through prevention, reduction, recycling and re-use	203–796 t of milled asphalt avoided per kilometre over 24 years after counting added latex (Table 5); break-even life ratio 1.06	Scenario-based; latex burden not assessed
13.1 Resilience to climate-related hazards	Improved retention of properties under repeated saturation, relevant to the flood hazard projected for parts of Africa (Pörtner *et al.,* 2022)	Indirect



SDG 12 is the focus of this article, and the claim for it is stated carefully. The scenario shows that, if latex extends life by more than about 6%, the asphalt waste prevented exceeds the latex added. It does not show that the total environmental burden falls, because the production of the latex has not been assessed. The wastes derived modifiers discussed elsewhere in the Rivers State University contribute to SDG 12 in a different way, namely, recycling and recovering wastes (target 12.5) and a combination strategy could be beneficial to both.

7. LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1 Limitations

- Each latex × immersion combination has a single reported value, so differences could not be tested against replicate scatter; the statistical companion article treats the 36 cells as an additive design.
- The latex is a commercial emulsion whose composition and solids content were not characterised, so results cannot be transferred to other products.
- Immersion of Marshall specimens is a laboratory proxy for flooding and does not reproduce traffic loading, drainage or temperature cycling.
- The fatigue ratio is a screening index from the Asphalt Institute criterion, and the assumption that service life is proportional to fatigue life is untested in the field.
- The waste scenario uses one geometry, three baseline intervals and a 6% latex charge as an upper bound. Embodied energy and emissions of latex are not assessed.
- The soaked latex mix does not outlast the dry unmodified mix (ratio 0.89 at day 7), so latex slows the effect of water without removing it.

7.2 Conclusions

1. A 6% concrete-latex addition improved all twelve measured properties; stability rose by 37% and the moduli by 28–35% on average, and the differences remained significant after multiplicity adjustment.
2. Latex raised the level of stiffness and strength rather than slowing their rate of loss; the retained-ratio criterion favoured 2–4% latex, while absolute performance favoured about 6.5%.
3. The estimated fatigue-life ratio of 1.20–1.31 implies that, in the scenario modelled, 203–796 t of milled asphalt per kilometre could be avoided over 24 years after counting the latex added, provided that field life extension exceeds a break-even ratio of about 1.06.
4. Latex belongs to the prevention tier of the waste hierarchy and complements the recycling-tier work with wastes at Rivers State University.
5. The results can support SDGs 9, 11, 12 and 13, subject to the limitations above.

7.3 Recommendations

- Run replicated tests, including wet-dry cycling and wheel-tracking, with a characterised latex product.
- Place trial sections on flood-prone roads and record service life against an untreated control.
- Carry out a life-cycle assessment of latex against waste-derived modifiers before recommending either on environmental grounds.
- Test hybrid mixes of a reduced latex dose with a waste-derived filler.

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