San Diego County BUILDING BETTER ROADS

GUIDANCE DOCUMENT S-2

RECYCLED PLASTIC ASPHALT ADDITIVES USE IN HMA

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ABSTRACT

This guidance document will detail the benefits of local agencies utilizing recycled plastic asphalt additives as a partial binder substitute.

The asphalt industry, like many industries, continues to look for innovative ways to reduce its carbon footprint and limit long-lasting environmental impacts. This guidance document explores an emerging method for creating a more sustainable asphalt concrete through the use of recycled plastic asphalt additives, also known as “RPAs”. It is important to note that the benefits and drawbacks of RPAs can vary depending on the specific additive product and manufacturer, as with any commercial product. The goal of this guidance document is to focus on common traits that are found across multiple recycled plastic asphalt additives and highlight some of the unique benefits that have been realized through the use of these products.

PROBLEM STATEMENT

Current asphalt production remains an environmentally costly process when it comes to oil consumption and overall carbon output.

Although the industry has taken great strides and is continuously finding new ways to cut back its carbon footprint, there is still a significant environmental impact resulting from asphalt production. According to the National Asphalt Paving Association (NAPA, 2022), the United States produced approximately 421.9 million tons of asphalt in 2019 alone, resulting in 21.7 million metric tonnes (equivalent to 23.9 million standard tons) of CO_2. This translates to 51.2 kg CO_2e/ ton of mix produced, which accounted for 1.3% of all industrial emissions across the United States in 2019. While the use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) are certainly the most popular processes contributing to a greener product, the use and production of asphalt binder is an important area of mix production that has not received an equitable level of sustainability efforts.

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Figure 1: Typical Asphalt Plant Setup

Sustainable improvements to asphalt binders have historically been an overshadowed area of research, even though it is perhaps the largest contributor to the overarching issue of current carbon emissions in the asphalt industry. Binder production accounts for 94% of emissions associated with raw materials and 53% of all emissions created in the production of asphalt materials, according to NAPA (Shacat et al., 2022). Although plastic in asphalt is not a new idea, it is only in recent years that the technology has caught up to the concept.

Key Issues:

- Asphalt production contributed 1.3% of U.S. industrial emissions in 2019, with significant CO2 output.
- Asphalt binders cause 94% of raw material and 53% of total production emissions.
- Advances in using plastic in asphalt offer new sustainability opportunities.

THE SOLUTION

The utilization of recycled plastic asphalt additives allows for both environmental and mechanical benefits along with possible economic advantages.

Recycled plastic asphalt additives, when used properly, have the ability to offset up to 29.76 kg of CO2 per ton of asphalt by influencing multiple stages of the asphalt production process. The first and most universal benefit of these products is the reduction of virgin asphalt binder. These additives typically allow for a 3-15% replacement of asphalt binder, by weight of oil, which translates to roughly 3-15 pounds of plastic per ton of asphalt. Specific dosing may vary and should be discussed with the manufacturer based on application, individual plant operations, and individual plant goals. Verifying the amount of binder replaced is as simple as weighing the amount of virgin binder included in the mix, weighing the amount

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of RPAs included in the mix, then conducting standard binder verification tests to obtain the final binder content of the mix. It is important to emphasize that these products can be used as partial binder substitutes as well as binder supplements.

Figure 2: Waste Plastic Stockpile

RPAs will never fully eliminate the need for oil in the production of asphalt mixes. As discussed earlier, oil consumption stemming from asphalt binder production and usage generates an immense carbon footprint. A key factor in the sustainability of this process is the replacement and extension of virgin oil. Simply adding plastic additives to a mix for mechanical improvements would still be advantageous, but without decreasing the oil, any intended carbon savings would be diminished. Even a minor reduction in oil per ton can lead to huge net-positive environmental impacts over time. Using the minimum recommended replacement of 3%, upwards of 744 kg of CO2 can be saved for every 100 US Tons of asphalt produced, with the carbon savings increasing in correlation with the percent replacement. Binder replacement is the primary benefit of recycled plastic asphalt products, but it is not the only factor in the carbon-savings equation for these products.

Figure 3: Waste Plastic Road

Key Takeaways:

- Recycled plastic asphalt additives can reduce up to 29.76 kg of CO2 per ton by partially replacing asphalt binder.
- These additives replace 3-15% of virgin binder by weight, significantly reducing oil usage and associated emissions.

- Even small binder reductions yield substantial long-term carbon savings, with 744 kg of CO_2 saved per 100 tons at a 3% replacement rate.

AT THE ASPHALT PLANT

Recycled plastic asphalt additives have two primary introduction methods at the asphalt plant and as a result, their differing impacts should be explored.

