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Publication date
2023

Document Version
Final published version

Citation (APA)
Jing, R., Apostolidis, P., Liu, X., Naus, R., Erkens, S., & Scarpas, A. (2023). *Recyclability of epoxy-modified open-graded porous asphalt*. Paper presented at Advances in Materials and Pavement Performance Prediction 2022, Hong Kong, Hong Kong.

Recyclability of epoxy-modified open-graded porous asphalt

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ABSTRACT: Epoxy asphalt attracted the attention of road authorities in many countries as a solution for durable open-graded porous asphalt (OGPA) surface layers with enhanced longevity. Nevertheless, the recyclability of aged epoxy asphalt materials has not been thoroughly studied yet. This research presents an experimental program conducted in the laboratory to assess the potential recyclability of epoxy-modified open-graded porous asphalt (EMOGPA) mixes. Results indicate that the aging increased the tensile strength of studied mixes, with the strength and strength development rate of aging EMOGPA mixes to be almost identical to standard OGPA mixes. The EMOGPA mixes have shown higher resistance against water damage than the OGPA mixes supporting the claim that the stone-mastic adhesion is improved with the use of epoxy binder. It was also proven that the aged material containing the epoxy binder could be re-melted to produce new pavement materials. The new EMOGPA mixes with the recycled epoxy material exhibited similar durability characteristics with the recycled standard OGPA mixes.

1 INTRODUCTION

Epoxy asphalt attracted the attention of road authorities in many countries as a solution for OGPA surface layers with enhanced durability and longevity (ITF 2017). Notably, epoxy asphalt is a two-part thermosetting binder consisting of an epoxy resin and a specially formulated binder. Once the two parts are mixed, curing reactions happen, leading to a binder of rubbery characteristics. Epoxy asphalt has been found to have high strength, stiffness, toughness, and aging resistance (Youtcheff et al., 2006; Herrington & Alabaster 2008; Widyatmoko & Elliott 2014; Apostolidis et al., 2020 & 2022). Nevertheless, the recyclability of aged epoxy asphalt materials has not been thoroughly studied yet. Only a few works provided preliminary laboratory results demonstrating that the reclaimed asphalt pavement materials containing epoxy-modified asphalt binders would be re-melted and re-used for new asphalt mixes (Alamri et al., 2020 & 2022; Jing et al., 2021a). The potential of using these aged materials in new pavements plays a pivotal role in enabling the wider acceptance of this technology, especially in countries with strict sustainability requirements. In this framework, this research presents a program conducted in the laboratory to assess the potential recyclability of EMOGPA designed for Dutch roadways. The performance characteristics of the new, aged, and recycled EMOGPA mixes were compared with these of standard OGPA mixes.

2 MATERIALS AND METHODS

2.1 Materials

The experimental program designed for the scope of this research includes one aggregate type, one aggregate gradation (PA 8G, commonly used in the Province of Gelderland, the Netherlands), and two binder types. Fibers (i.e., pelletized blend of 20% by weight cellulose fibers and 80% by weight of Fischer-Tropsch wax) were added in all three mixes by 0,3% (by mass of aggregates) to increase the allowable amount of binder in the mixes and prevent the excessive drain-down of binders during construction. Note that thick asphalt binder films around the mineral aggregates are desired to increase the stone-mastic adhesive bonding and aging resistance and avoid raveling. Thin binder films oxidize quickly, exacerbating the failure due to raveling. In this regard, the optimum binder content was 6,0% (by mass of aggregates) in all mixes.

A 70/100 PEN binder commonly applied in the Netherlands for OGPA mixes was used to produce the studied mixes. The epoxy binder consists of Part A (i.e., epichlorohydrin – bisphenol A) and Part B (i.e., a mix of a 70 pen petroleum binder with heavy naphthenic distillates and extracts). This epoxy binder was added to the standard 70/100 PEN binder in a percentage of 25% (by mass of binder) to fabricate the EMOGPA mixes (Apostolidis et al., 2020). According to the experience in New Zealand (Herrington & Alabaster 2008; Herrington 2010), it has been concluded that this epoxy-asphalt ratio can balance successfully between cost and performance as the original price of the neat epoxy asphalt binder is high.

2.2 Specimen Fabrication for Aging Studies

Although all mix samples were conditioned and tested under the same conditions, the pre-heating and mixing temperatures differed. For the control OGPA mixes, the 70/100 PEN binder was oven preheated at 155 °C for 4 hrs. The mineral particles were to be preheated at the same temperature overnight to ensure they were warm enough for mixing. The mixing of OGPA components was performed at 155 °C for at least 4 mins, and immediately afterward, the loose mix was compacted.

