Construction and Building Materials 184 (2018) 515–523

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# A comparative study on early-stage strength development and mechanical properties of cement emulsified asphalt mixture using brake pad waste

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## HIGHLIGHTS

- It is feasible to replace mineral filler by break pad waste (BPW) in CEAM.
- HWTT, SCB and OT tests are used to assess the engineering properties of CEAM.
- CEAM with BPW filler performs better against moisture, rutting and cracking.
- BPW filler improves fatigue life of CEAM compared to fillers concerned.

## ARTICLE INFO

*Article history:*
Received 29 March 2018
Received in revised form 26 June 2018
Accepted 2 July 2018

*Keywords:*
Brake pad waste
Cement emulsified asphalt mixture
Early-curing behavior
Moisture resistance
Overlay tester
Repeated semi-circular bending test

## ABSTRACT

This paper aims to investigate the feasibility of using brake pad waste (BPW) in cement emulsified asphalt mixture (CEAM). The effects of BPW filler on early-stage strength, mechanical properties and durability of CEAM were experimentally studied, while mixtures with basic oxygen furnace (BOF), fly ash (FA), hydrated lime (HL) and conventional limestone filler (LF) were prepared and tested as comparison. Results indicate that strength of BPW mixture in early stage and after fully cured are smaller than that for the contrasting mixtures with common by-product fillers. The reason might be that BPW filler has no significant effect on hydration reaction of cement, due to its non-active characteristic. However, the engineering performance of BPW mixture is comparable to that with artificial by-product fillers. Moreover, result of dynamic modulus test implies that the temperature and frequency dependence of CEAM is weaker than the HMA. And there is no obvious difference in viscoelastic characteristics of CEAM mixes using various fillers concerned. The research demonstrates that BPW filler can be used as an alternative material for mineral filler in CEAM.

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## 1. Introduction

In recent years, asphalt pavement has been commonly used throughout the world. While hot mix asphalt (HMA) is a typical construction materials for asphalt pavement, aggregate and asphalt binder are generally preheated up to a relatively high temperature, in order to ensure the workability of asphalt mixture during the mixing and compaction processes [1]. Large amounts of fuel would be consumed for producing the hot mix asphalt, which accounts for 15% to the total cost of HMA manufacture [2]. High energy consumption also contributes to the greenhouse gas emission [3,4]. Moreover, high temperature would increase the release speed and amount of volatile organic compounds (VOCs) from asphalt mixture, which is considerably harmful to environment and construction workers [5]. Therefore, eco-friendly asphalt mixture is gaining more and more attentions to mitigate the growing environmental problems in pavement industry.

Reducing the mixing and compaction temperature of HMA is recognized as a promising and efficient method to lower the energy consumption and exhaust gas emission, and thus improves the cost effectiveness. Considering the manufacture temperatures, current technologies can be divided into three categories: warm mix asphalt, half-warm mix asphalt, and cold mix asphalt [3,6]. As the most well-known cold mix asphalt, conventional emulsified

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https://doi.org/10.1016/j.conbuildmat.2018.07.013
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asphalt mixture (EAM) is produced by emulsion asphalt, aggregate and filler at ambient temperature [7]. Compared to HMA, conventional EAM shows inferior early-stage strength and requires extensive period to reach its full strength after paving, due to the breaking and curing characteristics of emulsion asphalt [8]. Moreover, inadequate long-term performance, e.g. susceptible to moisture damage and permanent deformation, also limits the widely application of conventional EAM as surface course [9,10].

In 1974, Head initially reported that cement can improve the Marshall stability of EAM [11]. The effect mechanism of cement on the engineering performance of EAM can be explained from two aspects. On the one hand, addition of cement would generate a large amount of hydration products to enhance the mechanical properties of EAM. On the other hand, cement hydration reaction would absorb part of moisture from emulsion asphalt, and hence accelerates the demulsification process [12]. These combination effects contribute to a significant improvement in both early-stage strength and long-term performance of EAM. Therefore, cement emulsified asphalt mixture (CEAM) shows considerable advantages over conventional EAM without cement.

Since then, a series of studies have been conducted to investigate the effect of material compositions and curing conditions on early-stage strength development and mechanical properties of CEAM by conventional HMA testing procedures and microstructural analysis methodologies. Oruc et al. indicated that EAM with low cement addition (2% by the mass of mixture) has comparative mechanical properties with equivalent HMA [13]. Xu et al. reported that reasonable aggregate gradation and suitable binder contents are required to obtain excellent engineering properties of CEAM [14]. García et al. found that environmental humidity level and cement content jointly affect the hardening characteristics of CEAM [15]. Lin et al. investigated the development mechanism of early-stage strength and dynamic characteristics of CEAM using recycled asphalt mixture [16,17]. They concluded that cement hydration, inner frictional resistance and asphalt demulsification provide the strength for CEAM. Although the viscoelastic characteristics for CEAM is significant weaker than that of the HMA, CEAM still shows frequency and temperature dependence under dynamic load in its early stage and fully cured stage. The previous studies confirmed that CEAM is a prospective road material for structural layer of pavement.

