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(IJIREV)**www.gaexcellence.com/ijirev**INDUSTRY PERCEPTIONS OF THE TECHNICAL
PERFORMANCE AND ENVIRONMENTAL BENEFITS OF
RUBBER-MODIFIED ASPHALT FOR SUSTAINABLE
ROAD CONSTRUCTION IN MALAYSIA**

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Abstract:

The rapid accumulation of end-of-life tires (ELTs) coupled with the increasing demand for sustainable road infrastructure, has intensified research efforts into alternative pavement materials. Rubber-modified asphalt (RMA) has emerged as a promising solution, offering a dual-benefit approach by enhancing pavement performance while simultaneously addressing the environmental challenges associated with waste tire disposal. This study evaluates industry stakeholders' perceptions regarding the technical performance and environmental benefits of integrating waste rubber into asphalt matrices for sustainable

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road and highway engineering. A quantitative survey was administered to 50 key industry professionals comprising contractors, site engineers, technical consultants, and representatives from municipal authorities in Kulim, Kedah, Malaysia. Data were analyzed using IBM SPSS through descriptive statistics and reliability analyses. The findings showed strong stakeholder support for adopting rubber-modified asphalt (RMA), particularly for pavement longevity and durability (mean = 4.04), structural load performance (mean = 4.00), and traffic load adaptability (mean = 3.99). From an environmental perspective, the utilization of waste tires was perceived as the most significant benefit (mean = 3.95), followed by reductions in embodied greenhouse gas emissions (mean = 3.94) and the conservation of natural resources (mean = 3.94). In contrast, RMA received comparatively lower agreement for noise-reduction capability (mean = 3.14). Overall, the results indicate broad industry acceptance of RMA and underscore its potential as a sustainable pavement material that enhances roadway performance while supporting environmentally responsible waste management practices.

Keyword:

Circular Economy, End-Of-Life Tires (ELTS), Rubber-Modified Asphalt (RMA), Stakeholder Perceptions, Sustainable Pavement Engineering



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Introduction

The rapid development of global transportation systems has increased the need for durable, high-performing pavement materials that are capable to withstand heavy traffic and challenging environmental conditions (Al-Sabaei et al., 2021). However, Mashaan et al. (2021) noted that traditional asphalt pavements, which utilize non-renewable petroleum-based binders, are susceptible to structural problems such as rutting, fatigue cracking, and moisture-related damage that negatively affect long-term performance and maintenance efficiency. Simultaneously, end-of-life tire (ELT) management has become an important issue due to the large number of ELTs generated annually and the non-biodegradability of vulcanized rubber (Caputo et al., 2023).

In addition, inappropriate disposal practices, such as landfilling and unauthorized dumping, contribute to environmental degradation, consume valuable land, and create public health and safety concerns (Soprych et al., 2023). In response to these problems, attention has been directed towards circular economy practices that encourage the valorization of post-consumer waste materials in transportation infrastructure systems (Anand & Raj, 2024).

Among the most viable alternatives is the incorporation of recycled crumb rubber into asphalt mixtures, known as rubber-modified asphalt (RMA) (Soprych et al., 2023). RMA is created by blending crumb rubber modifier (CRM), produced from scrap tires, into asphalt binders or mixtures. This RMA strategy provides two benefits. First, CRM enhances the rheological properties of asphalt. Second, it provides a viable and large-scale recycling option for waste tire utilization (Caputo et al., 2023; Blab, R et al., 2024; Sierra-Carrillo de Albornoz FJ, Moreno-Navarro F et al., 2022). Empirical evidence shows that adding crumb rubber to asphalt binders improves elasticity and fracture resistance against cracking, reduces temperature sensitivity, and increases long-term structural durability (Gao et al., 2022). Furthermore, enhanced elasticity and fracture resistance allow pavement structures to better resist traffic-induced stresses and varying environmental conditions, thus increasing their service life. Additionally, using waste tires in asphalt applications fits well within circular economy principles by converting a problematic and potentially hazardous waste stream into a usable construction material for transportation infrastructure (USTMA, 2022). Therefore, rubberized asphalt represents a sustainable engineering solution that promotes resource efficiency, environmental protection, and improved pavement performance.