The fabrication of EMOGPA required some extra steps to simulate the actual field operations since these mixes are thermosetting. The EMOGPA mixes were made with Parts A and B of epoxy binder heated separately for 4 hrs at 135 °C and 85 °C, respectively. The minerals were also held at 135 °C overnight. Parts A and B and the 70/100 PEN binder were blended at 135 °C for 1 min before being added minerals. The mixing of all components was performed at 135 °C as well for 4 min. The newly produced loose mix was held at 135 °C for 2 hrs before compaction to simulate the mix manufacturing operations to ensure that the mix viscosity is acceptable for compaction. In this way, it was expected to minimize the variation in the compaction density obtained from the laboratory and field studies.

A rolling wheel compactor was used to compact slab specimens of 50-mm height in a 500-mm by 500-mm steel mold. In accordance with AASHTO R30, oven conditioning of specimens at 85 °C for 120 hrs corresponds to 5- to 10-year field aging. In this study, the compacted specimens were subjected to oven aging for 12-weeks at 85 °C to simulate longer field aging. After aging, the slabs (height of approximately 50-mm) were drilled into cylindrical specimens of 100-mm in diameter. All specimens were prepared with three replicates for each sample.

2.3 Specimen Fabrication for Recycling Studies

The aged specimens, which were preheated at 130 °C for 1 hr, were broken into small pieces to produce the reclaimed asphalt (RA) materials. The RA materials from two mixes were sampled, and the binders were extracted from mixes using an automatic apparatus (EN 12697-1). During the extraction process, methylene chloride was used as a solvent. To separate binders out of solvent, a rotary evaporator was used according to EN 12697-3. To restore the rheology of the aged binders to their original state, a certain amount (i.e., 25%) of a 160/220 PEN grade asphalt binder was added to simulate one of the common hot recycling processes in asphalt plants.

Three recycling levels were evaluated (50, 75, and 100% wt. of RA materials of OGPA and EMOGPA). For this purpose, the soft binder was applied to the aged loose mixes, which were already preheated at 130 °C for 1 hr. To keep the mixing temperature consistent, the virgin aggregates used to produce the recycled mixes were pre-heated. The wet mixes were placed in the oven at the same temperature for another 1 hr to ensure that the mixes were warmed uniformly. As for the fabrication of specimens for aging studies, the gyratory compaction was utilized with a height controlled, and the same gradation was used for all recycled mixes. Note that the soft binder was not applied to the mixes with 100% RA to demonstrate the potential to remelt the epoxy-modified asphalt mixes.

2.4 Characterization Methods

Asphalt durability is the preservation of the structural integrity of compacted mixes over their expected service life when exposed to the effects of the environment, such as oxygen, temperature, water, and traffic loading. In this research, the effects of aging on two mixes were quantified phenomenological by performing indirect tensile tests at 15 °C (NEN-EN 12697-23) and determining the indirect tensile strength (ITS). All specimens were kept at 15 °C for a minimum of four hours before testing. The indirect tensile results presented were the mean values of three replicates. A representative graph of the overall responses of OGPA and EMOGPA mixes is shown in Figure 1.

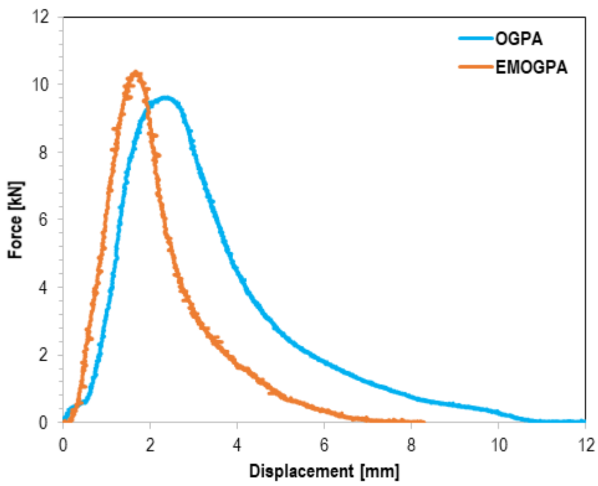

Figure 1. Representative force versus displacement curves of studied mixes (after 6-weeks oven-aging).

The studied mixes could be prone to water damage if the stone-mastic bonds weaken in the presence of water. The water sensitivity of the two mixes was evaluated by the indirect tensile strength ratio (ITSR) (NEN-EN 12697-12). Then, the ITS values were measured and compared with the ITS values of unconditioned specimens. The results of this procedure were the ratio of ITS values with and without water damage or the ITSR values. The ITSR values of mixes were also determined for all age conditioning periods. The minimum threshold ITSR value for accepting a mix is set at 80%, according to Dutch specifications. The same characterization program was followed for the recycled mixes.

