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EVALUATING MACREBUR'S MR6, MR8, AND MR13

A Comprehensive Analysis of Performance, Sustainability, and Cost-Effectiveness

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Evaluating MacRebur's MR6, MR8, and MR13: A Comprehensive Analysis of Performance, Sustainability, and Cost-Effectiveness

Executive Summary

Since 2016, MacRebur has converted post-consumer plastic waste into high-performance additives for asphalt, turning a major environmental liability into a valuable construction resource. Every mile of pavement incorporating MacRebur additives reduces demand for virgin materials, lowers lifecycle carbon emissions, and diverts plastic from the waste stream—making everyday roads a tangible part of the climate solution.

MacRebur additives improve asphalt performance while delivering clear circular-economy benefits, integrating seamlessly with conventional paving processes and existing supply chains. As a result, they can produce more durable, lower-maintenance pavements at reduced lifecycle cost. This report details the technical, environmental, and financial performance of MacRebur products and compares them to conventional mixes and competing PMB solutions.

Summary of MR6, MR8, and MR13 products

MacRebur's product family includes MR6, MR8 and MR13. All 3 additives offer graduated levels of modification and performance.

MR6 is a highly practical mid-range modifier that delivers a step-change in binder performance. Technically, MR6 significantly increases elastic response and high-temperature stiffness, improving rutting resistance and load-carrying capacity for typical heavy-traffic pavements while still maintaining good low-temperature and fatigue behaviour when correctly dosed. MR6 produces a high viscosity rise compared with low to mid PMB performance grades. MR6 is readily dispersed using calibrated dry-feed methods and can be processed at standard plant temperatures and shear conditions. The result is PMB-comparable rheological improvement (stronger DSR/MSCR indicators and improved rutting performance) with straightforward implementation and predictable, reproducible mix behaviour under BS EN–aligned test protocols.

From an environmental and economic standpoint MR6 represents a very attractive compromise between performance and cost/carbon footprints. Its formulation — leveraging recycled-polymer content — reduces embodied carbon relative to many virgin-polymer PMBs and diverts waste plastic into a long-life infrastructure application, improving material circularity. Because MR6 doesn't require specialised heated storage or lower-intensity blending compared to higher-viscosity modifiers, capital and operating costs for plant upgrades are much lower, and energy inputs during production are greatly reduced. These factors combine to shorten payback periods and lower whole-life costs: agencies gain durable, rut-resistant surfaces with reduced maintenance frequency and a smaller environmental footprint, making MR6 an excellent choice where high performance must be balanced with practical economics and sustainability goals.

MR8 serves as a partial replacement for conventional bitumen in asphalt mixes, designed to reduce costs and the environmental impact where a full polymer modified bitumen (PMB) is not required. MR8 is a blend of polymers derived from 100% recycled waste plastics, which extends the binder volume, allowing asphalt producers to lower the amount of fossil-based bitumen used. This additive is compatible with all asphalt types and is typically dry mixed at the asphalt plant. It is ideally suited for use in base, binder, and surface course layers on standard traffic roads, car parks, driveways, and local roads where sustainability and economy are prioritised.

From an environmental and economic viewpoint MR8 is highly attractive: its formulation often incorporates recycled polymer content, lowering embodied carbon and diverting waste plastics into durable infrastructure, and it supports higher reclaimed asphalt or recycled aggregate use by stabilising binder behaviour. The modest viscosity impact means only minimal plant modification and no additional heated storage is required, keeping capital and operating costs low and reducing energy consumption during production. Collectively, these features make MR8 a cost-effective, lower-carbon choice for programmes that prioritise simplicity, workability and whole-life value for lighter traffic and constrained production environments.

MR13 is MacRebur's high-performance modifier engineered to deliver pronounced rheological enhancement where pavements face severe rutting, sustained high temperatures or very heavy traffic loading. MR13 has been designed with TS2010 specifications in mind. Technically, MR13 substantially raises high-temperature stiffness and elastic recovery, improving resistance to permanent deformation and providing a more resilient binder response under repeated loading. These larger rheological changes translate into measurable gains in DSR/MSCR performance and mixture rutting indices versus lower-grade modifiers, making MR13 well suited to wearing courses, binder courses or base layers on major highways, ports and hot-climate networks. Because MR13 imparts a stronger modification, achieving full dispersion and stable performance can require attention to mixing shear, residence time and, in some installations, higher storage or blending temperatures; the product performs reliably whether introduced as a controlled dry feed or a central wet pre-blend when recommended procedures are followed.

From an environmental and economic perspective MR13 delivers high value despite its greater intensity of modification. Formulations that use recycled polymer content retain the sustainability benefits of diverting plastic waste and lowering embodied carbon compared with virgin-polymer alternatives, while providing a long-service pavement that reduces maintenance frequency and lifecycle emissions. Although MR13 can necessitate more robust plant capability—such as heated storage or dedicated high-shear blending in some settings—its ability to be effectively introduced via controlled dry-feed means that, where dry addition is suitable, the upfront capital and operational investments are substantially lower than those required for the high-specification PMBs typically used to meet a TS2010 specification; as a result, overall cost savings can be immense while still delivering extended pavement life and lower whole-life costs on high-demand routes.

1. Introduction

1.1 Purpose of the report

This report sets out to demonstrate, with clear methods and evidence, the technical, environmental and economic advantages MacRebur's specialist recycled-polymer additives can deliver in asphalt compared with conventional PMBs and other competing additives. It explains recommended addition methods (wet pre-blend and dry addition), binder recovery and test protocols aligned to BS EN standards, and provides head-to-head comparisons that highlight where MacRebur solutions typically outperform or match other PMBs in the market. A further objective is to correct misleading conclusions in some competitor reports by showing how appropriate test methods and handling produce reproducible, representative results.

1.1.1 Technical advantages

From a pavement performance perspective, MacRebur additives are formulated to deliver the key rheological improvements expected from PMBs — increased high-temperature stiffness and elastic response to resist rutting, while maintaining or improving low-temperature toughness and fatigue resistance. In practice this means mixes using MacRebur additives can achieve comparable or superior DSR/MSCR and BBR indicators versus unmodified binders and many alternative additives, with reliable performance across typical traffic and climatic conditions. Because the additives are designed for both dry-feed and wet pre-blend routes, they provide practical flexibility for different plant capabilities while still achieving full polymer dispersion and activation when recommended mixing shear, temperature and residence times are observed.

1.1.2 Environmental benefits

A major advantage of MacRebur's recycled-polymer approach is the strong sustainability profile. Using recycled polymers diverts plastic from waste streams, reduces the embodied carbon of the binder system compared with producing virgin polymer PMBs, and can materially lower lifecycle greenhouse-gas emissions for the pavement layer when assessed across manufacture, transport and in-service performance. The products can also enable higher recycled aggregate or reclaimed asphalt content in mixes without compromising performance, further improving material circularity. Where wet pre-blends are used, efficient plant practice and warm-mix techniques can minimise energy inputs; when applied as dry feeds the need for additional high-temperature blending is often reduced compared with some most other PMBs.

1.1.3 Economic benefits

Economically, MacRebur additives often offer lower whole-life costs than conventional PMBs. Typical savings arise from reduced capital investment (many plants can adopt dry addition without the large-scale heated storage and high-shear pre-blend equipment required for some PMBs), lower material cost (recycled polymer feedstocks versus virgin polymer modifiers), and extended pavement life that reduces maintenance frequency. Operationally, reduced handling complexity, compatibility with existing asphalt plant workflows and fewer specialised storage needs can decrease operating expenses and downtime. These economic gains are maximised when project-specific mix designs and MacRebur's QC protocols are followed.

1.1.4 Scope, Methods, and Standards

MacRebur's testing procedures have been rigorously conducted using BS EN-aligned test suites, including penetration, softening point, viscosity, DSR/MSCR, BBR, RTFOT/PAV ageing, and all relevant asphalt mixture tests. The report addresses both key application routes: guidance for wet pre-blending in centralised production facilities and for dry addition during in-plant dosing operations. To ensure robust and comparable results, all comparisons with standard bitumen, PMBs, and other additives have been performed using identical base binders, consistent ageing protocols, and meticulously documented sample handling, effectively eliminating artefacts and bias from analysis.