Asphalt additives are often categorized based on their introduction method, i.e. a wet process vs. a dry process. The wet process infers that the additive used be in a liquid state while the dry process infers that the additive be in a solid state. Plastic asphalt products are no different and can be categorized just the same.

Figure 4: Waste Plastic Mobile Hopper

Plastic asphalt additives are most commonly introduced as dry products due to the method's minimal impact on the asphalt manufacturing process. The specific introduction method, however, is primarily dependent on the type of asphalt plant and configuration being used. For example, at a continuous-mix drum plant, a mobile hopper is brought in and calibrated to dispense a predetermined amount of loose plastic asphalt additive directly onto the RAP belt. Once the hopper is set up, the only additional labor required is for an employee to occasionally check the hopper for clogs and to ensure that the hopper is not empty. There is no need to alter the speed of the RAP belt or any other standard process while manufacturing the asphalt mix. Meanwhile, batch plants typically use a slightly different process than continuous-mix drum plants. At a batch plant, pre-weighed low-melt bags of plastic asphalt additive are introduced directly into the weigh hopper, one bag for each ton of asphalt being mixed. The only labor required for this introduction method is for a single employee to toss the low-melt bags of plastic additive products into the weigh hopper of the batch plant. These processes provide precise dosing during the introduction phase and have historically eliminated the need for post-production verification of plastic content, although this can still be verified through standard binder content verification processes. Dry products are also easy to store, being able to be stockpiled in bulk-sacks anywhere the plant has space.

Figure 5: Types of Waste Plastic Pellets

The wet process is the lesser-used of the two introduction methods for RPA products, and this is due to a few fundamental reasons. It is important to note that in regards to this topic, wet asphalt additive products are manufactured from the same materials as dry products, just with slightly more processing. Typically, wet products require the use of high-shear milling in order to fully emulsify the plastic asphalt additives directly into the bitumen. Once the plastic asphalt additives are incorporated into the bitumen, additional heated and agitated tank space is then required to store the plastic-infused bitumen. From here, the bitumen can be introduced into the asphalt mix without any further changes to the plant's standard operating procedures. The need for additional processing heavily implies additional energy consumption as a result of this introduction method, though the exact figures are highly variable based on factors such as the efficiency of the machinery being used and how long the plastic-mixed bitumen is stored for. One potential benefit for this process is the eventual use of RPAs in lower-temperature materials such as warm-mix asphalt, emulsions, and sealcoat, although there are concerns about complete homogenization of the plastics at these temperatures. Successful real-world feasibility studies have yet to be conducted on these applications though, so unfortunately these uses are still hypothetical at this point in time.

Regardless of the introduction method used, the fundamental concept largely remains the same. The plastic asphalt additives are introduced into the asphalt mix where the polymers melt as a result of the temperatures already required to produce conventional HMA. The melted polymers then homogenize with the virgin oil used due to the use of specialized cross-linking polymers. It is important to note that, similar to the inclusion of fiber products, once the materials have been incorporated into the asphalt mix, all other production, placement, and testing

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parameters/standards for conventional asphalt concrete apply. Lab comparisons have consistently shown little to no differences in asphalt and binder performance or loss of intended benefits when looking at the wet process vs. dry process as introduction methods. These tests have indicated no significant difference in introduction methods when looking at:

- Marshall Stability
- Marshall Flow
- Deformation Resistance
- Moisture Resistance
- Tensile Strength
- Fatigue Resistance
- Penetration (binder)
- Elastic Recovery (binder)

These results paired with the increased labor, energy, and storage requirements of high-shear milling needed for the wet process has shown to accrue unnecessary costs that can be avoided through the use of the dry process. These factors contribute to the dry process being the introduction method of choice for plastic asphalt additives.

Key Takeaways:

- Plastic asphalt additives are most commonly introduced as dry products because they require minimal modifications to asphalt manufacturing processes, reduce labor costs, and eliminate the need for additional storage and energy consumption.
- While the wet process fully emulsifies plastic additives into the bitumen using high-shear milling, it requires extra energy, heated storage tanks, and increased operational complexity, making it less practical for most asphalt plants.
- Lab tests show no significant difference in key performance metrics (e.g., Marshall Stability, moisture resistance, tensile strength) between the wet and dry introduction methods, reinforcing the cost-effectiveness of the dry process.

ABOUT THE PRODUCTS

The specific performance expectations and attributes of recycled plastic asphalt products will vary based on the manufacturer, making it important to understand some of the differences and common benefits of current products on the market.

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When analyzing the benefits of plastic mixes, it should be understood that these products are past the point of being hypothetical. Recycled plastic asphalt additives have been used in both public and private projects dating back to 2018, with the first RPA mix to ever be used in California being used at UCSD of that same year.