The global transition to sustainable development has led to an increased adoption of eco-friendly pavement technologies that attempt to minimize life-cycle environmental effects while maintaining satisfactory engineering performance (Bilawala et al., 2022). In this regard, RMA has received significant interest due to its potential to decrease virgin aggregate consumption, lower embodied greenhouse gas (GHG) emissions through material recycling and divert large amounts of rubber waste from landfills (Mashaan et al., 2021). Previous research also indicates that rubberized asphalt surface courses can lead to reduced traffic noise and improved driving comfort, thus leading to both environmental and user-related pavement performance outcomes (Bilawala et al., 2022; Gao et al., 2022). Collectively, these benefits position RMA as a feasible, sustainable alternative to conventional hot-mix asphalt (HMA).

Despite RMA's technical and environmental benefits have been well documented, its adoption rate remains inconsistent globally; especially in developing economies like Malaysia (Mashaan et al., 2021). Even though regulatory agencies such as the Public Works Department (Jabatan Kerja Raya, JKR) have developed specifications and guidelines for modified asphalt applications, such as JKR/SPJ/2019-S4, the successful mainstream implementation of RMA depends not only on technical performance but also on the perceptions, confidence levels and acceptance of industry stakeholders (Li et al., 2023). Engineers, contractors, consultants and representatives of local authorities play a crucial role in material selection, project planning and construction implementation. Therefore, understanding their perceptions of RMA is vital for determining barriers and facilitators for its broader implementation in the road construction industry (Darko et al., 2021). Malaysia continues to expand its transportation infrastructure due to rapid urbanization and industrial development, which increases the need for sustainable construction materials and effective waste management strategies (Mashaan et al., 2021).

Although existing local research has primarily evaluated laboratory performance evaluations of rubberized asphalt mixtures' physical, rheological and mechanical properties, relatively little research has examined industry stakeholder perceptions of its operational application and sustainability benefits (Darko et al., 2021; Li et al., 2023). These evaluations are essential since positive laboratory results alone may not lead to widespread adoption if practitioners lack confidence in actual performance or risks. This is especially relevant in rapidly expanding

regions like Kulim, Kedah, where infrastructure development must be consistent with sustainability objectives.

This study investigates industry stakeholders' perceptions of RMA's technical performance and environmental feasibility within Malaysian road construction. Specifically, the study assesses opinions concerning major technical elements of RMA, including longevity or durability, structural load capacity, and traffic adaptability, as well as environmental advantages including resource preservation, GHG emission reduction, waste tire diversion/mitigation, and acoustic attenuation capability. The results provide empirical evidence for policymakers, regulators, and practitioners who are interested in promoting sustainable infrastructure and implementing circular economy practices.

Principles of Rubber-Modified Asphalt and Circular Economy

The rapid expansion of global infrastructure has intensified pressure on limited natural resources, driving the construction industry to embrace sustainable engineering principles/practices/circular economy principles. As previously noted, integrating post-consumer polymer waste into asphalt mixtures represents an innovative sustainable pavement technology strategy for enhancing resource efficiency/promoting environmentally sustainable transportation infrastructure (Mashaan et al., 2021). Among various waste polymer materials, ELTs have received considerable attention due to large amount generated annually and environmental problems associated with their disposal. As mentioned by Caputo et al. (2023), the non-biodegradable nature of vulcanized rubber makes ELTs a significant solid waste management issue, particularly when disposed via landfilling or unauthorized dumping. Therefore, reusing waste tire rubber into pavement applications provides dual benefits where it reduces the environmental impact of tire disposal while improving engineering performance of asphalt mixtures (Gao et al., 2022). In this respect, RMA constitutes a pragmatic implementation of circular economy concepts by converting nuisance waste materials into beneficial or value-added resources for transportation infrastructure development (Caputo et al., 2023; Gao et al., 2022).