1.1.5 Addressing Historical Misinterpretations in Testing

Previous studies have sometimes reported inconsistent or unfavourable results for recycled-polymer additives due to issues such as non-representative binder recovery, unsuitable choice of solvents, excessive solvent volumes resulting in polymer fraction loss, lack of appropriate equipment for recovering PMBs, exaggerated stiffness readings, or tests performed at conditions not representative of in-service environments. This report examines these failure modes in detail and provides corrective procedures tailored for new polymers designed to modify bitumen and retain polymer fractions during binder recovery. By outlining best-practice testing, appropriate recovery solvents and other methods, strict adherence to BS EN testing protocols, and setting clear objectives for modified bitumen, the report dispels misconceptions from earlier flawed methodologies and presents robust, validated comparative data.

1.1.6 Practical Guidance and Key Considerations

To fully realise both the technical and economic benefits of MacRebur products, it is important for producers to adhere to MacRebur's recommended dosing ranges, ensuring sufficient shear and residence time for proper dispersion, and to adjust mixing or storage temperatures when viscosity changes are anticipated. For dry addition, it is essential to accurately calibrate feeders and maintain thorough homogenisation in mixing drums to prevent segregation. For wet pre-blend applications, robust heated storage and precise pumping protocols are necessary for consistent dosing. Testing should follow MacRebur's procedures aligned with BS EN binder recovery and ageing methods, avoid solvents and practices that risk dissolving or fractionating the polymer unnecessarily, and rely on multiple performance endpoints instead of single factor assessments to comprehensively evaluate binder and asphalt behaviour.

1.1.7 Anticipated Results and Recommendations

When MacRebur additives are specified, mixed, and tested according to the standards outlined in this report, they reliably deliver rutting resistance, low-temperature performance, and fatigue durability equal or superior to conventional PMBs. Further, their use provides clear environmental and economic benefits by utilising recycled content and reducing the need for specialised plant modifications. This report highlights these advantages, setting MacRebur's polymer technology in contrast to typical ‘off-the-shelf’ PMBs and other bitumen modifiers, supporting informed selection for high-performance, sustainable asphalt construction.

2.0 Polymer Modified Bitumen (PMB) and Polymer Modified Asphalt (PMA)

Polymer Modified Bitumen (PMB) is bitumen that has been intentionally altered by adding polymeric additives to change its rheological (viscoelastic) behaviour. These modifications improve binder performance across a wide temperature range and under repeated loading, producing pavements with better rutting resistance at high temperatures, greater elasticity and toughness to resist fatigue and low-temperature cracking, and often improved overall durability compared with unmodified bitumen.

In asphalt production the benefits of PMB are practical and measurable. Modified binders increase stiffness and elastic response at elevated pavement temperatures, reducing permanent deformation and rutting on heavily trafficked routes. At the same time, polymers enhance fatigue life and low-temperature performance as well as resistance to crack initiation and propagation. The result can be longer service life and lower whole-life costs, and greater design flexibility because binder behaviour can be specified to match traffic loads, climatic conditions and particular layer functions.

A variety of polymer chemistries are used to achieve these effects, including block copolymers such as styrene–butadiene–styrene (SBS) and styrene–butadiene (SB), crumb rubber, and thermoplastic elastomers or engineered plastic blends. Each polymer type and formulation produces different changes in elasticity, temperature susceptibility and viscosity, so handling, mixing and storage requirements will vary by product.

Polymer Modified Asphalt (PMA) represents an advanced approach to asphalt mixtures, where the incorporation of Polymer Modified Bitumen (PMB) significantly elevates the performance and durability of standard asphalt. By enhancing the bitumen with polymers, PMA becomes resilient against a range of challenges, including temperature fluctuations, heavy loading, and moisture intrusion. This leads to a superior paving material suitable for high-performance applications in both urban and rural environments.

One of the key innovations in the production of PMA is the use of a dry mix process, particularly with additives such as those offered by MacRebur. This approach allows for the addition of polymer modifiers and other performance-enhancing materials separately from pre-mixed PMB. Traditional methods often require integrating the polymer directly into the bitumen before it is mixed with aggregates, which can limit the flexibility and adaptability of the formulation. However, with MacRebur’s dry additives, these components can be introduced at various stages of the mixing process, enabling a more tailored approach.

Using a dry mix process offers several advantages. First, it allows for precise dosing of additives based on the specific properties of the aggregates and the base bitumen being used. This is particularly important because different bitumen grades exhibit varying characteristics, and the quality of the bitumen can fluctuate over time. By measuring and adjusting the quantity of additives during the mixing phase, producers can achieve optimal performance characteristics for each specific batch of asphalt. Furthermore, since the additives remain dry until added, they retain their effectiveness and perform consistently, ensuring that the PMA achieves its intended specifications regardless of the inherent variability in the base materials.

MacRebur's MR6 and MR8 should ideally be dry mixed into the asphalt according to the specific instructions outlined in this report, ensuring optimal integration and performance enhancement. Meanwhile, MR13 has been expertly designed as an additive for creating Polymer Modified Bitumen (PMB) but can also be effectively dry mixed into asphalt to produce high-quality Polymer Modified Asphalt (PMA).

3.0 Comparative Description of Dry Mix and Wet Mix Applications

There are two principal routes to introduce polymeric modifiers or recycled-plastic additives into asphalt mixtures: the dry (direct) method and the wet (binder pre-blend) method. Both are used in practice; the choice depends on product form, desired performance, plant capability and logistics.

3.1 Dry (Direct) Addition

In this method, the modifier—available from MacRebur in granule form—is introduced directly into the hot aggregate stream or the mixing drum during the asphalt production process. MacReburs polymer granulates are engineered for dry dosing, allowing for physical blending into the mix rather than relying on a chemical reaction with the binder. The advantages of dry addition include limited need for equipment modifications, flexibility in dosing on existing production lines, and lower initial capital cost compared to installing high-shear blending systems. MacRebur works closely with asphalt manufacturers to make sure the MR modifiers are fully dispersed into the asphalt mix which may require adjustments in workability and stringent quality control measures are put into place to ensure dosing accuracy, temperature control and mix consistency.

3.2 Wet (Binder Pre-Blend / High-Shear) Addition

In contrast, the wet addition method involves blending the modifier into the bitumen before mixing it with aggregates, typically using a high-shear mixer to create a homogeneous polymer-modified binder (PMB). This approach is commonly used for conventional PMBs, such as those modified with styrene-butadiene-styrene (SBS), and certain recycled-plastic elastomeric modifiers (including MacRebur's) that require intimate mixing with the binder for certain applications. The main advantages of wet addition include the production of a uniform PMB with controlled and repeatable properties that meet specification targets, clearer improvements in high-temperature stiffness and elastic recovery, and simplified binder-level verification through direct testing of the PMB. However, this method necessitates high-shear blending capabilities and additional infrastructure to handle the higher viscosities of the modified binder, resulting in higher upfront costs and potential operational complexities, including risks of storage stability and phase separation if not properly stabilised. Logistics also become more critical, as the pre-blended binder needs to be managed as a discrete product with specific supply and storage controls.

Storing Polymer Modified Bitumen (PMB) at elevated temperatures presents several additional costs and environmental challenges that require careful consideration. One of the most significant financial burdens comes from the need for specialised infrastructure and equipment. This includes heated storage tanks and pumping systems designed to accommodate the high viscosity of PMB. The initial capital investment for such equipment can be substantial, and ongoing maintenance costs can further strain budgets. Additionally, maintaining the required temperature incurs continuous energy consumption, which can lead to higher utility expenses, particularly in regions where energy prices are elevated.

Moreover, effective PMB management necessitates sophisticated monitoring and control systems to ensure the stability and quality of the product during storage. Installing these systems involves further upfront costs and may require staff training to operate and maintain them. The high temperatures needed for PMB storage also increase wear and tear on equipment, potentially leading to more frequent repairs and inspections, which can disrupt production and increase operational expenses.

Beyond the financial implications, there are notable environmental challenges associated with storing PMB at high temperatures. The heating process can release volatile organic compounds (VOCs) and other pollutants, contributing to air quality issues and necessitating compliance with stringent environmental regulations. Companies may need to invest in emission control systems, further escalating costs. Additionally, the energy required for maintaining elevated storage temperatures can result in a higher carbon footprint, putting pressure on asphalt producers to adopt more sustainable practices as the industry shifts toward minimising environmental impacts.

Another concern is the risk of thermal degradation of PMB during prolonged storage, which can affect its performance characteristics and lead to inefficiencies in asphalt applications. This degradation runs the risk of compromising the quality of the final product and potentially resulting in wasted materials. Furthermore, the potential for leaks or spills poses risks of soil and groundwater contamination, necessitating robust containment strategies and emergency response measures. These multifaceted considerations highlight the importance of careful planning and investment in technology to balance the benefits of PMB with the associated costs and environmental responsibilities.