3 RESULTS AND DISCUSSIONS

3.1 Aging

Figure 2a shows the ITS for all two mixes over four different oven aging periods. The ITS values of EMOGPA mixes were almost identical with OGPA after 12-weeks of aging, while these mixes have shown a similar increasing rate of ITS. The ITSR values of all mixes are also shown in Figure 2b, where these values of EMOGPA show an increasing trend with the longer oven-conditioning periods. After 12-weeks of oven-aging, the ITSR values of OGPA and EMOGPA were 86% and 92%, respectively, indicating that the addition of epoxy binder increases the resistance of open-graded asphalt materials against water damage. This observation is consistent with earlier studies on epoxy asphalt concrete mixes (Luo et al., 2015; Qian & Lu et al., 2015; Wu et al., 2017).

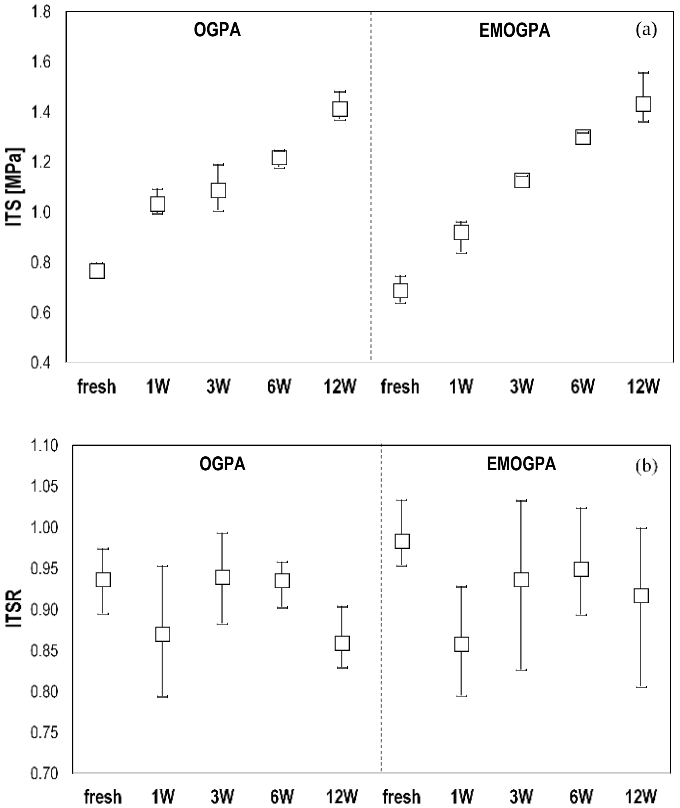

Figure 2. Effect of aging on indirect (a) strength and (b) strength ratio test results of studied mixes.

The benefits of the epoxy part in bitumen are mainly apparent after long-term aging (Apostolidis et al., 2022; Jing et al., 2021a). The 12-weeks of oven aging might not sufficiently reflect the positive influence of epoxy in bitumen. Longer time aging lengths in the oven would be recommended, which is also supported by (Wu et al., 2017). Nevertheless, in this contribution, the ultimate goal remains the reusability of the EMOGPA mixes. It is believed that the 12-weeks of oven aging is enough time to ensure that the materials are adequately hardened to perform recyclability analyses in EMOGPA mixes.

3.2 Recycling

The indirect tensile strength of recycled OGPA and EMOGPA mixes in relation to the proportion of added recycled OGPA and EMOGPA aggregates was evaluated. The representative graphs of the response of the recycled mixes with different amounts of RA material are shown in Figure 3.

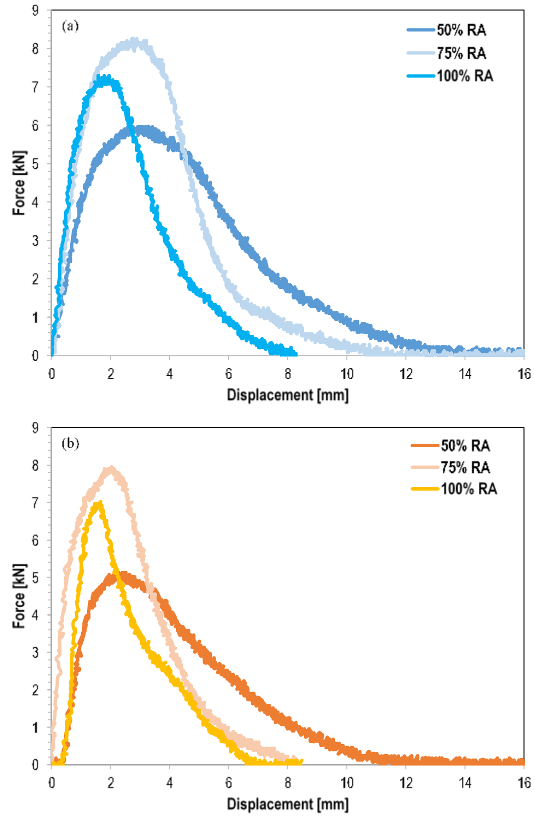

Figure 3. Representative force versus displacement curves of recycled (a) OGPA and (b) EMOGPA mixes.