The incorporation of CRM into asphalt mixtures is commonly achieved through two principal techniques, which are the wet and dry processes (Soprych et al., 2023). In the wet process, finely ground crumb rubber is blended directly with hot asphalt binder under controlled mixing conditions; this facilitates particle swelling and interaction with the bituminous phase and subsequently alters the rheological characteristics of the binders (Caputo et al., 2023). In contrast, the dry process coarser rubber particles are added to the aggregate blend before adding asphalt binder; this allows the rubber to act as a partial replacement for aggregate (Soprych et al., 2023). Although both processes operate through different mechanisms, they are designed to improve the mechanical performance and durability of asphalt pavements while reducing the environmental impacts associated with conventional tire disposal practices. As a result, CRM-modified asphalt has proven to be a viable sustainable pavement technology that can address both infrastructure performance requirements and waste management objectives.

Technical Performance of Rubber-Modified Asphalt

The engineering viability of rubber-modified asphalt (RMA) largely depends upon its ability to perform at least as well as conventional asphalt pavements in terms of thermo-mechanical performance under difficult operational conditions (Caputo et al., 2023; Gao et al., 2022). The

addition CRM alters the physical, rheological and viscoelastic characteristics of asphalt binders through a complex rubber-bitumen interaction network; this results in improved material performance and durability (Soprych et al., 2023).

Durability and Longevity

Pavement durability and longevity are major components affecting maintenance requirements and overall life-cycle costs. Numerous studies reported that incorporating CRM additions greatly increase resistance to fatigue cracking, thermal cracking and aging-related deterioration (Caputo et al., 2023; Soprych et al., 2023). The elastic properties of rubber particles help absorb and disperse traffic-induced stresses; this limits the initiation and propagation of microcracks within the pavement structure (Al-Sabaei et al., 2021). In addition, CRM binders show greater resistance to oxidative aging compared to conventional asphalt binders, allowing them to retain ductility and structural integrity over extended periods of time subjected to oscillating temperatures, as studied by Gao et al. (2022). Collectively, these characteristics extend pavement service life and minimize the need for maintenance activities or interventions.

Structural Performance

Structural performance refers to a pavement's ability to resist and distribute traffic loads without experiencing premature distress or failure. Recent studies have shown that the inclusion of CRM may improve key rheological properties, including the complex shear modulus (G^*) and phase angle (δ), resulting in greater resistance to rutting at elevated temperatures while maintaining sufficient flexibility at lower temperatures (Gao et al., 2022; Zhu et al., 2022). Furthermore, optimal CRM concentrations in asphalt mixtures enhance dynamic stability and stress recovery under repeated loading (Soprych et al., 2023; Zhu et al., 2022). This improved balance between stiffness and elasticity allows more effective load distribution throughout the pavement structure, thereby minimizing potential for permanent deformation and structural deterioration.

Adaptability to Traffic Loads

Conventional asphalt mixtures frequently show susceptibility to plastic deformation under heavy or repetitive traffic loads. Conversely, enhanced elastic recovery afforded by crumb rubber enables RMA mixtures to deform under loading and recover more effectively upon load removal. This property improves resistance to rutting and fatigue damage, rendering RMA especially suitable for high-volume traffic corridors, industrial zones, and other locations exposed to large volumes of heavy vehicle traffic (Mashaan et al., 2021). Thus, RMA represents an appealing alternative for enhancing pavement resilience under increasingly rigorous transportation demands.

Environmental Sustainability Dimensions

Evaluation of RMA encompasses not only engineering performance but also environmental contributions throughout the pavement life cycle. Inclusion of waste tire rubber into asphalt mixtures supports multiple sustainability objectives through reduction of waste generation, conserving natural resources, and reduction of environmental impacts associated with conventional pavement construction (Bilawala et al., 2022; USTMA, 2022). By transforming

ELTs into valuable construction resources, RMA employs circular economy principles within transportation infrastructure (Caputo et al., 2023; Mashaan et al., 2021).

Conservation of Natural Resources

Resource conservation is essential for sustainable construction. Partial replacement of virgin aggregates and bitumen with recycled rubber reduces reliance on primary raw materials and helps preserve limited natural resources (USTMA, 2022). Replacement of virgin materials with recycled rubber improves resource efficiency and supports long-term sustainability goals in the construction sector.

Reduction of Greenhouse Gas (GHG) Emission

Life-cycle assessment (LCA) studies show that incorporating recycled tire rubber into asphalt mixtures may decrease embodied greenhouse gas (GHG) emissions. These reductions primarily result from reduced demand for energy-intensive activities such as bitumen production, aggregate extraction, and material transportation (Bilawala et al., 2022). Thus, RMA may contribute to broader decarbonization strategies in the infrastructure sector.