However, moisture damage potential still raises logical doubts and uncertainties about the extensive application of CEAM [18]. Since filler plays an important role in determining the interfacial adhesion between cement-emulsified asphalt mortar and aggregate, many researchers attempted to improve the anti-moisture damage property of CEAM by addition of artificial by-products fillers, such as fly ash (FA) [8,19], coal ash (CA) [20], silica fume (SF) [21], hydrated lime (HL) [22], and granulated blast furnace slag (GGBS) [10,23].

Additionally, the brake pads must be replaced regularly to ensure the safety of automobiles. Failed brake pad could not be degraded naturally, which would cause enormous space waste and environmental pollution. An experimental study by Hu et al. found that brake pad waste (BPW) filler can enhance the bonding characteristics between the asphalt and aggregate, and hence improves the resistance to water damage of hot mix asphalt [24]. Their findings might provide an alternative material to modify the moisture sensitivity of CEAM. However, few literatures are found to investigate the effect of BPW filler on moisture stability and other related mechanical properties of CEAM. Moreover, previous study has highlighted the hydration process delay caused by some artificial by-products filler [25]. From this point of view, there is also a need to better understand the early-stage strength development of CEAM using BPW filler.

The main objective of this paper is to study the feasibility of using brake pad waste in CEAM. The effect of curing conditions on early-stage strength development of CEAM using BPW filler is investigated by comparing with mixtures using other artificial by-products fillers. Then, the mechanical properties of these CEAM mixes after full cured are comparatively studied by the moisture susceptibility test, dynamic uniaxial creep test, Hamburg wheel tracking test, overlay tester and semi-circular bending tests. Moreover, viscoelastic characteristics of CEAM mixes are evaluated by the dynamic modulus test as well. This work aims to gain a comprehensive understanding of the engineering properties for CEAM with BPW filler in both early stage and fully cured stage.

## 2. Materials and experimental methods

### *2.1. Materials*

Slow breaking cationic emulsified asphalt was prepared with 60/80 pen base binder and emulsifier in laboratory. The base asphalt and emulsifier in this study were obtained from market. The basic properties of emulsion asphalt are shown in Table 1 using test procedures in JTG E20-2011 [26]. The aggregate used in this study was crushed diabase, which is a mafic, holocrystalline, subvolcanic rock equivalent to volcanic basalt. The diabase has a density of 2.953 g/cm$^3$ and a particle size less than 16 mm.

Limestone filler (LF) with a density of 2.699 g/cm$^3$ was also used in this research. Besides LF, there were other five types of fillers used in this study. Composite Portland cement (CPC) 32.5, fly ash (FA) and hydrated lime (HL) were obtained from the market. Basic oxygen furnace (BOF) slag was supplied by Metallurgical Slag Corp., Wuhan Iron and Steel. Brake pad waste (BPW) was obtained from the local truck garage in Wuhan. The detailed preparation procedure of BOF slag and BPW fillers was described in a previous research work [24]. All the fillers with a particle size less than 0.075 mm were obtained by screening test in laboratory. Density and specific surface area of fillers are shown in Table 2. Chemical composition of fillers (major oxides) was analyzed by EDX, energy dispersive X-ray fluorescence spectrometer. The results are shown in Table 3.

**Table 1**
Properties of emulsion asphalt.

| Type | Value | Specification |
|---|---|---|
| Residue by distillation (%) | 63 | ≥55 |
| 1.18 mm sieve test (%) | 0.06 | ≤0.1 |
| 1d storage stability (%) | 0.7 | ≤1 |
| 5d storage stability (%) | 1.9 | ≤5 |
| pH | 5.15 | – |
| Penetration of residue, 25 °C (0.1 mm) | 72 | 45–150 |
| Ductility of residue, 15 °C (cm) | 71 | ≥40 |
| Ductility of residue, 25 °C (cm) | 118 | – |
| Softening point of residue (R&B) (°C) | 48.4 | – |

**Table 2**
Physical properties of fillers.

| Types | CPC 32.5 | LF | BOF | FA | HL | BPW |
|---|---|---|---|---|---|---|
| Density (g/cm$^3$) | 3.096 | 2.699 | 3.081 | 2.323 | 2.325 | 2.295 |
| Specific surface area (m$^2$/kg) | 365 | 324 | 410 | 380 | 396 | 385 |

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