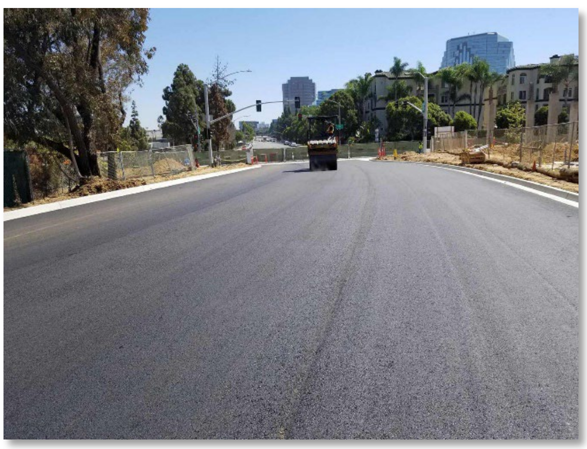

Figure 6: Road Constructed using Waste Plastics- University of California San Diego

Since then, plastic additives have been a staple at multiple asphalt plants across the county, being used as everyday mixes for multiple forward-thinking paving contractors. Though there has been a lack of public trials and testing throughout the state of California so far, there have been a notable amount of other states leading the charge on RPA utilization and providing insight into just how powerful of a tool these materials are. One of the common benefits of current plastic asphalt additives in the market is the ability to allow for increased RAP usage. Studies recently conducted in Texas by a third-party lab have shown to increase the number of cycles to failure for Hamburg Wheel Tracking Test results by 29%, 152%, and 41% at RAP contents of 20%, 30%, and 40%, respectively (see Figure 7) when incorporating MacRebur Southern California's "MR8", one of their RPA products.

Table 1. Hamburg Wheel Rut Results with & without MR8

Quarry	RAP %	# of Cycles without MR8	# of Cycles with MR8	% Improvement
West San Antonio	30	7,934[1]	20,000[2]	152%
North San Antonio	20	8,500[1]	11,000	29%
North San Antonio	40	14,171	20,000[2]	41%

Note 1: These mixes failed to meet the minimum design requirement of 10,000 passes for a PG 64-22 on the Hamburg without MR8.

Note 2: These mixes not only exceeded the design requirement of 10,000 passes for a PG 64-22, they actually met the design requirement for a mix with PG 76-22, which is a maximum rut depth of 12.5 mm after 20,000 passes of a Hamburg Wheel Rut Test. Also note that the test stops running after 20,000 passes.

Figure 7: HWT Results

This attribute has both environmental and economic benefits for asphalt plants. The increased RAP naturally allows for reduced virgin oil content and remains a cost-effective alternative to using new aggregate. Certain brands of products currently on the market also have added rejuvenating qualities, removing the need for additional costly rejuvenators required for these high-RAP mixes. With San Diego County looking into the viability of consistently implementing high-RAP mixes in the near future, recycled plastic additives would easily allow for the implementation of these high-RAP mix designs.

Another common benefit is the ability to modify neat oil into polymer modified oil. This use of plastic additives has shown the largest improvement in mechanical properties. The extent of these improvements is product and manufacturer dependent, but all in all, properly manufactured and implemented use of RPAs will not force a trade-off of quality in exchange for sustainability. In fact, depending on the product, recycled plastic asphalt additives can be shown to enhance mechanical performance of asphalt mixes.

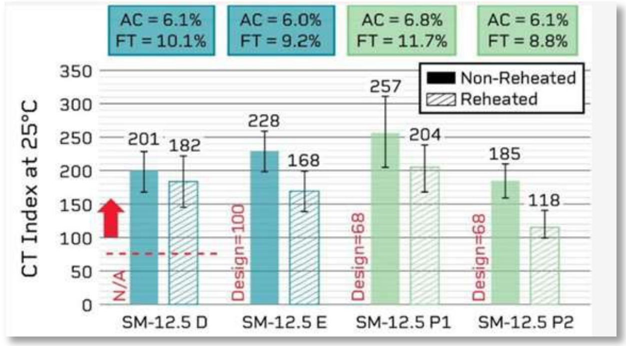

Figure 8: CT Index Test Results

The CT Index results depicted in Figure 8 come from trials conducted with the Virginia Department of Transportation (VDOT) in September of 2021. This round of testing compared two trials of RPA mixes (green) against two different grades of polymer modified bitumen mixes (blue). Their 'D' designation corresponds with a performance grade of PG 70-22, while their 'E' designation corresponds with a PG 76-22 performance grade (Virginia, 2011). As can be seen, recycled plastic mixes yielded results similar to or exceeding those of the two polymer modified mixes, with the average of the two trials outperforming the SM-12.5 D mix while just underperforming when compared to the SM-12.5 E mix. These figures indicate RPA mixes yielding a finished product which exhibits a resistance to cracking on par with current polymer modified bitumen mixes.