Mitigation of Waste Tire Accumulation

The accumulation of discarded tires creates significant environmental and public health concerns due to their persistence in the environment, which can harbor disease vectors and cause high fire risk (Caputo et al., 2023). Utilizing CRM in asphalt pavements provides an efficient, high-volume recycling pathway by diverting scrap tires from landfills and stockpiles into productive infrastructure applications (Mashaan et al., 2021). This approach not only addresses waste management challenges but also promotes the beneficial reuse of post-consumer materials.

Acoustic Attenuation Capabilities

Traffic-generated noise resulting from tire-pavement interaction represents significant environmental concern in urban settings. Rubberized asphalt pavements have been reported to reduce noise levels through a combination of surface texture characteristics and the sound-absorbing capabilities of embedded rubber particles (Bilawala et al., 2022; Gao et al., 2022). The open-graded or gap-graded surface structures typical of RMA facilitate dissipation of sound energy, which can improve acoustic performance and user comfort.

Stakeholder Perceptions and Technology Adoption

The successful implementation of innovative construction technologies depends not only on demonstrated technical performance but also on stakeholder acceptance and willingness to adopt new practices (Li et al., 2023). According to Darko et al. (2021), the key industry participants, including engineers, contractors, consultants, and representatives of government agencies, exert substantial influence on material selection/project implementation. Their decisions often reflect their perceptions of technical reliability, economic feasibility, implementation risks, and regulatory compliance. While positive perceptions can facilitate the adoption of emerging technologies, concerns regarding production complexity, storage stability, construction requirements, and long-term cost-effectiveness may impede widespread

implementation (Anand & Raj, 2024). Therefore, understanding stakeholder perceptions is needed to identify barriers and opportunities for broader RMA deployment.

Research Gap

Although extensive research has validated the physical, rheological, and mechanical properties of RMA under laboratory conditions (Caputo et al., 2023; Gao et al., 2022; Soprych et al., 2023), less emphasis has been placed on analyzing industry professionals' perspectives on its operational and environmental viability, particularly within emerging industrial economies such as Malaysia. Existing studies have focused mainly on material characterization and laboratory performance, leaving a significant gap in how practitioners evaluate RMA's operational feasibility, field performance, and sustainability benefits (Darko et al., 2021; Li et al., 2023). Since technical performance alone does not guarantee widespread adoption, stakeholder confidence and acceptance remain primary determinants of successful implementation. Consequently, this study attempts to fill this gap by empirically assessing industry perceptions of RMA across technical, environmental, and practical dimensions within the Malaysian road construction industry.

Methodology

Research Design and Study Area

This study utilized a quantitative cross-sectional research design to evaluate industry stakeholders' perceptions regarding the technical performance and environmental sustainability of rubber-modified asphalt (RMA) in road construction projects. A structured questionnaire survey served as the primary data collection tool, enabling systematic collection of standardized quantitative data from respondents representing various professional backgrounds in the construction and infrastructure sectors (Creswell & Creswell, 2018; Saunders et al., 2019).

The study was conducted in Kulim, Kedah, Malaysia, a rapidly developing industrial region in northern Peninsular Malaysia with significant growth in transportation and infrastructure. Kulim was selected as study site due to its tropical climate, characterized by high temperatures, intense solar exposure, and heavy seasonal rainfall. These climate factors accelerate pavement degradation through mechanisms including asphalt oxidation, binder aging, and moisture-related distress. Therefore, Kulim provides a suitable context for evaluating industry perceptions of RMA as a sustainable pavement material that capable of enhancing long-term pavement performance and durability under severe service conditions (Mashaan et al., 2021).

Population and Sampling

The target population comprised professionals actively involved in road construction and pavement-related projects, including site engineers, contractors, technical consultants, and municipal authority representatives. These stakeholders were selected because they are directly involved in pavement design, material selection, construction supervision, and maintenance decision-making.