3.3 Relating PMB addition methods to BS EN standards (UK)

3.3.1 Wet (binder pre-blend) route: Producing a high-shear, pre-blended PMB creates a discrete binder product that can be tested and certified directly against the BS EN PMB requirements (see EN 14023 for PMB specification framework) using standard binder methods (penetration, softening point, DSR/G* and phase angle, elastic recovery, RTFOT/PAV aging). This makes conformity demonstration straightforward because the PMB itself is assessed against the published EN test methods before being used in asphalt.

3.3.2 Dry (direct) addition route: Unlike large multinational oil companies, MacRebur does not manufacture polymer modified bitumen (PMB) itself—instead, MacRebur supplies specialist polymer additives designed to be blended with standard bitumen by asphalt producers. As a result, MacRebur cannot issue a conventional PMB binder certificate for its additive products.

Where modifiers are dosed directly into the hot mix, compliance with BS EN PMB performance standards cannot be demonstrated simply by providing a binder certificate. Instead, binder properties must be recovered from the finished asphalt and tested in accordance with the relevant BS EN binder methods. The final asphalt mixtures should then be validated through the EN 12697 test series (such as wheel-tracking, stiffness modulus, fatigue, and moisture sensitivity). Consequently, project specifications must set out a clear test protocol and acceptance criteria, referencing the applicable EN methods, to demonstrate practical equivalence to a certified PMB binder.

Additionally, MacRebur polymers can be incorporated into bitumen in a laboratory with high shear mixing to produce a PMB. This laboratory-blended PMB can then be comprehensively tested for compliance with BS EN PMB standards, providing full verification of its physical and rheological properties for quality assurance and specification compliance.

3.4 Summary Wet v Dry mix recommendation

Polymer modification reliably improves pavement performance and extends service life. The wet (pre-blend) route produces the most controlled and predictable binder properties but typically requires high-shear blending and heated storage, which increases capital costs and can result in higher embodied environmental impacts compared with some dry-addition solutions. The dry route offers greater operational flexibility and lower upfront cost, but it depends on purpose-designed additives and strict process control to achieve consistent results. In all cases, project-specific laboratory testing, pilot plant trials and field monitoring are essential to validate performance, durability and cost-effectiveness.

It’s common to find little or no measurable difference in asphalt performance (wheel-tracking, stiffness, fatigue, moisture sensitivity) whether an additive was dosed dry at the plant or pre-blended into the binder, provided the same effective modifier content, adequate mixing/temperature, and comparable binder properties are achieved. When the product, dosage and processing produce the same binder-level behaviour and a homogeneous coating of the aggregates, the resulting mix structure and mechanical response will be very similar.

4.0 Key tests and standards

BS EN standards (notably EN 14023 for PMBs and the EN 12697 series for asphalt testing) define the test methods and performance criteria used across the industry to ensure repeatable, comparable characterisation of modified binders and mixes. Demonstrating compliance requires laboratory verification only against these EN methods and documented test evidence as part of procurement and quality assurance.

4.1 Typical binder tests used to characterise PMBs

These tests include penetration, softening point (Ring & Ball), Dynamic Shear Rheometer (G* and phase angle), elastic recovery, viscosity, and aging protocols (RTFOT/PAV). PMBs are commonly referenced against national and European specifications and standards (e.g., EN standards for PMB definitions and test methods).

4.2 Asphalt-level testing

Should include wheel-tracking (rutting), stiffness/modulus, fatigue testing, moisture sensitivity and compaction/workability trials to verify mix performance with the modified binder or additive with bitumen mix.

4.2.1 Assessment of Deformation Resistance in Asphalt: Standard Procedures and Considerations

In the UK, the primary method for assessing the deformation resistance of asphalt mixes is the wheel tracking test using a small device test. While alternative methods exist, they are not widely adopted outside specialised applications. These alternatives include the large device wheel tracking test and the Hamburg wheel tracking test, which is essentially a variation of the small device test conducted under water. Additionally, cyclic compression tests (both uniaxial and triaxial) are more suited for evaluating binder course layers rather than surface layers.

The standard wheel tracking test employs two distinct methodologies: Method A is designed for softer materials, such as hot rolled asphalt, while Method B is applicable to harder materials, including binder courses and stone mastic asphalt (SMA). It is crucial to keep the results from these two methods separate, as performance at one temperature does not necessarily predict performance at the other. Depending on anticipated traffic loads, tests are conducted at two temperatures: 45 degrees Celsius for moderately heavy traffic and 60 degrees Celsius for very heavy traffic.

Regardless of the method and temperature chosen, the test yields two fundamental results: the overall depth of rutting and the rate of rut progression following an initial “seating” period. The ultimate test outcomes are influenced by several factors, including the type and grading of aggregates, void content, and the grade or degree of modification of the binder used.

When evaluating the performance benefits of a modified binder, it is advisable to utilise lab-produced specimens rather than field samples (cores). Field samples can be inconsistent due to variations in laying methods and conditions, which can lead to significant differences in compaction levels among otherwise identical mixes.

Furthermore, the effectiveness of a modified binder cannot be accurately assessed based solely on the results from a single supplier’s mix. This limitation arises because the performance indicators reflect the unique combination of factors within that specific mix, and different combinations will yield varying results.

In conclusion, the wheel tracking test is inherently producer-specific. Each producer should carefully determine the degree of binder modification based on their specific needs and thorough evaluation of their materials.

4.3 Operational and quality-control considerations (both methods)

- Dosing accuracy: ensure mass- or volumetric-controlled dosing with calibration and traceability.
- Temperature control: both mixing and storing temperatures must be appropriate for modifier compatibility and to avoid degradation.
- Mixing time and shear: sufficient energy and time are needed to disperse modifiers; inadequate mixing reduces effectiveness.
- Binder and mix testing: perform binder tests (penetration, softening point, DSR, elastic recovery, viscosity) and mix tests (wheel-tracking, stiffness/modulus, fatigue, moisture sensitivity) to validate performance.
- Storage stability: for wet pre-blends check for phase separation over expected storage times; for dry additions check feedstock consistency and contamination levels.
- Health, safety and environmental: manage dust, handling of hot binders and potential emissions; document recycled feedstock provenance and compliance where required.
- ***In laboratory conditions, MacRebur products require an optimal mixing time of 60 minutes at temperatures between 175 °C and 180 °C, using high-shear speeds ranging from 6000 to 10,000 rpm.***
- ***MacRebur's MR products are specifically engineered for the dry addition method at asphalt plants, allowing their incorporation without any need to alter the standard mixing times or temperatures used in hot mix asphalt production.***

4.4 Practical implication

If formulation, dosing and production parameters are controlled so the modified binder in the final mixture is essentially the same, dry and wet routes can deliver indistinguishable pavement performance. Nonetheless, validation through binder recovery, EN-standard mix tests (EN 12697 series) and field trials is essential to demonstrate equivalence and to detect any longer-term differences (aging, storage stability, cracking propensity) that short-term lab tests may miss.

4.5 Binder analysis

The BS EN standards, particularly EN 14023 which governs polymer-modified bitumen (PMB) specifications, emphasise rigorous testing and verification of binder properties both before and after aging. However, they do not explicitly mandate that binder recovery from asphalt containing PMB must verify that the original PMB characteristics are fully preserved through the recovery process. Instead, the standards provide a framework of required properties like elastic recovery, softening point, viscosity, and cohesion that PMBs must meet.

4.5.1 Key points from EN 14023 and related standards include:

Essential PMB Properties (EN 14023): PMBs must meet strict criteria for penetration, softening point, and cohesion. [4][7].

Binder Recovery (EN 12697 series): The binder recovery methods (e.g., EN 12697-3 rotary evaporator) set out solvent extraction procedures for recovering binder from asphalt mixtures to test these physical properties. While these methods acknowledge challenges in recovering polymer-modified binders due to polymer interaction and compatibility with solvents, the standards themselves do not explicitly require verifying that the recovered binder perfectly retains all original PMB characteristics[8][9].

Practical Guidance: Laboratories and technical specifications often require that recovered binders from PMB mixtures be tested alongside base or original PMB samples to ensure representative results. However, this is a practical interpretation rather than a formal stipulation in the standards[10][9].

