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A simple treatment of electronic-waste plastics to produce asphalt binder additives with improved properties

Mohd Rosli Mohd Hasan [a], Baron Colbert [b], Zhanping You [c,*], Ali Jamshidi [d], Patricia A. Heiden [e], Meor Othman Hamzah [a]

[a] School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Seberang Perai Selatan, P. Pinang, Malaysia
[b] Keweenaw Bay Ojibwa Community College, 111 Beartown Road, P.O. Box 519, Baraga, MI 49908, USA
[c] Department of Civil and Environmental Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931-1295, USA
[d] Japan Society for the Promotion of the Science (JSPS), Faculty of Engineering Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan
[e] Department of Chemistry, Chemical Sciences and Engineering Building, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931-1295, USA

HIGHLIGHTS

- Pavement durability was improved using electronic-waste plastic to modify bitumen.
- We compared effects from an “activated” e-waste (e-waste + ROOH) and untreated e-waste.
- The activation promotes molecular bonding between e-waste plastics and asphalt.
- Both modified asphalt binders were stiffer and more elastic than the control binder.
- The activated e-waste modification gave the best results.

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ABSTRACT

This study evaluated the performance of e-waste modified asphalt binders. E-waste modifiers Acrylonitrile Butadiene Styrene (ABS), Acrylonitrile Butadiene Styrene-Polycarbonate (ABS-PC) and High Impact Polystyrene (HIPS) were used after 100% of the material passed through a #50 (300 μm) sieve. A conventional asphalt binder, PG58-28 binder, was used as a control. The e-wastes were blended with the control binder as untreated (UT) and chemically treated (T) modified binders. Chemically treated (T) modifiers were processed with cumene hydroperoxide before blending into PG58-28, to promote covalent molecular bonding between the e-waste plastic and asphalt. Results showed that untreated e-waste modified asphalt binders were stiffer and more elastic behavior than the control binder, but when these same e-waste plastics were first treated with cumene hydroperoxide, the increases were significantly higher. Use of chemically treated e-waste modifiers also significantly improves the resistance to rutting of asphalt binders, as shown by the work dissipated per loading based on the analysis conducted at 1.59 Hz. The improved results are attributed to the cumene hydroperoxide promoting direct covalent molecular bonding between e-waste plastic powders and the asphalt binder. These results suggest that when polymer modifiers are used in asphalt, radical reactions, at least at the interface with the modifier, should be promoted rather than prevented by added radical inhibitors.

1. Introduction

The use of polymers in asphalt pavements has grown rapidly since the early 1970s [1], though the earliest patented modification process of polymer modified asphalt was more than 100 years earlier, in 1843 [2]. Previous studies showed that the modification of asphalt binders using polymer materials significantly improved the properties of asphalt material in several ways, such as a reduction in temperature susceptibility, improved rheological characteristics, and enhanced material durability [2–8]. These enhancements can be seen through the improved functional properties of bituminous pavement, which include the resistance to rutting, fatigue, low temperature cracking, stripping, wear resistance, and aging [2,9,10]. The most common polymers used to modify the performance of bituminous binders are styrene butadiene styrene

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* Corresponding author.
E-mail address: zyou@mtu.edu (Z. You).

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(SBS), styrene-butadiene rubber (SBR), ethylene-vinyl acetate (EVA), as well as virgin or waste polyethylene modifiers [6,11,12]. They are used because of their engineering behavior, (influenced by the morphology of the composite), availability, and lower production costs [12–14]. According to Airey [6], SBS copolymers derive their strength and elasticity through the cross linking of their molecules into a 3-D network. The rigid polystyrene end blocks are thought to convey their strength to the polymer while the center polybutadiene block gives the asphalt binders exceptional elasticity. However, Isacsson and Lu [5] and Whiteoak [15] stated that the effectiveness of crosslinking molecules in asphalt binders deteriorates rapidly above 100 °C, the glass transition temperature for polystyrene. The strength and elasticity of the polystyrene domain copolymer are restored though when the temperature falls below 100 °C.

Another potential, but still little studied, material additive for asphalt binder modification is electronic waste (e-waste) plastic. E-waste comprises approximately 23.3% by weight of computers that are disposed of worldwide [16]. The rapid growth of electronic gadgets and computer technologies is making e-waste disposal a significant issue, resulting in negative environmental impacts [17]. The utilization of e-waste to modify asphalt not only relieves pressure on landfills by providing a valuable use for electronic waste plastics but also leads to substantial savings in infrastructure resources. Several studies have been conducted involving the use of e-waste include: Yokoyama and Iji [18], Anandhan et al. [19], Li et al. [20], Achilias et al. [21], Jeong et al. [22], Colbert and You [23,24] Perez-Belis et al. [25], Wang and Xu [26], and Mueller et al. [27]. A recent study by our group, Colbert and You [23] and Colbert et al. [28], studied the benefit of using Acrylonitrile Butadiene Styrene (ABS) and High Impact Polystyrene (HIPS) plastics as asphalt binder modifiers. The results showed that the e-waste modified asphalt binders met the virgin binder high temperature performance criteria. Furthermore, the e-waste modified asphalt binders were found to be stiffer at low temperatures compared to virgin asphalt binders. The addition of low percentages of e-waste yielded an adequate low temperature performance compared to neat asphalt binders.