A non-probability sampling approach, combining purposive and convenience sampling techniques, was used to select respondents who possess relevant technical knowledge and

practical experience in road construction and pavement materials (Etikan et al., 2016). The sampling frame was developed using records of contractors registered with the Construction Industry Development Board (CIDB) Malaysia and operating in Kedah.

Based on the sample size determination criteria outlined by Krejcie & Morgan (1970), a minimum sample size of 45 respondents was considered sufficient for generating statistically reliable results at a 95% confidence level with a 5% margin of error. The study obtained 50 valid and fully completed questionnaires for subsequent analysis. The number of valid responses exceeded the minimum requirement, providing an adequate basis for descriptive and reliability analyses.

Survey Instrument Development and Measurement Scale

The questionnaire was developed based on established constructs and validated items from previous studies on sustainable infrastructure technologies and stakeholder perceptions (Darko et al., 2021; Li et al., 2023). It consisted of four sections. Section A (Demographic Profile) collected respondents' background information, including age, professional designation, years of industry experience, and familiarity with RMA technology. Section B (Technical Performance Perception) assessed perceptions of RMA's technical performance using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The three key technical attributes evaluated were longevity and durability, Structural performance, and Adaptability to traffic loads. Section C (Environmental Sustainability Perception) evaluated respondents' perceptions of the environmental benefits afforded by RMA using a five-point Likert scale similar to Section B. The four sustainability attributes assessed were conservation of natural resources, reduction of greenhouse gas (GHG) emissions, mitigation of waste tire accumulation, and acoustic attenuation capability. Section D (Operational Insights and Adoption Challenges) included open-ended questions designed to collect qualitative insights into practical implementation of RMA, including perceived technical, institutional, and economic barriers to adoption.

The questionnaire was administered electronically using Google Forms. Respondents were informed of the study objectives and assured of anonymity, confidentiality, and the voluntary nature of participation prior to completing the questionnaire.

Conceptual Framework

This study's conceptual framework establishes RMA as the central technological innovation for promoting sustainable pavement construction. As depicted in Figure 1, stakeholder perceptions of RMA are evaluated through two primary dimensions: technical performance and environmental sustainability.

The technical performance dimension comprises three constructs: longevity and durability, structural load performance, and adaptability to traffic loads. The environmental sustainability dimension encompasses natural resource conservation, greenhouse gas emission reduction, mitigation of waste tire accumulation, and acoustic attenuation capability. Together, these dimensions influence stakeholders' overall evaluation of RMA and its potential for wider adoption within the road construction sector.

This conceptual framework served as the foundation for questionnaire development, variable selection, and subsequent statistical analyses undertaken in the study.

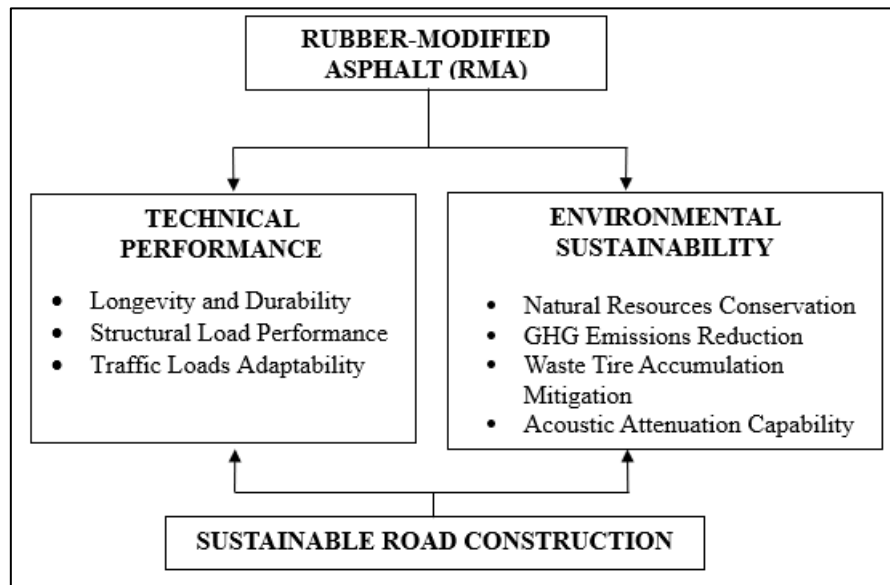


Figure 1: Conceptual Framework for Assessing Stakeholder Perceptions of RMA

Data Analysis

The collected survey data was coded and analyzed using IBM SPSS Statistics Version 28.0. The reliability and internal consistency of the measurement scales were evaluated using Cronbach's alpha (α) prior to the main analysis. Based on Hair et al. (2019), a Cronbach's alpha value equal to or greater than 0.70 was considered indicative of acceptable construct reliability and internal consistency.