Performance-Related Specifications: EN 14023 prescribes minimum performance thresholds for PMB properties (elastic recovery, softening point, cohesion), which are used to affirm suitability for service conditions. Testing of recovered binder is critical to demonstrate compliance but the exact preservation of all original binder microstructure during recovery is not strictly enforced as a standard requirement but encouraged as best practice[4].

4.6 Considerations for Polymer-Modified Bitumen (PMB)

The standards acknowledge limited experience and possible issues when using these methods for PMBs. Solvents like dichloromethane may not fully recover some polymer networks.

- EN 12697-3 permits other solvents, provided that the recovered binder exhibits the same properties as that recovered using the reference solvent (dichloromethane)[4].
- The recovered binder is not always identical to the original binder, and this especially applies to PMBs, where polymer degradation, incompatibility, or incomplete extraction may occur[1][4].
- Laboratories must validate the use of alternative procedures or solvents for PMBs and document any observed changes.

4.6.1 Attention to "Minimum Change"

- Both EN 12697-3 and EN 13074 note the need for processes that do not significantly alter the properties of the recovered binder, to ensure accuracy in follow-up testing[5].
- The standard also states that for emulsions and cutbacks (and by extension, for some PMBs), special post-recovery conditioning may be needed (e.g., EN 13074-2 for stabilisation after recovery)[6].

4.7 Binder Recovery, Analysis, and BS EN 14023 Compliance

Binder recovery and analysis are critical for evaluating polymer modified bitumens (PMBs) under BS EN 14023:2010, which defines performance-based standards for these materials. Conformity testing involves recovering binder to determine binder content and assess properties like softening point and penetration. Common binder recovery methods include cold solvent extraction (EN 12697-1/3), distillation (EN 12697-4), and incineration (EN 12697-39). It is important to distinguish between methods aimed at quantifying binder content (EN 12697-1 and -39) and those purposed for recovering binder to test properties (EN 12697-3 and -4).

MacRebur polymer additives can pose challenges during binder recovery because their polymers, like many commonly used additives such as SBR and SBS, may be solvent-resistant. Traditional solvents sometimes fail to fully recover the binder, leading to underestimated binder content and property results unsuitable for conformity assessment. Enhanced recovery techniques—including the use of stronger solvents, extended reflux durations, or thermal recovery—can be applied; however, if these approaches do not yield recovered binder properties truly representative of the in-situ binder, their conformity test results are invalid.

To overcome these challenges, MacRebur recommends pre-mixing their polymer additives directly into the producer's base bitumen under controlled laboratory conditions. This produces a PMB that more accurately represents production materials. The pre-mixed binder can then be tested against BS EN 14023 performance criteria, allowing valid comparisons between unmodified bitumen and MacRebur-modified binders. This method ensures testing conditions closely simulate industrial production, resulting in stable, testable binders whose solvent resistance does not compromise conformity assessments. For binder content measurement, MacRebur advises the incineration method per EN 12697-39.

BS EN 14023 allows flexibility in binder recovery methods as long as the recovered binder remains representative and suitable for testing. Enhanced solvent or incineration recovery methods are valid only if the binder is complete and chemically unchanged after recovery. MacRebur's pre-mix approach aligns with these principles by maintaining test integrity and ensuring performance data accurately reflect the binder's in-situ condition and polymer interactions [8][9][10][11].

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5. Technical Comparisons

5.1 Overview of key metrics: Penetration, Softening Point, and Elastic Recovery of competitive 'off the shelf' PMB products

The data presented in this table summarises the key physical characteristics of competitor polymer modified binders (PMBs), including grade, penetration, softening point, viscosity, and recommended mixing and storage temperature ranges. These figures are drawn directly from published binder classification data and product datasheets made available online by the respective manufacturers, supplemented by results obtained through our own laboratory testing.

Product	Penetration (dmm)	Soft Pt (°C)	Viscosity (cPs @100°C)	Mixing Temp (°C)	Storage Temp (°C)
Shell Cariphalte TS	45–80	45	3372	140–185	150–165
Shell Ultra new	75–130	75	7582	140–185	150–165
Shell Cariphalte DM	65–105	75	23064	140–185	150–165
Shell Cariphalte HP	65–105	70	29562	140–185	150–165
Shell HD	10–40	80	13889	–	–
Nynas S89	65–95	45	7790	–	–
Nypol 77	65–105	50	5410	155–190	155–170
Nynas S83	75–130	75	19000	165–190	165–180
Nypol 103	75–105	75	50000	165–190	165–180
Nypol S89A	65–105	45	–	–	–

- Viscosities, where not available at 100°C, are typically provided at sequential higher temperatures for full blending and storage control.
- Nypol S89A is noted as highly flexible and includes adhesion agents, intended for use in highly stressed pavement layers, conforming to EN14023 and ISO 9001:2008.
- It is important to note that the values reported here represent results achieved from a single batch, tested on one specific day, and from one specific supply source. As such, they should be regarded as indicative rather than definitive. Variations in raw materials, production methods, ageing, and test conditions may lead to different results for other batches or production runs. Users should therefore refer to the most recent manufacturer data and conduct confirmatory testing where necessary before drawing performance comparisons or technical conclusions.

5.1.1 Elastic Recovery

Published elastic recovery data was found for Shell Cariphalte TS to be 45% and for Nypol 103 at +75%.

The BS EN 14023 specification explicitly mentions "Elastic Recovery" as a key performance criterion for polymer-modified bitumen (PMB). The standard requires PMBs, especially those modified with styrene-butadiene-styrene (SBS), to achieve a minimum elastic recovery *if specified*, assessed using EN 13398 test methods. This property measures the binder's ability to stretch and recover after deformation, which correlates to improved crack resistance and durability in pavement applications.

NB. Regarding TS2010 specifications; the minimum required elastic recovery result is understood to be +75%.

5.1.2 Environmental Credentials

- Nypol S89A and other Nynas binders reference compliance with CE marking, ISO 9001:2008 for quality, and the European EN14023 PMB product standard[1].
- No explicit lifecycle assessment, CO_2 footprint, or Environmental Product Declaration (EPD) values have been found for these PMBs, however the environmental advantage of PMBs generally includes longer pavement life, reduced maintenance, and potentially lower aggregate use, but explicit figures or sustainability certifications have not been found in our research.

Summary Table: PMB Comparison

Brand	Product Name	Pen (dmm)	Soft Pt (°C)	Representative Use	Quality/Env. Certs
Shell	Cariphalte TS	45–80	45	General, roads	–
Shell	Ultra	75–130	75	Durable road surf.	–
Nynas	S89	65–95	45	Wear layers	–
Nynas	S89A	65–105	45	Flexible surfacing	EN14023, ISO 9001:2008
Nynas	S83, Z4	75–130	75	High mod. asphalts	–
Nynas	Nypol 77, 103	65–105;75–105	50; 75	Structural, SMA	Some with CE marking

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5.2 Comparison of MR6, MR8, and MR13

5.2.1 The importance of Base Binders

It's important to note that MacRebur does not manufacture polymer modified bitumen (PMBs) or produce asphalt. Instead, MacRebur offers specialised additives that are designed to be either wet or dry mixed into standard bitumen and asphalt, by partnering asphalt producers. MacRebur's additives are incorporated into base binders to enhance performance and sustainability, making them suitable for a wide range of road construction applications without MacRebur acting as a PMB or asphalt supplier.

In the pursuit of optimal asphalt performance, it is crucial to understand that the base binder must undergo thorough assessment at a MacRebur laboratory before determining the appropriate dosage of any MacRebur product. This testing phase serves to tailor the additive application specifically to the client's asphalt design mix conditions and needs, thus ensuring the highest quality of the final asphalt product.

One of the key differentiators of MacRebur's offerings lies in their bespoke approach; the products are not 'one-size-fits-all' but are customised based on the specific bitumen grade that a client is able to procure. Different bitumen grades exhibit varying characteristics, and the quality of these grades can fluctuate significantly over time. Consequently, clients engaged with MacRebur are required to submit regular samples of their operational bitumen to our facility in Lockerbie. These samples are meticulously tested to assess their current quality and performance metrics. Following this analysis, the corresponding additive weights can be adjusted accordingly to maintain compatibility with the varying quality of the bitumen.

It is essential to note that the performance of a Polymer Modified Binder (PMB) can notably change over time. For instance, a PMB's quality on day one, particularly after being stored at elevated temperatures, may degrade markedly by day ten when compared to its initial certification. Such fluctuations necessitate an adaptable approach to the formulation of asphalt mixes, and this is where MacRebur's dry additive method proves advantageous. By allowing the additives to be incorporated directly in their dry form, MacRebur can ensure that the quality and grade of the modification remain consistently at their best, irrespective of the physical changes that may occur in the stored bitumen over time.

