ABSTRACT

Waste management has two main problems: the lack of adequate space and disposal infrastructure, which lead to serious environmental issues. By applying circular economy principles, reusing and recycling by-products, combined with technologies that reduce energy consumption during production, can produce a holistic approach to tackle the ongoing concern. This research focused on unveiling the potential beneficial effect of using two by-products in the production of cold recycled asphalt mixtures and cementitious composite.

Over 90% of the national roads are paved with asphalt. Traditionally, the hot mix asphalt (HMA) is used for paving highways. However, HMA releases higher amounts of GHGs and pollutes the environment. In that sense, the use of low-temperature paving technologies with the use of reclaimed asphalt pavement (RAP) in asphalt mixtures has been promoted. The combination of these two approaches leads to a more environmentally friendly technology known as cold recycling. However, the main disadvantages of cold recycled mixtures (CRM) are that they demand more curing time and present lower mechanical performance, related to their higher air void content, than traditional HMA.

Based on this, the first part of this research delved into adding a carbon by-product, carbon black (CB), into the CRM composition. Different CB ratios (5%, 10%, 15% by volume of asphalt binder) were blended in CRM prepared with 100% RAP and emulsified asphalt. The compactability, volumetric, and mechanical properties were investigated. Findings suggest that CB addition generates a dual beneficial effect by enhancing compactability and increasing the mixture cohesion of the CRM samples. Specifically, 10% by binder volume produced a significant improvement. On the other hand, CB weakens the interface zone of CRM in climates with freeze-thawing (F-T) cycles like Indiana. Still, CB is a material with a high electrical conductivity, property that can be leveraged to overcome the previous finding.

According to the FHWA, around 70% of the national territory is covered with snowfall and ice during winter. This problem leads to around 25% of car accidents and $2 billion in maintenance services. Conventionally, mechanical and chemical treatments such as snow-plowing and de-icing salts are used for this purpose. Nevertheless, these treatments negatively impact the pavement's durability and service life. There have been former studies on how carbon-fillers can produce electrically conductive asphalt pavement using HMA, but the economic aspect limited its application. A by-product like CB with CRM, their synergically utilization can represent an opportunity to develop a sustainable electrically conductive pavement. Moreover, the assessment of electrical conductivity in CRM containing CB remains unexplored. Outcomes of this study indicate that CB inclusion remarkably improves the electrical conductivity of CRM mixtures. In fact, the minimum required to produce an electrical threshold was 15% by asphalt binder volume. Furthermore, this percentage can potentially develop a controlled-curing cold mix asphalt system. This carbon-modified pavement might have other capabilities such as self-healing, snow-melting, and RAP binder reactivation that can be applied to fight the CRM drawbacks and winter impact.

The second part of the research investigated the impact of using a plastic by-product, recycled polypropylene (PP) fibers, into cold recycled mixture and cementitious composite. Plastics are used in every industry, but the main problem is their proper waste management. FHWA's policies allow plastic usage in the pavement composition. Some researchers showed that recycled PP fibers have improved the mechanical behavior of HMA in terms of rutting resistance and Marshall stability, but other properties were negatively affected such as indirect tensile strength. Similar results have been found in cold mix asphalt (CMA), but the studies have only included virgin plastic in the CMA composition. From this gap, the incorporation of recycled PP plastic in the CRM mixture was studied using a 0.2% by weight of aggregate. Results exhibited that recycled PP fibers increase the air voids after curing and reduce the mixture cohesion between emulsified asphalt and the recycled plastic. However, when CRM samples were compacted to reach the same air voids after curing, the indirect tensile strength was similar in the CRM mixtures with and without plastic in dry conditions. Contrary, the effect of recycled PP plastic in CRM was detrimental for F-T cycles.

For the cementitious composite, substituting fine aggregate with recycled PP fibers was investigated in mortars. Some researchers have already studied the effect of recycled PP fibers on mortars and concrete. The main outcomes discussed the benefits of this addition, such as increased flexural strength, abrasion resistance, and fire resistance, but there were also drawbacks like reduction in compressive strength and slump. Nonetheless, the effect of fiber length of recycled PP on the mechanical and thermal performance of mortars has not been explored. Three different fiber lengths were tested (10, 20, and 30 mm) with four different percentages of replacement (0, 0.5, 1, 2, and 3% by volume of sand). Results exhibit that the substitution of fine aggregate for recycled PP fiber produces a mortar with higher flexural strength in comparison to plain mortar. The 20-mm fiber length performs better than the 10-mm and 30-mm fiber lengths. There was no trend for the fiber length on the compressive strength and thermal conductivity, but the recycled PP fibers can produce a mortar with thermal insulator properties. In addition, despite the trend to reduce the compressive strength, the 20-mm fiber length displayed a minimal loss, less than 5% to the plain mortar. After comparing the effect of recycled PP fibers in both composites, they were more beneficial for cementitious composites than cold recycled mixtures.

In conclusion, the use of by-products in the transportation and construction sectors can lead to tackle the waste management, to enhance the mechanical performance of the composite materials, and to overcome technical challenges through novel proactive approaches.