Based on these graphs, it can be concluded that the EMOGPA mixes developed with 100% RA can be re-melted and re-used without applying any recycling agent, as it illustrates an identical mechanical response with the 100% recycled OGPA mixes. The ITS values of 100% recycled OGPA and EMOGPA mixes were 0,93 and 0,89 MPa, respectively (see Figure 4). The ITS values of both OGPA and EMOGPA mixes containing 75% of recycled materials (i.e., 0,96 MPa for OGPA and 0,97 MPa for EMOGPA) were higher than those of the 50% (i.e., 0,66 MPa for OGPA and 0,60 MPa for EMOGPA) of recycled materials, mainly due to the softening effect of added binder (see Figure 4a). Mixes containing recycled EMOGPA materials exhibited sufficient ITS values without remarkable strength differences with mixes produced by replacing new aggregates with recycled OGPA materials. The ITSR values of both recycled OGPA and EMOGPA were almost identical (see Figure 4b). The ITSR values are greater than 80% in OGPA and EMOGPA mixes containing 50% and 75% of RA materials, fulfilling the requirement prescribed by the specification. Water resistance issues were noticed in 100% recycled mixes, but it should be considered that no soft binder or other recycling agent was utilized to develop them. Overall, no remarkable differences in the ITS and ITSR values were observed when the new aggregates in mixes were replaced with recycled materials with epoxy.

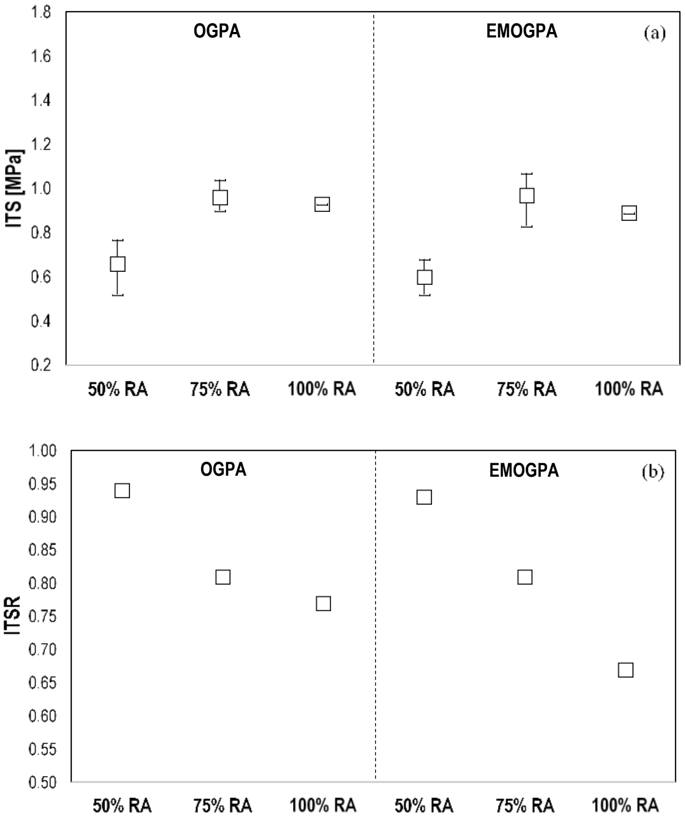

Figure 4. Effect of recycled material on indirect (a) strength and (b) strength ratio test results of studied mixes.

4 CONCLUSIONS

The main objective of this study was to evaluate the durability characteristics of new, aged, and recycled epoxy-modified open-graded asphalt (EMOGPA) mixes. These mixes are also compared with the standard open-graded porous asphalt (OGPA) mixes, and the main findings are summarized as follows:

- EMOGPA mixes have shown the highest resistance against water damage dictating that the stone-mastic adhesion strength is improved with the use of epoxy binder.
- The strength of both OGPA and EMOGPA mixes containing 75% of recycled materials was higher than those with 50% of recycled materials, mainly because of the softening effect of the applied bituminous binder. No remarkable differences in the water susceptibility were also observed when the new aggregates in mixes were replaced with recycled materials, with the mixes with 50% and 75% of recycled materials to fulfill the water resistance requirements.
- EMOGPA mixes developed with 100% recycled epoxy material exhibited similar durability characteristics with OGPA mixes containing 100% recycled asphalt materials without applying any recycling agent. This response dictates that the aged material containing the epoxy diluted asphalt binder can be re-melted and re-used to produce new road materials.

5 ACKNOWLEDGMENTS

Financial support from the Province of Gelderland and Province of Noord Holland on the Epoxy-modified Asphalt project is gratefully acknowledged. The authors thank ChemCo Systems for supplying the materials.

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