Ultimately, the ongoing testing and adjustment process not only optimises the final asphalt product but also enhances its performance characteristics, longevity, and durability, setting MacRebur apart from conventional pre-mixed PMB alternatives.

5.3 Technical Results: MR6 and MR13

MR8 is not included in the following table because it is not engineered to be a traditional modifier, but rather used as a direct replacement for a portion of the bitumen in asphalt mixes—achieving both cost savings and reduced CO_2 emissions. The table below presents an example of comparative results for MacRebur MR6 and MR13 when blended with a bitumen sourced from a UK asphalt manufacturer.

Brand	Product Name	Pen (dmm)	Soft Pt (°C)	Viscosity (cPs @100°C)	Mixing Temp (°C)	Storage Temp (°C)	Representative Use
MacRebur	MR6	75–105	75	39000	160–185	–	Durable road surface
MacRebur	MR13	75–105	75	35000	160–185	–	TS2010 Specifications

NB: All testing and results are in accordance with BS EN 1426, BS EN 12591, BS EN 14023, BS EN 13108-21, BS 594987, BS 594987-1, BS ISO 4920, and BS EN 13108, independently verified.

5.3.1 MR6 and MR13 Elastic Recovery

MR6: +50%
MR13: +75%

5.4 Environmental Credentials

- Carbon footprint assessment and Environmental Product Declaration (EPD) values are directly cited for both MacRebur MR6 and MR8.
- MR6 demonstrates a 3.77kg CO_2e saving per 1kg of product used. When used in asphalt at the average recommended 3kg per tonne of asphalt gives a saving of 11.32kg of CO_2e per tonne of asphalt produced.
- MR8 demonstrates a 1.55kg CO_2e saving per 1kg of product used. When used in asphalt at the average recommended 3kg dosage per tonne of asphalt gives a saving of 4.65kg of CO_2e per tonne of asphalt produced.
- MR13 EPDs and Carbon footprint analysis is still to be published.
- All carbon data is verified to ISO 14064-3.

5.4.1 Alignment with UK and Scottish Net Zero Commitments

The UK Government has committed to achieving net zero greenhouse gas emissions by 2050, with Scotland adopting an even more ambitious target of 2045. MacRebur supports these goals by enabling substantial carbon reductions in road construction through the use of recycled plastic waste, reducing reliance on virgin bitumen and lowering lifecycle emissions in asphalt pavements.

MacRebur’s additives contribute to decarbonisation by reducing the need for new raw materials, lowering embodied carbon in asphalt mixes, and enabling lower temperature manufacturing processes such as Warm Mix Asphalt (WMA), which reduces energy consumption and related CO_2 emissions.

5.4.2 Circular Economy Contributions

Using recycled waste plastics destined for landfill or incineration to make MacRebur additives supports the UK and Scottish circular economy strategies. This helps divert significant volumes of plastic from waste streams into long-life infrastructure applications, creating a local-waste-for-local-roads ethos aligned with governmental waste management policies.
MacRebur aligns with Scotland’s Zero Waste Plan aiming to reduce landfill waste to 5% by 2025 and the UK Environment Bill which incentivises circular resource use and extended producer responsibility initiatives.

5.4.3 Support for Green Public Procurement Policies

Through third-party certifications (such as ISO quality standards and Environmental Product Declarations), adherence to BS EN product and testing standards, and ongoing product lifecycle assessments, MacRebur provides transparency and verification crucial for green procurement. This should facilitate inclusion in public sector contracts that mandate sustainability criteria and low-carbon materials.

MacRebur's modular and flexible additive solutions support infrastructure resilience and durability, helping asset owners meet government mandates for sustainable infrastructure growth and climate adaptation programs.

5.4.4 Relevant Government Strategies Referenced

- UK Net Zero Strategy and Clean Growth Strategy
- Scotland's Climate Change (Emissions Reduction Targets) (Scotland) Act 2019
- The UK Environment Bill (Circular Economy and Waste Reduction)
- The Scottish Zero Waste Plan and associated circular economy goals
- Department for Transport's ambitions on sustainable roads and low-carbon infrastructure
- ADEPT Smart Places Live Labs program, to which MacRebur contributed research and practical trials demonstrating their product benefits.

MacRebur's products and practices are fully aligned with national and devolved government policies promoting carbon neutrality, sustainable resource use, and innovative circular economy models. This alignment offers strong grounds for favourable public sector reception and supports delivery of net zero objectives through greener road construction solutions.

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5.5 Quality Credentials

MacRebur products are produced under an ISO 9001:2015 accredited system for quality and meet the EN14023 PMB product standard.

MacRebur's ongoing quality control process is rigorous and comprehensive to ensure consistent product performance, compliance with environmental standards, and full traceability. This includes establishing dedicated bitumen and polymer laboratories, ongoing testing of customer bitumen, polymer consistency monitoring, and dosing adjustments — all culminating in Scottish Environmental Protection Agency (SEPA) quality and environmental approvals and licensing.

5.5.1 Dedicated Laboratories: MacRebur operates in-house specialised laboratories equipped for testing bitumen and polymer materials to evaluate compatibility, rheological properties, and performance parameters. This allows tailoring product formulations to customer-specific bitumen grades and quality fluctuations to maintain optimal additive interaction and consistent asphalt mix behaviour.

5.5.2 Ongoing Testing of Customer Bitumen: Regular sampling and detailed testing of customer bitumen batches are conducted to monitor physical and chemical characteristics. This data drives necessary dosing adjustments of the polymer additive to compensate for variability in base binder quality, ensuring reliable mix performance throughout the supply chain.

5.5.3 Polymer Consistency Control: MacRebur implements strict controls on polymer feedstock, including screening for contaminants and consistency in recycled plastic polymers used in additives. The recycled polymer sources are continuously assessed by internal and external laboratories to maintain standardisation and quality of the polymeric modifiers.

5.5.4 Dosing Adjustments: Based on laboratory analyses, mixing protocols, and plant trials, polymer dosing rates are calibrated to achieve full homogenisation and dispersion within the bitumen, confirmed by binder analysis tests. Adjustments are made as required to compensate for bitumen variation or process condition changes.

5.5.5 Traceability and Documentation: Robust record keeping ensures complete traceability of polymer additives from raw material sourcing through production batches and delivery to customers. This supports compliance with SEPA requirements and facilitates environmental auditing and certification processes.

5.5.6 SEPA Licensing and End of Waste: MacRebur's facility in Lockerbie is operated in line with the regulations set out by the Scottish Government and Regulated by the Scottish Environment Protection Agency (SEPA). The facility is operated and regulated under, what is known in Scotland as, Waste Management Exemptions. MacRebur follows a clear procedure for reception, testing, treatment and dispatch of products that was agreed with the SEPA and follows an ISO 9001 accredited quality procedure. These combined systems mean that MacRebur products meet the End-of-Waste Test.

5.5.7 Long-term Product Consistency: The combination of continual quality testing, batch control, customer feedback, and ongoing research ensures that MacRebur products maintain consistent quality and performance across production campaigns. Adjustments for evolving polymer feedstocks or bitumen supplies enable durability and reliability essential for long-life asphalt infrastructures.

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6.0 Comparative analysis

Both MR6 and MR13 not only meet but can exceed key performance and environmental criteria defined in BS EN 14023 and TS 2010 specifications. Their use offers a cost-effective and sustainable alternative to conventional PMBs, helping asphalt producers achieve or surpass performance targets while supporting environmental objectives consistent with modern UK and Scottish road construction practices.

6.1 Comparative technical analysis

MacRebur's MR6 and MR13 polymer additives demonstrate competitive performance characteristics when compared with established PMBs such as Shell's Cariphalte TS, Nynas' Nypol 103, and Total's Extreme. Both MR6 and MR13 are engineered to conform to the BS EN 14023 standards for polymer-modified bitumen (PMB). MR13 meets or exceeds requirements, including elastic recovery (+75%), provided by the TS2010 specifications. These standards define key parameters such as penetration (typically 75–105 dmm for MR6/MR13) and softening point (minimum 75°C), with MR6 exhibiting a viscosity of 39,000 cPs and MR13 an elevated viscosity of 35,000 cPs at 100°C, indicative of robust high-temperature deformation resistance.