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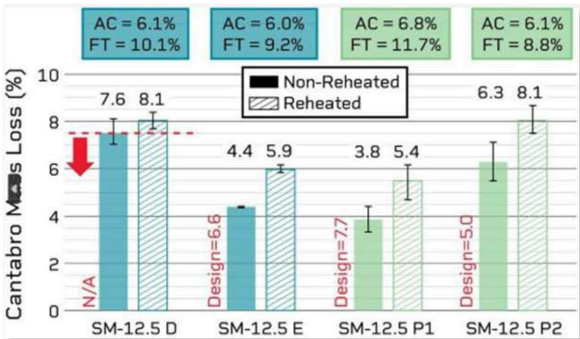

Figure 9: Cantabro Mass Loss Test Results

Cantabro Mass Loss testing was also conducted in that same 2021 VDOT pilot study, once again comparing two trials of recycled plastic mixes (green) against two different grades of polymer modified bitumen mixes (blue). The results can be seen in Figure 9. On average, the RPA mixes exhibited greater mass loss values than the SM-12.5 E mix, but lower mass loss values than the SM-12.5 D mix, once again, illustrating that RPA mixes are consistent with or outperform current polymer modified bitumen options. The results of both the CT Index tests and the Cantabro Mass Loss tests allowed this specific recycled plastic mix to qualify and act as “D Premium Mixtures” per VDOT standards.

After understanding the benefits of these products, it is critical to realize the importance of responsibly sourcing the plastics that are used to create these additives. The decision to use recycled plastics vs new plastics can be the difference between achieving the goal of having a net-positive environmental impact, and directly adding to current emission outputs. While there are no direct performance impacts as a result of new vs recycled plastics (assuming that both pass quality control measures), using recycled plastics directly diverts plastic from landfills, resulting in another source of environmental saving. When new plastics are manufactured for this process, added emissions accrue, greatly limiting the environmental benefits of the product. The recycled aspect of these products is what truly sets plastic apart from conventional asphalt when it comes to sustainability, and thus the focus of these products should remain on recycled plastics.

Along a similar line of sustainability, two prominent areas of environmental concern when discussing the utilization of plastics, and more specifically, the melting of plastics, are additional fume generation and the creation and dispersion of microplastics. Once again, it is important that these products remain an environmental benefit and not create additional lines of ecosystemic hardship down the road. As with many aspects of these materials, results may vary based on manufacturer and specific product. That

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being said, each manufacturer that provided input for the creation of these guidance documents had received 3rd party testing on their materials. Each manufacturer had independently found that their products did not see an increase in fume generation nor an increase in microplastics generated. In some cases, microplastic levels were even shown to decrease with the inclusion of RPAs, suggesting that the additives actively help prevent the shedding of microplastics as a result of the additional bonding (New Village, 2021).

Key Takeaways:

- RPAs have been used successfully since 2018, with studies showing they enhance durability, increase RAP usage, and match or outperform polymer-modified bitumen.
- RPAs reduce virgin oil use, cut costs, and divert plastic waste from landfills, but using recycled plastics is key to maximizing sustainability.
- Studies show no increase in fume generation or microplastics from RPAs, with some evidence suggesting they reduce microplastic shedding through improved bonding.

CONCLUSION

Recycled plastic asphalt products not only benefit the industry in terms of sustainability but also have mechanical and potential economic advantages as well, depending on the brand chosen.

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The asphalt industry has made commendable environmental efforts in recent years but there is still work to be done to achieve both local and national carbon neutrality goals. There are tens of thousands of metric tons of CO2 that could be saved by each asphalt plant each year. Agencies that produce just 100k tons of asphalt annually could potentially save up to 1,488 metric tons of CO2 each year, diverting 1.2 million pounds of plastic in the process. To put that into perspective, that equates to:

- 11,420,697 plastic bottles
- 49,482,764 plastic bags
- or 647,988,571 plastic straws

Those numbers only grow with each additional ton of asphalt produced. RPAs provide a viable and already-existent step forward in meeting local and national emission goals by increasing RAP allowances and extending binder. This reduces the use of virgin binder, in turn providing economic benefits to plants when used correctly. These additives also hold the ability to enhance asphalt performance at varying degrees dependent on product, in notable areas such as fracture resistance and resistance to deformation. This unique amalgamation of benefits speaks loudly to the viability of recycled plastic asphalt additives in San Diego County and beyond.

Key Takeaways:

- RPAs save 1,488 metric tons of CO2 and divert 1.2 million pounds of plastic per 100k tons of asphalt.
- RPAs cut virgin binder use, boost RAP allowances, and support carbon neutrality goals.
- RPAs enhance fracture and deformation resistance in asphalt.

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