Descriptive statistics techniques were utilized to describe respondents' perceptions of the technical and environmental attributes of rubber-modified asphalt (RMA). These analyses included frequency distributions, percentages, mean scores, and standard deviations, facilitating identification of central tendencies, response patterns, and the relative importance of each evaluation criterion. Mean scores were further used to rank the perceived benefits and performance characteristics of RMA across the assessed dimensions.

Additionally, responses obtained from the open-ended questions in Section D were analyzed using thematic analysis following the approach proposed by Braun and Clarke (2006). This qualitative procedure involved coding responses, identifying recurring themes, and categorizing key insights related to the technical, institutional, and economic challenges associated with adopting RMA. Integration of quantitative/qualitative findings provided a comprehensive understanding of stakeholder perceptions and the factors influencing RMA implementation in the road construction sector.

Results and Discussion

Respondents' Demographic Profile

The study received 50 valid, fully completed questionnaires from professionals involved in civil engineering and road construction activities in Kulim, Kedah. The respondent pool comprises diverse groups of industry stakeholders: site engineers (30%), project contractors (26%), technical consultants (22%), site supervisors (14%), and representatives of municipal authorities (8%). This broad professional representation enabled study to capture perspectives from individuals involved in pavement planning, design, construction, supervision, and regulatory oversight, providing a comprehensive evaluation of stakeholder perceptions of rubber-modified asphalt (RMA).

The demographic analysis also indicated that 58% of respondents were under 30, reflecting the increasing involvement of younger professionals in Malaysia's civil engineering and construction sectors (Darko et al., 2021). This trend suggests an evolving workforce in which younger professionals increasingly participate in infrastructure development and project management activities. Moreover, all respondents possessed relevant technical qualifications and practical experience in pavement construction, asphalt pavement applications, or road maintenance operations. Their professional backgrounds and industry exposure provided a credible basis for evaluating RMA's technical performance and environmental sustainability.

Perceived Technical Performance of Rubber-Modified Asphalt

The first objective of this study was to evaluate industry stakeholders' perceptions of rubber-modified asphalt's technical performance. The study evaluated three key performance dimensions: longevity and durability, structural performance, and traffic load adaptability. Descriptive statistics, as shown in Table 1, reveal generally favorable perceptions of RMA among respondents, with all evaluated technical attributes displaying mean values approaching or exceeding the agreement threshold. These findings indicate robust industry confidence in RMA's ability to enhance pavement performance compared to conventional hot-mix asphalt (HMA).

Table 1: Descriptive Statistics for Perceived Technical Performance of RMA (N=50)

Technical Performance	Mean Score (M)	Standard Deviation (SD)	Overall Ranking
Longevity and Durability	4.04	0.870	1
Structural Load Performance	4.00	0.841	2
Traffic Loads Adaptability	3.99	0.829	3

Among the technical performance attributes evaluated, longevity and durability received the highest level of agreement from respondents, with a mean score of 4.04 (SD = 0.870). This finding suggests that industry stakeholders view rubber-modified asphalt (RMA) as possessing significant potential for enhancing pavement service life and minimizing need for maintenance. These perceptions align with previous research showing that incorporating crumb rubber modifier (CRM) alters the rheological properties of asphalt binders. By absorbing lighter bitumen fractions and swelling, CRM forms a viscoelastic network that improves resistance to

oxidative aging, thermal deterioration, and fatigue-induced microcracking (Caputo et al., 2023; Soprych et al., 2023). The enhanced elastic recovery of rubber-modified binders enables pavements to better withstand repeated traffic loading, delaying distress propagation and reducing the frequency of maintenance interventions (Al-Sabaei et al., 2021).