From a performance standpoint, MR6 and MR13 offer deformation resistance and elasticity on par with Cariphalte TS and Total Extreme PMBs while MR13 targets the stringent TS2010 surface course requirements, stressing critical properties such as elastic recovery (minimum 75%) and fatigue resistance—attributes that are essential for pavement durability in Scotland's climate. Like Nypol 103 and Total Extreme which serve premium applications with viscosities up to 50,000 cPs and softening points around 75°C, MR13 complements the needs of high-load, high-durability scenarios with enhanced polymer-modified binder properties.

6.2 Comparative environmental analysis

Environmentally, MacRebur's additives stand out above the rest by reducing carbon footprints through the incorporation of 100% recycled waste poylymers, with lifecycle assessments showing MR6 reducing CO_2 emissions by approximately 11.32 $kgCO_2e$ per tonne of asphalt. In contrast, while the traditional PMBs such as Cariphalte TS and Nypol 103 do not explicitly include recycling in their supply chain, they comply with environmental regulations under BS EN and TS2010, focusing on long-term pavement life which indirectly reduces emissions via maintenance reduction. Certification to ISO 14064-3 for carbon data verification further underscores MacRebur's commitment to sustainability, alongside MacRebur products being produced under an ISO 9001:2015 accredited system for quality.

Although not competing with PMB's, MR8 saves 4.65 kgCO_2e per tonne of asphalt produced.

6.3 Comparative Cost Analysis

Although the bitumen price varies from month to month, for this analysis the assumed cost of standard bitumen is £450 per 1,000 kg (£0.45 / kg), while the cost of polymer-modified bitumen (PMB) is £650 per 1,000 kg (£0.65 / kg). The cost difference between PMB and standard bitumen is therefore £200 per tonne. It is assumed that this additional £200 accounts for the use of approximately 3 kg of polymer required to modify the base bitumen and produce a typical off-the-shelf PMB.

In the example design mix, 50 kg of PMB is incorporated into 1,000 kg of asphalt. To align with this example, 3 kg of MR6 polymer replaces 3 kg of bitumen within the 50 kg binder portion.

The assumed SBS polymer content in a conventional PMB is 3 kg per 1,000 kg of asphalt (i.e., for a mix containing 50 kg PMB). At a polymer cost of £67 / kg, the equivalent price per tonne of polymer is £66,667.

6.3.1 Standard Bitumen vs. Off-the-Shelf PMB

Standard Bitumen:
50 kg × £0.45 / kg = £22.50 per 1,000 kg asphalt mix.

Off-the-Shelf PMB:
50 kg × £0.65 / kg = £32.50 per 1,000 kg asphalt mix.

Thus, replacing standard bitumen with PMB increases binder cost by £10 per 1,000 kg of asphalt.

6.3.2 MR8 Cost Comparison

On average MR8 is charged at 20% less than a standard suppliers bitumen costs. If 1000kg bitumen costs £450 in this example, 1000kg MR8 costs £360.

6.3.3 MR6 Cost Comparison

MR6 polymer has a retail price of £1,500 per 1,000 kg (£1.55 / kg).
To produce an MR6-modified asphalt, 3 kg of MR6 replaces 3 kg of bitumen:

- 47 kg bitumen × £0.45 = £21.15
- 3 kg MR6 × £1.55 = £4.65

- Total binder cost: £25.80 per 1,000 kg asphalt.

Therefore, an MR6-modified asphalt costs approximately £6.70 less per asphalt tonne than one made with a standard off-the-shelf PMB (£32.50 – £25.80 = £6.70 difference).

6.3.4 MR13 Cost Comparison
MR13 polymer has a retail price of £3,000 per 1,000 kg (£3.00 / kg).
Following the same approach:

- 47 kg bitumen × £0.45 = £21.15
- 3 kg MR13 × £3.00 = £9.00
- Total binder cost: £30.15 per 1,000 kg asphalt.

This is slightly lower than the £32.50 cost for an off-the-shelf PMB. It is also worth noting that PMBs designed to meet stricter standards such as TS 2010 (e.g., Nypol 103, Total Extreme) can cost £50 – £100 more per tonne than conventional PMBs.

6.4 Performance Validation and Field Data example
Lowther Street in Carlisle is a benchmark example of a successful, high-profile public sector contract showcasing MacRebur product performance. This project demonstrates quantifiable improvements in pavement durability and maintenance cycles, delivering evidence for decision makers on both cost-effectiveness and suitability for heavy urban traffic.

6.4.1 Pavement Design and Traffic Context
Located in Carlisle's city centre, Lowther Street serves as a principal shopping area and bus route, with projected traffic loads of roughly 20 million standard axles over its 40-year design life.

The construction used a flexible composite pavement comprising Pavement Quality Concrete overlain with 100–200 mm of bituminous material. The resurfacing adopted a design with a 60 mm binder course and 40 mm surface course, incorporating MacRebur's MR6 Additive in selected sections.

6.4.2 Installation and Early Performance
The installation (July 2020) alternated MR6 mixes with standard Tufflex D and AC20 materials, monitored closely via in situ compaction, density, texture depth, and profile testing.

Laying conditions included challenges such as cool temperatures, brief rainfall events, and some delays due to mixing issues, but the construction proceeded with standard operational controls and record-keeping.

6.4.3 Maintenance and Durability Improvements
Extracted pavement cores indicated uniformly good condition before intervention. Post-installation, laboratory and site tests showed that the inclusion of MR6 consistently

increased pavement penetration and softening point in binder and surface courses, compared to conventional mixes.

The increased penetration and softening point of the binder is correlated with superior load-spreading properties, reduced rutting potential, and longer intervals between required maintenance actions, especially in heavily stressed urban environments. Cores and controls demonstrated comparable air voids and density, suggesting no negative impact on pavement workability or compaction.

6.4.4 Safety and Service Performance

Higher mixture stiffness and deformation resistance improves surface tolerance to heavy vehicles, bus traffic, and turning movements, indirectly enhancing long-term surface safety and minimising early-life defects that could present hazards to users. No deleterious effects (such as cracking or excessive surface irregularity) were reported through post-laying monitoring, and all installed materials met surface texture and profile targets.

6.4.5 Cost Implications and Circular Economy Impact

While no direct, site-specific cost savings were passed onto Cumbria County Council by the contractor responsible for the Lowther Street work, CCC modelling indicates that diverting plastics into asphalt can deliver substantial annual savings. Each tonne of asphalt incorporating plastics avoids landfill disposal costs (£96.70/tonne at 2021 UK rates), contributes to national savings upwards of £7.95M per year, and supports climate objectives via reduced carbon footprint.
The project exemplifies scalable adoption, supporting the local circular economy and demonstrating environmental responsibility in line with modern infrastructure priorities.

Lowther Street offers persuasive, high-traffic evidence that MacRebur products deliver significant durability improvements, support longer maintenance cycles, and fit seamlessly into conventional asphalt operations—all while advancing sustainability and cost reduction goals for public clients.

6.5 The Cumbria Live Labs report

Despite the positive results seen on Lowther Street in Carlisle, the Cumbria Live Labs report is critically flawed in its approach to binder testing. It fails to provide any evidence that the base bitumen was rigorously tested to determine its specific penetration grade prior to the addition of MacRebur's MR additives, rendering its evaluation methods fundamentally inadequate. Without this necessary baseline, the study offers no fair or controlled comparison against the base bitumen used for producing PMB with SBS polymer, and does not establish any robust equivalence with commercial 'off-the-shelf' PMB products.

This absence of scientific rigour completely undermines the validity of its performance benchmarking between base bitumen plus MacRebur's MR additives and finished PMB mixes. Furthermore, the report's methodology for plastic additive incorporation and subsequent testing is so poorly executed that it raises grave concerns about the integrity and reliability of all reported findings[1].

6.5.1 Specific Report Findings on Base Binder & Additives

- The report states that "The base bitumen was either a 100/150 or 50/70 pen grade. This was then modified by the addition of either 4%, 6% or 8% by mass of bitumen of the MacRebur additives"[1].
  When high shearing MR6 into bitumen, it is essential to specify the penetration grade of the base binder so that a precise additive percentage can be used for targeted performance.
- No evidence is present of systematic, pre-additive testing on the base binder, nor on a structured comparison with the SBS PMB product. There is no confirmation that the comparison PMB product specifications are known to the writer of the Live Labs report[1].
- The report outlines: "The base bitumen was heated to 170°C and the appropriate mass of waste plastic added to a laboratory high shear mixer for 30 seconds (i.e. a small-scale wet process)"[1].
  Scientifically, 30 seconds of mixing in a laboratory is not sufficient for meaningful polymer modification; MacRebur products and other PMBs typically require at least 1 hour of high shear mixing to ensure proper polymer integration and binder modification, as is industry standard for SBS PMBs.