In addition to the use of e-waste to improve the properties of asphalt binders, the addition of free radical initiators was also tested in this study to enhance the performance of e-waste modified asphalt binders. Peroxide and hydroperoxide initiators like cumene hydroperoxide (CHP) decompose to produce alkoxy ($RO^{\cdot}$) and/or hydroxy ($HO^{\cdot}$) radicals (Fig. 1) that can go on to abstract a labile hydrogen (as $H^{\cdot}$) from the plastic and/or the asphalt, thereby producing new radical (Fig. 2). These new radicals can then couple giving covalent bonding between the additive and the binder to promote interfacial adhesion and between different parts of the asphalt itself to enhance branching (Fig. 2). Fig. 3 shows how a new radical ($RO^{\cdot}$) produced as shown in Fig. 1, can abstract an $H^{\cdot}$, leading to a reactive radical on a polymer backbone (e.g. a styrene unit in ABS or SBS with the labile H atom shown in bold) or a labile hydrogen on hydrocarbon components that are commonly present in bituminous asphalt (the above representative aromatic component shows seven labile hydrogen atoms) leading to new reactive radicals. The last line in Fig. 3 shows the coupling of radicals, such as a styrenic radical from e-waste (e.g. ABS) and a radical on an activated aromatic component of asphalt.

$$RO{-}OR \xrightleftharpoons{\text{heat}} RO\cdot \; + \; \cdot OR$$

Fig. 1. Peroxide (ROOR) and hydroperoxide (one or both R's = H) free radical initiators decompose to produce alkoxy ($RO^{\cdot}$) and/or hydroxy ($HO^{\cdot}$) radicals that will initiate chemical changes leading to interfacial adhesion.

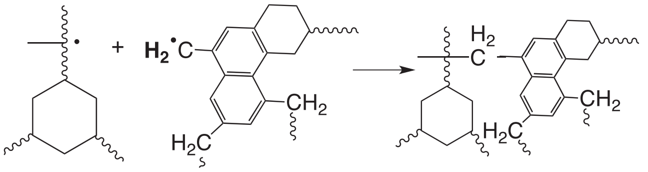

Fig. 2. Example of how generated radicals may lead to increased branching in asphalt components. Here, a representative activated aromatic radical couples with a representative activated saturate radical.

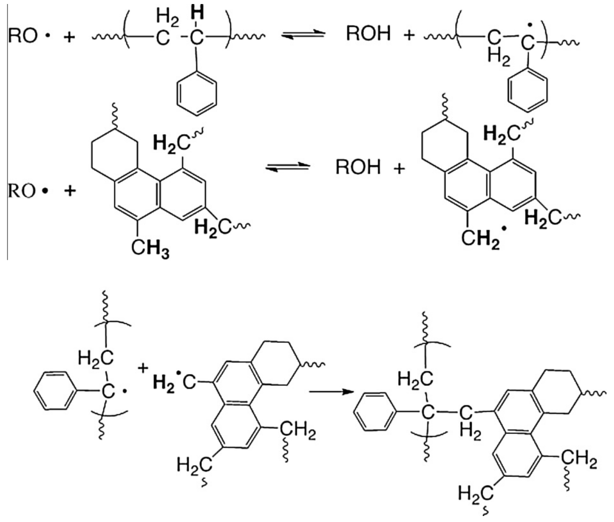

Fig. 3. Reaction sequence showing how a radical initiator (e.g. RO–OR) forms reactive radicals. Here we should abstraction of an $H^{\cdot}$ from a styrene repeat unit and from a representative asphalt hydrocarbon, which then couple, giving branching by covalent bond giving a strong interface.

These bonding scenarios were proposed to show how radical reactions can be used beneficially to improve the tensile strength, intermolecular interaction, and the molecular weight of an e-waste modified asphalt binder. However, in contrast to this approach, other studies have investigated the possible benefits of preventing radical reactions in asphalts. A study conducted by Li et al. used anti-oxidants as free-radical scavengers to prevent radicals from reacting and altering the more susceptible butadiene block in styrene-butadiene-styrene (SBS) modified asphalt (5%), and by doing so, improved the aging resistance of [29]. A typical anti-oxidant scavenging reaction is illustrated in Fig. 4. However, it is important to recognize that butadiene repeat units possess C=C bonds and that bond can react over time, making that segment more brittle. Here, we are targeting different radical reactions that can promote branching and covalent bonding between the polymer modifier and asphalt binder. The effects of these modifications on aging remain to be studied.

The ultimate goal of this study is to demonstrate that there is value in using e-waste plastic in the bituminous materials to

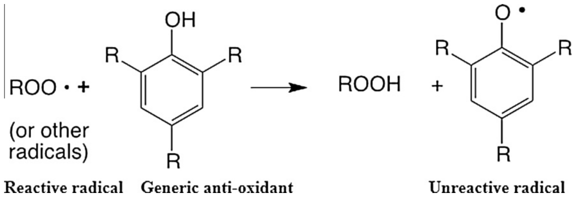

Fig. 4. Reaction showing how a typical anti-oxidant works by providing an easily abstracted $H^{\cdot}$, and leaving behind a new but unreactive radical.