Structural load performance received the second-highest mean score ($M=4.00$, $SD=0.841$), indicating strong stakeholder confidence in RMA's load-bearing capacity and structural resilience. CRM inclusion has been demonstrated to alter rheological properties (complex shear modulus (G^*) and phase angle (δ)), resulting in improved resistance to rutting at elevated temperatures while maintaining sufficient flexibility at low temperatures (Gao et al., 2022; Zhu et al., 2022). These material modifications enhance pavements' capability to distribute traffic-induced stress more efficiently while maintaining structural integrity at elevated temperatures. Respondents' positive perceptions align with laboratory findings demonstrating substantial enhancements in dynamic stability, stress recovery, and resistance to permanent deformation in CRM-modified asphalt mixtures (Zhu et al., 2022).

Adaptability to traffic loads received a mean score of 3.99 ($SD=0.829$), reflecting robust agreement on the suitability of RMA for roads subjected to heavy, repetitive traffic loading. Respondents acknowledged the ability of rubberized asphalt mixtures to accommodate fluctuating traffic demands through their enhanced elasticity and recovery characteristics. Unlike conventional asphalt mixtures, which exhibit susceptibility to plastic deformation under sustained loading, RMA can better absorb and dissipate stress generated by heavy axle loads. This characteristic renders RMA particularly suitable for high-volume roadways, industrial corridors, and urban traffic networks where long-term pavement performance is critical (Mashaan et al., 2021).

Overall, the findings indicate strong industry confidence in the technical performance of rubber-modified asphalt. The consistently high mean scores across all three dimensions suggest that stakeholders perceive RMA as a reliable, durable pavement material that enhances pavement longevity, improves structural stability, and accommodates severe traffic conditions. These perceptions align closely with the scientific literature, which has documented the superior mechanical and rheological performance of CRM-modified asphalt mixtures compared with conventional hot-mix asphalt. Consequently, the results support increasing acknowledgment of RMA as a technically viable and sustainable pavement solution for modern road infrastructure development.

Perceived Environmental Sustainability Benefits of Rubber-Modified Asphalt

The second objective of this study was to assess industry stakeholders' perceptions of the environmental sustainability benefits of using rubber-modified asphalt (RMA). The study evaluated four key environmental dimensions: waste tire accumulation mitigation, greenhouse gas (GHG) emission reduction, natural resource conservation, and acoustic attenuation capability. Table 2 presents the descriptive statistics for these dimensions.

Table 2: Descriptive Statistics for Perceived Environmental Sustainability Benefits of RMA (N=50)

Environmental Sustainability Benefits	Mean Score (M)	Standard Deviation (SD)	Overall Ranking
Waste Tire Accumulation Mitigation	3.95	0.861	1
Greenhouse Gas Emissions Reduction	3.94	0.898	2
Natural Resources Conservation	3.94	0.890	3
Acoustic Attenuation Capabilities	3.14	0.843	4

Waste tire accumulation mitigation received the highest level of agreement, with a mean score of 3.95 (SD=0.861). The finding demonstrates that respondents strongly recognized the role played by RMA in addressing the escalating problem of ELT disposal. Incorporating CRM into asphalt mixtures offers an efficient recycling pathway to divert large volumes of waste tires from landfills and stockpiles, reducing associated environmental and public health risks (Caputo et al., 2023; USTMA, 2022). The results reflect industry awareness of RMA as a practical manifestation of circular economy principles by converting waste materials into valuable construction resources.

Greenhouse gas (GHG) emission reduction (M=3.94, SD=0.898) and natural resource conservation (M=3.94, SD=0.890) ranked second and third, respectively, demonstrating identical high mean scores among the evaluated environmental attributes. These findings indicate that stakeholders recognize the broader sustainability benefits of using recycled tire rubber in pavement construction. Previous life cycle assessment studies have shown that partially replacing virgin aggregates and petroleum-based materials with recycled CRM can reduce embodied carbon emissions, lower energy consumption, and decrease demand for raw material extraction (Bilawala et al., 2022). The high degree of agreement among respondents further indicates increasing appreciation for resource efficiency and sustainable material management in the Malaysian construction sector, consistent with emerging circular economy initiatives and sustainable infrastructure development goals (Anand & Raj, 2024).

