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Influence of chemical additives on mixing procedures and performance properties of asphalt emulsion recycled mixture with reclaimed cement-stabilized macadam

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HIGHLIGHTS

- The additives' addition methods affect the mix ratio and strength of the mixture.
- The improvement of the additives on the mixture depends on its types and contents.
- The interface mechanism was proposed to explain the effect of mixing procedures.

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ABSTRACT

During rehabilitation of pavement structure with cement-stabilized macadam (CSM) base course and hot mix asphalt (HMA) surface course, it is expected to recycle severe cracked CSM layer using the same method as HMA layer. In this study, asphalt emulsion and chemical additives were adopted to stabilize reclaimed CSM aggregates. Considering the surface characteristic of the CSM aggregate, the addition procedures of chemical additives were investigated by volumetric parameters and strength tests. The moisture susceptibility and rutting resistance test were conducted to evaluate effect of different chemical additives on performance properties of the recycled mixture. To understand the mixing procedures and performance characteristic, the microstructure images of the recycled mixture were observed by environmental scanning electron microscope (ESEM). The results of volumetric parameters and strength tests indicate the addition procedures of chemical additives affect the optimum composition and mechanical strength of the recycled mixture. It is recommended to add cementitious additives prior to asphalt emulsion during mixing process. Furthermore, the optimum composition and performance properties of the recycled mixture depend on types and content of chemical additives. Some suggestions are provided for the selection of chemical additives. The interface bonding mechanism between the recycled aggregates and cementitious materials is proposed to explain the mixing procedures and performance characteristic of the recycled mixture.

1. Introduction

Cement-stabilized macadam (CSM) is a composite material composed of aggregates with proper gradation, 3%–8% cement of the aggregates weight, and water at optimum content [1,2]. The hydration and hardening of cement induce the significant incensement of stiffness and strength of unbound aggregates [3,4]. Compared with granular layer, CSM layer provides a better distribution of traffic loading and a smaller tensile strain or stress on the bottom of hot mix asphalt (HMA) layer [5,6]. Therefore, CSM has widely been utilized as base course materials to improve the load bearing capacity of asphalt pavement structure in many courtiers.

CSM layer is usually paved and compacted without joints because of low cement content. The dry shrinkage and temperature contraction of cement paste lead to inevitable cracking in CSM base course [7,8]. The effect of vehicle loading and environmental temperature makes HMA surface course gradually appear a large number of reflective cracks [9,10]. Simultaneously, the existing cracks in CSM layer are being deteriorated. Therefore, this inherent disadvantage in CSM accelerates the performance degradation of pavement structure. When the load bearing capability

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of pavement structure is decreased to an unacceptable level, it has to restore the performance of HMA layers and CSM layers by reasonable rehabilitation methods.

For asphalt pavement consisted of CSM base course and HMA surface course, it is expected to rehabilitate severe cracked CSM layer using the same method as recycling HMA layer. Cold recycling technologies provide a cheaper, faster and more eco-friendly rehabilitation way to recovery the bearing load capability of asphalt pavement structure [11]. During traditional cold recycling, reclaimed asphalt pavement (RAP) is treated by stabilizing materials and is recompacted as a base course of new pavement structure without heating [12]. The most common stabilizing material is mixing grade asphalt emulsions [13]. The emulsion recycling RAP has been researched and applied more than 40 years [14,15]. However, the surface characteristic of reclaimed CSM aggregates is different from that of RAP. There is still a lack of understanding about the mix design and performance properties of the emulsion recycled mixture with reclaimed CSM aggregates.

Asphalt emulsion needs a long curing time to regain the rheological properties of original asphalt binder [16]. This leads to low mechanical strength and inadequate performance properties at early-age of the emulsion stabilized materials [17]. The pavement structure containing the emulsion mixture is easy to generate rutting, moisture damage and fatigue cracking [18]. In the early 1970s, cement was applied to modify the curing rate under moisture condition of asphalt emulsion stabilized materials with original aggregates [19]. A study carried out by Brown [20] indicated that cement could improve the stiffness modulus, rutting resistance and fatigue life at low strain of asphalt emulsion mixture. The modified mechanism was explained by cement hydration and enhancement of binder viscosity. The improvement of cement on stiffness, moisture and rutting resistance of the emulsion mixture is positively related to its content [21]. Moreover, the emulsion content influences the hydration process of cement and microstructure of hydrated products [22]. With the development of cold recycling technology, cement was recommended to modify the emulsion recycled mixture [23]. Especially in recent 10 years, cement was widely used in cold in-place recycling [24] and full depth reclamation [25]. The effect of cement on the performance properties of the emulsion recycled mixture is similar to the influence of cement on the ordinary emulsion mixture [26]. Moreover, some researchers even employed hydrated lime [27], fly ash [28] or other chemical materials [29] to enhance the performance properties of the emulsion recycled mixture. However, these researches are all focus on RAP other recycled aggregates are ignored.