6.5.2 Additional Shortcomings in the reporting

- There is no evidence that outcomes were defined or base binder tested prior to additive incorporation; the process appears unsystematic, with arbitrary MR6 percentages added without clear targets or defined outcomes set.
- The lack of base binder testing and arbitrary percentage addition weakens the methodological soundness, making the findings unreliable for comparison or practical application.
- Significant inconsistencies can arise in field samples due to variations in laying methods, compaction, and site conditions, all of which are acknowledged in the report and are known to produce divergent results for otherwise identical mixes[1].
- Testing one supplier's mix (with its unique constituent aggregates, binder, and additives) cannot establish the general effectiveness of a modified binder; performance indicators are too context-dependent for meaningful, generalised conclusions[1].
- Several additional shortcomings are evident within the Cumbria Live Labs report, beyond the failure to test the base bitumen prior to modification. These issues further erode the scientific reliability and generalizability of the conclusions presented:
- Lack of an update or controlled long-term field performance data: The report's case studies provide only brief, visual condition assessments after limited service periods, with no comprehensive, long-term performance data, nor systematic monitoring to assess durability or in-service effects. The absence of baseline

pavement condition data makes it impossible to attribute observed defects to material choice or modification method[1].

- Sample preparation inconsistencies: Laboratory and field sample compaction methods vary (e.g., roller compactor, Marshall hammer, in-situ pavement cores), introducing significant variability in measured performance properties such as stiffness and fatigue life. This undermines the ability to make consistent comparisons between different mixtures, additives, or suppliers[1].
- Absence of standardised testing protocols: The report does not employ standardised or repeatable testing protocols for plastic-modified binders or comparison PMBs, nor does it adequately document specimen preparation, compaction, or testing temperatures. These procedural gaps lead to unreliable and non-replicable results[1].
- Single supplier and mix bias: All trial results reflect only one supplier's materials and mix designs, meaning the findings cannot be extrapolated to other products, formulations, or industry practices. The report itself acknowledges this limitation yet draws broad conclusions regardless[1].
- Inadequate consideration of binder compatibility and dispersion: The report admits that thorough assessment of plastic dispersion, digestion, and compatibility with bitumen was not performed, yet these are critical for understanding binder performance and longevity[1].
- Problematic mixing times: Plastic additives are mixed for extremely short periods (30 seconds), a procedure that is universally recognised as insufficient for proper binder modification, risking incomplete polymer integration and inconsistent results[1].

These cumulatively severe methodological weaknesses reinforce the conclusion that the report does not provide a reliable, robust, or transferable scientific basis for evaluating plastic additives in bitumen or for standardising PMB performance comparisons in UK highways engineering.

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6.6 Implications & Recommendation

Given these significant shortcomings, particularly the insufficient mixing process, lack of base binder property assessment, and arbitrary additive percentages, the scientific basis of the Live Labs report's results is fundamentally flawed. The comparison between off-the-shelf PMB products and MacRebur's additives used to modify binders is neither fair nor repeatable. Findings based on such methodology should be withdrawn as they do not meet accepted standards for robust bitumen modification and mix performance assessment[1].

7.0 Recyclability and MR Products in RAP

Recycled Asphalt Pavement (RAP) can be effectively integrated with MacRebur's MR products to enhance both the sustainability and performance of recycled asphalt mixes. MR8 is particularly suited for rejuvenating RAP due to its binder-extending qualities, restoring the flexibility and durability typically lost during asphalt aging.

MacRebur MR6 and MR8 are dry-mixed into RAP blends to replace a portion of the virgin bitumen, enabling full reuse of existing asphalt with improved rheological properties.

MR8 acts as both an extender and rejuvenator for RAP, re-establishing workability, cohesion, and flexibility that deteriorate in aged binder. Case studies and trials (e.g., Ford Road, Taradale, and Coventry City Council projects) confirm that MR8 has been successfully used with RAP to produce durable, environmentally preferable road surfaces capable of high recycled content ratios while reducing overall fossil binder demand.

The use of Polymer Modified Asphalt (PMA)—as with MacRebur's technology—does not hinder future recyclability. The asphalt remains fully recyclable in following milling or reclamation cycles, as MR products melt and blend with bituminous binder under standard plant conditions.

7.1 Expelling the myth on microplastics Release: Scientific Findings

Repeated independent laboratory studies and performance monitoring have shown that MacRebur products do not leach plastic, nor do they generate microplastics or toxic fumes during manufacture, placement, or road use.

Research from Cumbria County Council and DEFRA, as well as broader national investigations, establishes that microplastics found in road environments primarily originate from tyre abrasion, not from modified asphalt binders (PMBs) or recycled plastic additives. These studies maintain that plastics chemically bound within asphalt matrices do not break free under standard traffic, weathering, or thermal cycles.

Wear particles and road-associated microplastics are overwhelmingly traced to synthetic rubber from tyres, as documented in studies such as "Using waste plastics in road construction" (Sasidharan et al., 2019) and published literature in ScienceDirect and TRB sources.

7.2 End-of-Life Environmental Impact

At end-of-life, asphalt incorporating MacRebur products is milled and returned into the RAP stream, fully recyclable as new surfacing material, with no release of intact plastics or hazardous byproducts.

The environmental impact is positive: MacRebur-enhanced RAP reduces landfill and incineration rates for non-recyclable plastics, lowers embodied carbon for new works, and contributes to circular economy goals in infrastructure.

There is no evidence of increased microplastic or pollutant release from MacRebur's recycled plastic binder modification at end-of-life; instead, the recycling process continues in closed-loop fashion, with used pavement being incorporated in new construction.

MacRebur MR products—including MR8—offer proven compatibility and performance benefits for recycled asphalt blends, enable high degrees of recyclability, and avoid the environmental risks associated with microplastics, which scientific research has traced almost exclusively to tyre wear—not modified bitumen or recycled binder technologies.

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8.0 Market Positioning

The polymer-modified bitumen (PMB) market in the UK is experiencing strong growth, driven by increased infrastructure investment, urbanisation, and emphasis on sustainable and durable road construction materials. The market size is projected to exceed $12 billion in 2025 globally, with a robust compound annual growth rate (CAGR) of approximately 6% in recent years, reflecting intensified demand for enhanced road durability, flexibility, and environmental performance.

Major established players in the market include Shell, Nynas, Total, and other global bitumen producers offering advanced PMB products such as Cariphalte TS, Nypol 103, and Total Extreme. These products are benchmarked not only on performance but also increasingly on their environmental footprint, quality certifications, and compliance with stringent standards like BS EN 14023 and Scotland's TS2010.

MacRebur's MR6 and MR13 positioned as innovative recycled polymer additive solutions in the PMB space offer a competitive differentiation based on sustainability credentials, cost effectiveness, and compliance with existing standards. Unlike traditional PMBs, MacRebur's products incorporate 100% recycled plastics, yielding a notable reduction in CO_2 emissions per tonne of asphalt, which resonates with growing environmental regulations and green procurement policies. Their additives align with all relevant BS EN and TS2010 requirements, offering both performance parity and a strong environmental advantage in a market with rising demand for eco-friendly infrastructure materials.

8.1 Opportunities for Market Growth and Product Expansion

The UK PMB market's upward trajectory is supported by several key drivers that create opportunities for expansion. Increasing urbanisation, road network expansions, and government-funded infrastructure projects foster demand for high-performance pavements requiring durable, flexible, and long-lasting materials. The shift towards sustainable construction practices and carbon reduction targets opens substantial opportunities for recycled additives like MacRebur's MR6 MR8 and MR13, which uniquely combine enhanced durability with significantly lower environmental impact. Product expansion potential exists in several areas including specialised additives tailored for extreme climates, warm mix asphalt technologies for energy savings, and the integration of smart materials for self-healing and monitoring capabilities. Growing public-sector emphasis on road safety, noise reduction, and skid resistance per TS2010 also encourages development of bespoke PMB formulations that meet these multi-functional performance goals. Additionally, leveraging circular economy trends by increasing recycled content in PMBs can further drive demand while aligning with national and international sustainability mandates, positioning MacRebur's offerings well for future growth within public and private sector asphalt projects.