In contrast, acoustic attenuation capabilities received the lowest mean score (M=3.14, SD=0.843), indicating only moderate degree of agreement among respondents. Although previous studies have demonstrated that rubberized asphalt surfaces can reduce traffic noise-induced noise levels through enhanced sound absorption and damping properties of embedded rubber particles (Bilawala et al., 2022; Gao et al., 2022), industry practitioners appear to recognize these benefits less widely. Relatively lower rating may reflect limited exposure to field applications or limited awareness of acoustic performance of RMA pavements. Therefore, increased dissemination of field evidence, demonstration projects, and technical training programs may be necessary to improve stakeholder understanding of this secondary environmental benefit.

Synthesis and Industry Discussion

The findings show a strong relationship between perception of technical performance and environmental sustainability. Industry views both areas as related and not independent. Most respondents see RMA as having the potential to improve both the physical performance of pavements and to have positive environmental impacts. This view aligns with technology adoption theories, which state that acceptance of sustainable construction materials depends on how well they meet technical performance requirements while also addressing environmental issues (Darko et al., 2021; Li et al., 2023).

The high ratings for both technical and environmental benefits indicate strong industry acceptance among Malaysian road contractors for wider use of RMA in Malaysian road construction. However, converting positive views of RMA into widespread use will require additional institutional support and policy interventions. Developing the regulatory framework, standardizing mix design specifications, and issuing implementation guidelines from agencies such as the Public Works Department (JKR) will help reduce uncertainty around the use of modified asphalt technologies. Furthermore, robust life cycle cost analysis and long-term field performance data will build confidence in RMA and make it easier to transition away from conventional hot-mix asphalt (HMA) to more environmentally friendly pavement alternatives (Anand & Raj, 2024; Mashaan et al., 2021).

Conclusion

This study investigated industry stakeholders' perceptions regarding the technical performance and environmental sustainability of rubber-modified asphalt (RMA) as a part of the movement toward sustainable road construction in Malaysia. As the need for transportation infrastructure grows and concerns about the disposal of ELT increase, RMA offers a potential solution that can improve pavement performance and contribute to circular economy goals.

The findings indicate high confidence in RMA's technical capabilities. Among the technical characteristics evaluated, longevity and durability were rated highest mean score (M=4.04), followed closely by structural performance (M=4.00) and traffic load adaptability (M=3.99). These findings show that Malaysian road construction professionals widely recognize RMA as a resilient, long-lasting pavement material that can meet the demanding performance requirements of modern transportation infrastructure.

From an environmental perspective, waste tire mitigation was the most highly rated benefit (M=3.95), with GHG emission reduction (M=3.94) and natural resource conservation (M=3.94) being rated similarly. However, acoustic attenuation capability received only moderate support (M=3.14), indicating that more education and awareness efforts may be needed.

This study contributes to the literature by moving beyond laboratory evaluations of materials to evaluate practitioner perceptions in an emerging industrial economy. The findings suggest that Malaysian road construction professionals generally perceive RMA as both technically acceptable and environmentally advantageous. Nevertheless, successful adoption of RMA will depend on supportive regulatory frameworks, standardized technical specifications, clear procurement policies, and comprehensive life-cycle performance and cost data.

Future studies should expand the scope of investigation with larger and more geographically diverse samples across Malaysia. Additionally, longitudinal studies evaluating the in-service performance of RMA pavements under varying traffic and climatic conditions would provide additional evidence to support broader implementation and policy development efforts throughout Southeast Asia.

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Ethics Statement: This study was conducted in accordance with ethical research standards. All procedures involving human participants were reviewed and approved by the UiTM Pulau Pinang Branch Ethics Research Committee (BERC), approval number BERC/6/2025 (UG/MR/356). Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity. The data collected were used solely for academic purposes.

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Declaration on the Use of Artificial Intelligence (AI) “The author(s) declare that generative AI or AI-assisted technologies were used during the preparation of this manuscript. The following tool(s) were used: Microsoft 365 Copilot. The tool(s) were used to refine sentences and improve the overall clarity, flow, and phrasing of my original draft. All AI-assisted content was reviewed and verified by the author(s), who take full responsibility for the accuracy, originality, integrity, and final content of the manuscript.”

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