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Sealed accelerants facilitate epoxy asphalt concretes opening to traffic quickly

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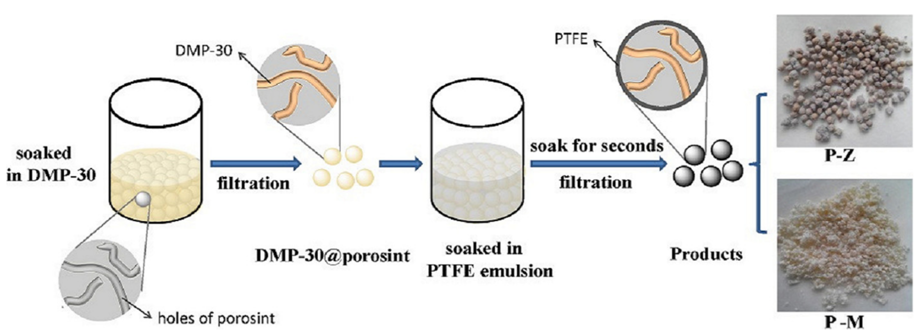
HIGHLIGHTS

- Sealed macroporous resins and accelerants microcapsules were made, respectively.
- Sealed macroporous resins containing accelerants quicken epoxy asphalt post-cure.
- This approach facilitates epoxy asphalts to be ideal long-life paving materials.

GRAPHICAL ABSTRACT



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ABSTRACT

Epoxy asphalt composites (EACs) have been recommended to be a prior choice to obtain long-life pavements. However, the present anhydrides-cured EACs have to be field-maintained in high summer for over 45 days to achieve their ultimate performance. To be opened to traffic immediately, sealed accelerants, triggered by the compact pressure when paved, were employed to accelerate post-cure of EACs. Compared with microcapsules complicatedly synthesized by interfacial polymerization, sealed macroporous-resins containing accelerants, which was simply prepared by covering accelerant-soaked macroporous-resins with polytetrafluoroethylene (PTFE), made it possible to be opened to traffic quickly. It is attributed to the bigger capsule sizes and higher encapsulation efficiencies for them to be easier crushed by aggregates and encapsulate enough accelerants to be released when compacted. This paper reports the facile, low-cost and scalable approach to make anhydrides-cured EACs open to traffic quickly which facilitates EACs to be ideal long-life paving materials.

1. Introduction

The OECD/ECMT (Organization for Economic Co-operation and Development, European Conference of Ministers of Transport) Joint Transport Research Centre has piloted an international collaborative research program on the economically paving materials for long-life pavements [1]. Results indicate that epoxy asphalt composites (EACs), which have been widely used to pave steel deck bridges and the similar heavy loading traffic roads [2–5], show the great potential to be a better choice to achieve long-life roads [1,6–8].

Usually, EAC is a two-component system that results from the reaction of asphalt including curing agents (component A) with

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epoxy resin (component B) [1]. According to the curing agents, EACs are categorized to amine-cured EACs and acid-cured EACs (including anhydrides-cured EACs) [1,9–14]. Their paving processes differ from conventional asphalt concretes for the curing reactions involved, but somewhat like the hydration of cement binders, as shown in Fig. 1(solid lines). Typically, the two well-weighted components are heated to a high temperature (e.g., 120 °C for acid-cured systems, which is primarily determined by the curing agents), respectively; then, the two components are quickly blended to be homogeneous at this high temperature. Consequently, hot aggregates (e.g., 120 °C, the same temperature as the epoxy asphalt binder) are uniformly mixed with the epoxy asphalt binder. All above-mentioned operations have to be finished in a period of time (i.e., pot life, determined by the specific curing systems and operation temperatures, usually, greater than 45minutes for acid-cured EACs.), otherwise, the EAC would be chemically gelled, and could not be operated. That is, the operating temperatures of EAC, especially here used Ningjue®2910, have to be strictly controlled in the range of 110 °C to 121 °C. Then, this hot mixture (including the aggregates and the epoxy asphalt binder) is maintained for 3 h at 120 °C to achieve their stable Marshall Stabilities ultimately in the lab [9,10]. Otherwise, in the field, the hot mixture is transported to the paving site using heat-preserved trucks, paved and compacted (Fig. 1, Field stage I, solid lines). However, once it is paved, temperature of the asphalt mixture drops rapidly to the neighborhood of ambient temperature; and thus, the curing reaction rates among epoxy resin and acids (and/or anhydrides) slow down quickly. Surely, initial Marshall Stabilities of EAC concretes are greater than those of the traditional thermoplastic modified asphalt mixtures; and they are strong enough to support common traffic loadings. Specially, unlike traditional thermoplastic asphalt binders, the EACs have poorer self-healing ability as they are (quasi-)thermosetting. Namely, once they were damaged, they could not heal themselves like thermoplastic binders with an increase of temperature. Therefore, to avoid the damage caused by initial heavy overloads and obtain the excellent ultimate performance, site paved acids-cured EAC concretes are not opened to traffic immediately when paved but maintained for a long time to obtain greater values of Marshall Stability (Fig. 1, Field stage II, solid lines). Based on the empirical Arrhenius equations of chemical reaction rate theory or van't Hoff approximation rule:

$$\frac{k_{T+10}}{k_T} = 2 \sim 3 \qquad (1)$$

where k_T and k_{T+10} represent chemical reaction rate at temperatures of T K and (T+10) K, respectively, to accomplish/approach the same curing reaction extent to that of labs (i.e., 3 h at 120 °C), the EAC is heat-maintained in hot summer for a long term, e.g., about 45 days experienced in the pavements of Nanjing Changjiang 2nd Bridge (2000, China) and Nanjing Changjiang 3rd Bridge (2005, China) [15,16]. Furthermore, if acids-cured EACs were paved at cold regions or the pavement bridges would have to be opened to traffic immediately, heating devices would be necessary, e.g., 3000 sheets of electric blankets were used to heat the paved EAC surface for 13 days at Daguangming Bridge (April 15th to May 1st 2007, Tianjin, China) [17]. Undoubtedly, they are highly time- and energy-consuming processes. To overcome the shortcomings, some amine-cured EACs have been presented [16,18,19]. However, they are more expensive than acid-cured EACs.

Microcapsule, as a control and release method, has been extensively applied in self-healing systems or the likes, such as microencapsulated epoxy resins or other functional materials [20–25]. Also, it was employed for rejuvenation of paved asphalt materials [8,26]. In general, inside active materials of microcapsules are separated from outside matrix by capsule shells before they were destroyed. Once shells of the microcapsules are cracked, the inside active materials will be released to affect the composite's matrix [27,28]. Inspired by the control and release mechanism, we conceived that, to keep the pot life of EAC, the curing accelerant was encapsulated; and it was released triggered by the pressure to speed the post-cure process of EAC when compacted, as shown in Fig. 1 (yellow dash lines).

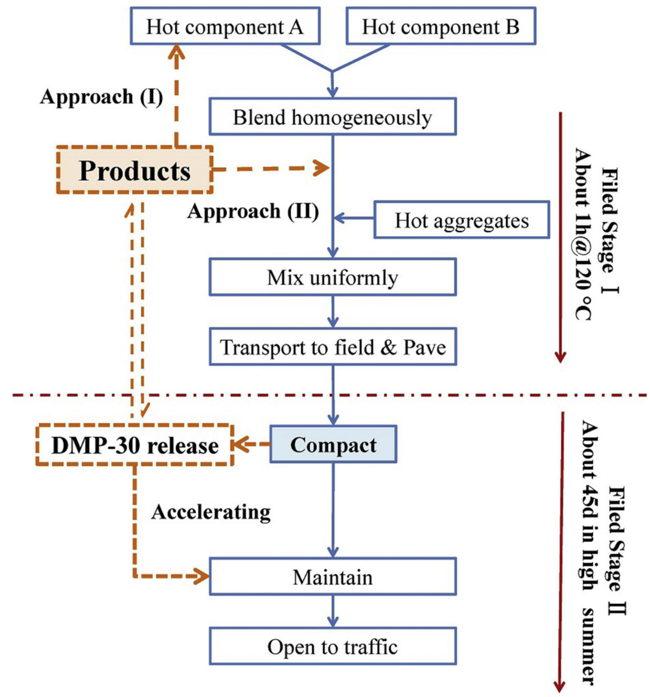

Fig. 1. The processes of EAC's pavement with and without encapsulated DMP-30 accelerants. Solid lines describe the common process of EAC's pavement, and dash lines represent the conceived process for accelerating post-cure of EAC. During Field Stage I, to keep the mixture easy to be operated (i.e., enough pot lifetime), DMP-30 has to be encapsulated; and during Field Stage II, without DMP-30 accelerant, the mixture has to be maintained at 120 °C for 3 h in the lab, or in high summer for about 45 days (red solid line). Products of encapsulated DMP-30 mingled with hot component A or homogenous blend of A and B via Approach (I) and Approach (II) at Field Stage I would be cracked in the process of "Compact", and released to accelerate the post-cure process of EAC mixture, thus, EAC will be opened to traffic immediately. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this paper accelerant of 2,4,6-tris(dimethylaminomethyl)phenol (abbrev., DMP-30) was encapsulated by two approaches. Approach (I), DMP-30 was encapsulated by interfacial polymerization of epoxy resin and ethylenediamine, and Approach(II), DMP-30 was absorbed by porous materials which were subsequently sealed by polytetrafluoroethylene (PTFE). Then, the capsulated DMP-30 was added to EACs, and then, they were released triggered by the pressures of "Compact" to accelerate the post-cure of EACs, as depicted in Fig. 1 (yellow dash lines). The morphologies, diameters and distributions, thermal stability properties of prepared capsules, and their laboratory effects on accelerating post-cure of EACs were investigated systematically.

2. Experimental

2.1. Materials

The bisphenol-A diglycidyl ether epoxy resin (E-51, CAS No.: 61788-97-4, eq/100 g: 0.48–0.54), ethylenediamine (CAS No.:107-15-3, purity, 99%), 2,4,6-tris(dimethylaminomethyl)phenol (DMP-30, CAS No.: 90-72-2, purity, 96%), Span®80 (CAS No.: 1338-43-8), Tween®80 (CAS No.:9005-65-6) and dimethicone