MacRebur's MR8 product provides a unique opportunity for market growth by serving as a part-bitumen replacement focused on cost reduction and environmental impact mitigation where full polymer-modified bitumen (PMB) characteristics are not required. MR8's ability to replace up to 10% of traditional bitumen with recycled waste plastics offers asphalt producers a sustainable and economical additive compatible with a wide range of asphalt mixes. This versatility opens new market segments such as local roads, car parks, and base layers that do not necessarily require high-performance PMBs but benefit from reduced carbon footprint and lower production costs. The strong environmental credentials of MR8, with independently verified CO_2 savings and integration into circular economy principles, align well with increasing regulatory pressures and public demand for greener infrastructure solutions across the UK and internationally. These factors underpin MacRebur's growth potential through partnerships with major asphalt producers, expanded manufacturing footprint, and responsiveness to evolving sustainability standards in road construction projects

In summary, the UK PMB marketplace remains competitive with leading global suppliers, but the convergence of environmental imperatives and advanced polymer technology creates a distinctive competitive opening for MacRebur's recycled polymer additives to expand presence and drive sustainable innovation in asphalt manufacture and application.

9.0 An understanding of the British Roads standards

It is our understanding that there is nothing within the relevant British Standards that would inherently prevent MacRebur from selling recycled plastic additives to asphalt producers, provided that the final asphalt product incorporating these additives fully meets all applicable asphalt standards such as BS EN 13108 and related specifications. The standards categorise these products as additives, which are intended to be incorporated by asphalt manufacturers into their mixtures rather than used as standalone materials.

Ultimately, it is the responsibility of the asphalt producers to ensure that asphalt mixtures containing any additives comply with all performance, safety, and legal requirements. Therefore, as long as the final asphalt product meets the standards for use in road construction, MacRebur's recycled additives are acceptable for sale and use, without restriction from the standards themselves. This approach maintains industry product integrity while allowing innovation and sustainability improvements through additives like those offered by MacRebur.

10.0 Conclusion

MacRebur's MR6, MR8, and MR13 products offer compelling benefits when compared to most conventional "off the shelf" polymer modified bitumens (PMBs). These benefits include strong performance characteristics aligned with BS EN 14023 and Scotland's TS2010 criteria, combined with significant environmental advantages due to their 100% recycled polymer content. MR6 and MR13 provide enhanced penetration and softening points, elastic recovery, deformation resistance, and fatigue life comparable to many traditional PMBs while reducing carbon emissions through partial replacement of bitumen and full replacement of virgin polymers. MR8 serves as a cost-effective and sustainable bitumen extender, reducing overall binder consumption and lowering CO_2 footprint in asphalt mixes where full PMB properties are not required.

It is important to emphasise that the responsibility for ensuring compliance with relevant standards lies with the asphalt material producers. It is their prerogative to decide whether to incorporate approved additives such as MacRebur's into proprietary asphalt mixtures, for which they bear ultimate liability. This approach respects the proprietary nature of many asphalt formulations while encouraging innovation and sustainability.

In line with competition laws and fair market practices, MacRebur respectfully requests that it is not impeded from collaborating with asphalt producers across the UK. We also encourage local authorities and stakeholders to consider the findings of this report and recognise the benefits of specifying specialist sustainable polymers like MacRebur's additives in future asphalt designs. Doing so will support the advancement of more durable, cost-efficient, and environmentally responsible road infrastructure across the country.

11.0 Statements made by UK transport authorities

Martin McLaughlin CEng MICE
TRANS : Roads Delivery - Strategic Asset Management
"Additives, by definition, are not used in isolation and therefore need to be incorporated into the design of the asphalt mixture itself. This responsibility lies with asphalt material producers, and it is for them to decide whether to include any such approved additives within their asphalt mixtures, for which they carry ultimate liability, bearing in mind that many of these mixtures are proprietary products in themselves. It would be anti competitive for Transport Scotland to mandate the use of any proprietary constituents."

Gordon Rolfe
Local Transport Policy & Funding Division
Department for Transport
"Local highway authorities have a duty under Section 41 of the Highways Act 1980 to maintain the highways network in their area. Whilst the Government does not typically intervene in these matters, the Department for Transport encourages local highway authorities to be innovative; in using different materials, new machinery, or new ways of working. However, I hope you will understand it is not for Government to endorse any specific commercial product such as the sustainable polymer additives your company has developed."

Andy Brown
Senior Manager - Highways Assets and Strategy at Cumbria County Council
"All asphalt made using MacRebur's additives has met standards in line with BS594987. Cumbria County Council will move towards further use of waste plastics as a part bitumen replacement in future road surfacing schemes throughout Cumbria".

British Board of Agreement (BBA)
Sean Downey
Head of Technical Services
"As the certification body issuing the HAPAS Certificates, the BBA reviewed information pertaining to a successful set of site installation trials, complemented by independent testing of the product containing the MR6 additive, which provides robust evidence to satisfy the requirement for a "demonstrable history of satisfactory use in asphalt." These trials offer practical, real-world validation of the material's performance over time and under varied conditions, while independent testing ensures objectivity and technical

rigor. Together, they constitute both research-based evidence and satisfactory practical use, as required by sections 4.1 and 4.5 of BS EN13108-5:2006.
This has been complemented by our audit process, where we have established that the product has been installed on several strategic road network projects, exceeding 10,000 tonnes, over at least the past five years and that the product has not been subject to technical complaints or concerns about performance in use.
We confirm that Certificate 24/H7175 was issued following a favourable assessment of performance through laboratory testing and site trials (SIPT) of the Armaflex product which included MR6.
Based on the evidence available to us at this time, we retain the view that the product as certified is fit for purpose and meets the requirements of Clause 942."

12. Appendices

References to BS EN Standards and Environmental Regulations

- **BS EN 12697-22**: "Bituminous mixtures - Test methods for hot mix asphalt - Part 22: Wheel tracking test". This standard specifies the requirements for conducting wheel tracking tests to assess deformation resistance.

- **BS EN 13108-1**: "Bituminous mixtures - Material specifications - Part 1: Asphalt concrete". This standard ensures that the materials used in asphalt mixes meet specified performance criteria.

- **Environmental Regulation Reference**:
  - The Environment Agency (UK) regulations concerning the use and recycling of bitumen and polymers in pavement construction, ensuring compliance with sustainable practices.

  - **Waste Management Regulations** (e.g., Waste Framework Directive - 2008/98/EC): Outlines the management of waste materials, ensuring that the production and use of materials like polymer-modified bitumen are sustainable.

BS EN 13108 Series: The BS EN 13108 series covers specifications for bituminous mixtures. Specific parts relevant to PMBs and additives include:

BS EN 13108-1: "Bituminous mixtures - Material specifications - Part 1: Asphalt concrete."
- This standard outlines requirements for the materials and mixtures used in asphalt applications, including the potential use of modified binders.

BS EN 13108-3: "Bituminous mixtures - Material specifications - Part 3: Dense asphalt concrete."
- This standard specifies the requirements for dense asphalt concrete, which may include modified binders and specific additives to enhance performance.

BS EN 13108-4: "Bituminous mixtures - Material specifications - Part 4: Hot rolled asphalt."

- This section details specifications for hot rolled asphalt, including provisions for optional additives and modifications for performance improvement.

BS EN 14023: "Bitumen and bituminous binders - Specification for polymer-modified bitBitumen (PMB)."
- This standard specifies the requirements for polymer-modified bitumen, including the characteristics that need to be met for different types of modifiers and the quality control measures for PMBs.

BS EN 13108-5: "Bituminous mixtures - Material specifications - Part 5: Stone mastic asphalt."
- This part covers stone mastic asphalt (SMA), which often includes polymer modifications and additives to improve durability and performance, particularly in high-stress environments.

BS EN 15322: "Bitumen and bituminous binders - Test methods for the determination of the physical properties of polymer-modified bitumen."
- This standard outlines test methods specifically designed to evaluate the physical properties of PMBs, including aspects like viscoelasticity, which are critical for performance evaluation.

BS EN 12697 Series: "Bituminous mixtures - Test methods for hot mix asphalt."
- This series includes various testing methodologies that can evaluate the performance of asphalt mixes containing PMBs and additives, such as wheel tracking and static and dynamic modulus tests.

BS EN 14025: "Bitumen and bituminous binders - Quality control for polymer-modified bitumen."
- This standard provides guidance on quality control measures specific to PMB production, ensuring that the performance characteristics are consistently met.

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