When the reclaimed CSM aggregates are used in the emulsion recycled mixture, the surface characteristic of the aggregates should be considered. The objective of this research is to investigate the effect of chemical additives on the mixing procedures and performance properties of the emulsion recycled mixture with reclaimed CSM aggregates. Cement and other chemical additives were introduced to design the recycled mixture combined with asphalt emulsion. The performance properties of the recycled mixtures were evaluated by several laboratory tests. Furthermore, this research also provides insight into the interface adhesive mechanisms between the cement asphalt mastic and reclaimed CSM aggregates by observing the interface microstructure.

2. Materials

The reclaimed CSM aggregates were obtained from distressed asphalt pavement with CSM base course. The cement content in CSM aggregates was at 5% of the aggregates weight. The rock type of the recycled aggregates was limestone. The water content, water absorption and crushing value of the aggregates were at 0.3%, 4% and 28% of the aggregates weight respectively. The engineering properties of the recycled aggregates satisfy the requirements of base course mixture according to Chinese pavement specification [30]. The designed gradation and its limits are shown in Fig. 1. The gradation of CSM aggregates is in the required range of Chinese pavement recycling specification [31]. The slow-setting cationic asphalt emulsion was used to design the recycled mixture. The physical properties of the emulsion are provided in Table 1. Three types of chemical additives were chosen to combine with asphalt emulsion. These materials included hydrated lime (HL), type II composite Portland cement (CPC) and ground-granulated blast-furnace slag (GGBF). The composite additive was composed of HL and GGBF. The mass ratio of HL to GGBF was 1:3. The basic properties of these chemical materials are presented in Table 2.

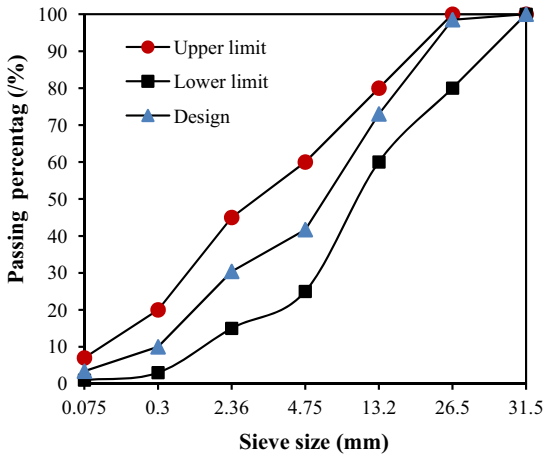

Fig. 1. Gradation of reclaimed CSM aggregates.

Table 1
Test results of cationic asphalt emulsion.

Properties	Specification	Value
Residue by distillation/%	⩾55	58
1.18 sieve test/%	⩽0.1	0.06
5d storage stability/%	⩽5	0.1
PH	–	5.11
Residue test		
Penetration (25 °C, 100 g, 5 s)/0.1 mm	45–150	59
15 °C ductility/cm	⩾40	72
Soft pointing (R&B)/°C	–	48

Table 2
The basic properties of chemical additives.

Type of additives	Specific gravity (g/cm^3)	BET surface area (m^2/g)	Methylene blue value (g/kg)	CaO (%)	SiO_2 (%)
CPC	2.878	4.258	0.47	14.8	52.9
HL	2.329	7.029	0.52	62.5	–
GGBF	2.381	6.415	0.18	39.3	34.2

3. Mixture design and test methods

3.1. Mixture design procedures

There is no universally accepted design method for asphalt emulsion recycled mixture [32]. Most agencies have developed their own mix design procedures based on laboratory tests [15,32]. In this study, a modified Marshall volumetric method was proposed to design the emulsion recycled mixture with reclaimed CSM aggregates.

In order to improve the coating and compaction ability, the premix water was sprayed into the recycled aggregates before the addition of cement and asphalt emulsion. To ensure the recycled