State of Knowledge Report on Rubber Modified Asphalt

by

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Executive Summary

Every year almost 300 million scrap tires are generated in the United States. Recycled rubber obtained from scrap tires can be used in a number of beneficial ways. One of the most beneficial uses involves producing Ground Tire Rubber (GTR) from scrap tires and using the GTR to create Rubber-Modified Asphalt (RMA). RMA has been used in the U.S. since the 1960s, but extensive market adoption is yet to occur. Thus, a central question regarding RMA that still remains unanswered is, **can RMA help eliminate scrap tire stockpiles in the U.S., boost pavement sustainability and longevity, and allow more miles of roads to be repaired?** Researchers at the University of Missouri-Columbia tested this hypothesis in collaboration with the U.S. Tire Manufacturers Association (USTMA) and The Ray, a philanthropic organization dedicated to the discovery and implementation of sustainable transportation technologies. The resulting **State of Knowledge (SOK) report** provides an up-to-date review of RMA, including its historical development and use, production methods, field performance, economics, safety, driver comfort, environmental impact, and sustainability benefits. Knowledge gaps and recommendations for future research and investment are also assessed in the SOK report.

The SOK study reviewed 311 scholarly articles and reports dating back to the early 1960's, and involved a **survey of 26 U.S. state highway agencies to better ascertain the gaps in knowledge and barriers to more widespread adoption of RMA nationwide** . The key findings of the SOK are summarized below and address the effect of RMA on pavement performance, economics, and sustainability:

Performance Benefits: The overarching research shows that rubber modified asphalt extends pavement life; resisting early pavement failures modes such as rutting and cracking . Additionally, RMA was also found to significantly mitigate noise from traffic, and enhance ride quality and safety.

- **Longevity** - The past two decades of research indicate that all three primary RMA approaches, i.e., traditional wet process, terminal-blend wet process, and the modern dry process (engineered crumb rubber) lead to **extended pavement life** as compared to pavements made with unmodified binders. Moreover, RMA can provide similar performance as pavements constructed with costly polymer-modified binders [1,2]. RMA is particularly **resistant against early pavement rutting failures**, owing to the stability provided to the liquid binder system imparted by the swollen, elastic rubber particles [3,4] . RMA is also **very resistant to fatigue cracking in high traffic volume applications and to low temperature cracking** [5–8].
- **Pavement noise reduction -** or more precisely, the mitigation of road noise emanating from vehicles, has been quantified in several studies in recent years. **Noise reduction arising from RMA use has been measured to range from 1-10 decibels**, depending on a mix type, traffic level, vehicle speeds, and other environmental variables. Due to the exponential nature of the dB scale, **a reduction of just 2-3 dB creates a similar environmental benefit as a 50% reduction in traffic noise intensity**. In addition, long-

term field observations have indicated that noise reduction due to RMA decreases over the years but at a substantially lower rate as compared to other surfacing alternatives [9–11].

- **Ride Quality and Safety** - RMA has been shown to **create smoother pavements and therefore better ride quality for motorists** [12]. In addition, the use of RMA provides **better pavement skid resistance, which can reduce traffic accidents during wet weather** [13].

Economic Benefits: RMA has been shown to be a cost-effective option as it increases the service life of a pavement and reduces and/or delays the occurrence of maintenance activities. This leads to significant cost savings when evaluated using life cycle cost analysis techniques.

- **Initial costs** – Based on initial, per-ton costs only, RMA is generally more expensive than unmodified asphalt, but less expensive than polymer modified asphalt [14]. However, in the case of asphalt overlay rehabilitation projects on a cost-per-square-yard basis, it has been shown that **thin RMA overlays can be built at a lower cost as compared to unmodified asphalt overlays** - **approximately 43% less cost with a 10% boost in pavement life** [15]. Similarly, an earlier study [16] demonstrated that **a 50% reduction in pavement layer thickness can be achieved by using RMA** in lieu of unmodified mixtures while achieving better performance.
- **Life cycle cost savings** – **Life cycle cost analysis (LCCA) studies have reported life cycle cost savings for RMA spanning widely**, from a range of 4% to 40% savings in a study compiled for Caltrans [17] to more than 400% savings [8] when basing the results on laboratory-based fatigue performance. More work is needed to develop a more comprehensive national database of pavement costs, including both initial costs and subsequent maintenance costs, and pavement service life, which can be used to more accurately assess the life cycle cost benefits of RMA.
- **Implications** – The current economic outlook for RMA has significant implications for the renewal of our nation's transportation infrastructure considering that most pavement expenditures are devoted to restoring the surface characteristics (smoothness, skid resistance) of existing roadway and airfield pavements. **By using RMA to upgrade significantly more miles of pavement each year for each dollar spent**, cities and states can begin to **address the** current **backlog of deferred pavement maintenance** that exists in their network. **Motorists will** also **benefit by saving on vehicle repair and fuel costs** by spending more time **driving on smoother pavements**.

Environmental Benefits: The use of RMA results in the reduction of CO_2 emissions and lower energy consumption over the lifetime of a pavement. Additionally, since RMA pavements are stiffer and smoother, they reduce the generation of tire wear particles and improve water quality in roadway runoff.

- **Reduction in tire wear -** Generation of micro-particles from on-road vehicle traffic has generated significant research interest in recent times. Studies have shown that the use of **RMA pavement surfaces can significantly reduce tire wear** as compared to concrete pavements, **by providing a much smoother ride** as characterized by lower measured values of the International Roughness Index (IRI) [18–20]. In addition, converting scrap tires to ground tire rubber and **'entombing' the rubber into very low permeability asphalt binder films in RMA**, has been shown to significantly reduce the chances of leaching of any potentially toxic chemicals from the scrap tire rubber to aquatic eco-systems [21,22].

- **Reduction in rolling resistance and fuel consumption –** Studies have shown that substantial savings can be achieved by constructing stiffer pavements, leading to reductions in vehicular fuel consumption due to lower, localized pavement deflection and subsequently lower rolling resistance [23]. Compared to standard asphalt pavements, **RMA surfaces are usually stiffer and smoother**, and should therefore **lead to lower rolling resistance**. The existing literature on the impact of rubber modification on fuel consumption is sparse, but the limited studies available indicate a minor-yet-positive effect in RMA surfaced pavements as compared to polymer modified in terms of vehicle fuel consumption [24].
- **Environmental impact of RMA as estimated through LCA –**
  - Life cycle assessment/analysis (LCA) studies that have focused exclusively on the production process of RMA, without focusing on the whole life cycle and wider boundary conditions, unsurprisingly reported negative impacts of RMA. This is mostly due to higher production temperatures and the energy-intensive process needed to produce high-quality crumb rubber from scrap tires. On the other hand, **studies that considered the whole life cycle of RMA pavements in comparison to conventional or traditional polymer-modified pavements, with proper assumptions of service life and lift thicknesses, have shown RMA pavements to have a net positive environmental impact. These benefits include a reduction in CO_2 emissions and lower energy consumption, driven in large part by extended service life and lower maintenance requirements** [25,26].
  - The majority of LCA studies in the literature are ***attributional***, meaning that these studies present a comparison between two or more products of the same kind; for instance, comparing roads comprised of unmodified, rubber-modified, and polymer-modified asphalt mixtures. However, **given the need to leverage the growing circular economy paradigm shift, there is a need to develop up-to-date, *consequential* LCA studies to drive policy-based decisions that optimize the utilization of ground tire rubber (GTR) in various engineering applications, such as in sports turfs, embankments, roads, etc.**

Knowledge Gaps: Based upon the comprehensive State-of-Knowledge (SOK) assessment of rubber-modified asphalt carried out in this study, the following general knowledge gaps were identified:

- **Most state highway agencies and asphalt contractors have limited-to-no experience with modern RMA products**, and limited knowledge of the new performance trends, economics, and sustainability of RMA. Rather than the current piece-meal approach, comprehensive, **national efforts to provide highway agencies and contractors with up-to-date technical data, best practice summaries and sample specifications are critically needed**. Incentives for the deployment of RMA in demonstration projects as a sustainable and economical solution to address deferred pavement maintenance backlogs may also be needed to overcome current inertial barriers in the paving industry.

- **Almost none of the modern, advanced asphalt binder and mixture performance tests and associated specifications were developed with RMA in mind.** This must be addressed in new, purpose-built specifications for modern RMA materials and construction methods.
- **The ability to accurately design pavement layer types and thickness with RMA is currently difficult at best**. Additional research is needed to better reflect RMA properties and characteristics as inputs in modern pavement design software programs for new pavements and rehabilitation activities, such as resurfacing with asphalt overlays.
- **Life expectancy assumptions for rubberized pavements during the use phase in LCA studies are currently based on outdated studies**, particularly in the case of dry process RMA and impact categories for LCA studies involving RMA need to be expanded. Along with addressing these gaps, the LCA impacts of rubber-modified RAP should be more accurately quantified. **A comprehensive study is needed to facilitate more accurate consequential LCA calculations to be made for RMA materials, which will allow decision makers to properly assess where to best utilize RMA in their pavement networks.**
- LCA models for impact categories related to quantifying eco-toxicity are, at the current time, underdeveloped. This creates an undesirable level of uncertainty for those impact categories. **With the recent increase in attention to the question of generation of microparticles by RMA and its effects on aquatic life, it is a good time for the industry to come forward and establish an Environmental Product Declaration (EPD) for using rubber modification in asphalt mixtures.** An EPD standardizes the process of quantifying and communicating the environmental impacts of a product to the end user.
- **A more rigorous quantification of improvement in functional characteristics** (noise reduction, skid resistance) of pavements **resulting from the use of RMA is needed**. National-level collaborations to quantify and standardize these social elements of LCA, categorized as functional performance of pavements, is important.

In addition to the identified research gaps, **a comprehensive set of recommendations for future research and strategic investments** to enable the expanded use of sustainable, durable, and economical RMA pavements in the US **are provided at the end of the SOK report**.

In conclusion, RMA is a well-studied material that delivers significant, proven benefits in terms of pavement durability, economics, and environmental sustainability. It is hoped that the findings and recommendations of this report will help to facilitate the rapid growth in RMA usage in the United States and beyond. RMA is a proven and mature technology that is poised to play a key role in increasing the sustainability and resilience of America’s highway and airfield pavement infrastructure as it is rebuilt and modernized in the coming years.

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