Pergamon

Cement and Concrete Research, Vol. 28, No. 5, pp. 635–641, 1998

0008-8846/98 $19.00 + .00

PII S0008-8846(98)00038-6

EXPERIMENTAL STUDY OF CEMENT-ASPHALT EMULSION COMPOSITE

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(Received January 16, 1998; in final form March 9, 1998)

ABSTRACT

An experimental investigation was conducted on a three-phase cement-asphalt emulsion composite (CAEC), in which asphalt was introduced as a cushion layer in between coarse aggregates and cement mortar matrix by dispersing asphalt emulsion-coated coarse aggregates into cement mortar matrix. Laboratory tests on fatigue, strength, rigidity, temperature susceptibility, and stress-strain relationship were implemented to evaluate the mechanical properties of the CAEC. The preliminary test results showed that CAEC possessed most of the characteristics of both cement and asphalt, namely the longer fatigue life and lower temperature susceptibility of cement concrete, and higher toughness and flexibility of asphalt concrete. This experimental study suggested that CAEC might be an alternative way of a base course material in pavement. *© 1998 Elsevier Science Ltd*

Introduction

It is known that a comparatively ideal pavement base course should possess the characteristics of long fatigue life, low susceptibility to temperature, high toughness, suitable flexibility, and so on. Up to now, the dominant base courses, cement-treated base course and asphalt-treated base course, have not possessed the required properties independently. When cement and asphalt are combined properly, however, there exists a potential to obtain the expected performance due both to the complementary of the mechanical properties of cement and asphalt and to the composite mechanism. There has been a long history of using cement asphalt composite in pavement base course, particularly cement-asphalt emulsion composite (CAEC) due to the compatibility of cement and asphalt emulsion as well as the ease of paving technology. In the 1970s, because of traffic load increase, petroleum crises, and the environmental protection movement, the use of asphalt emulsion in pavement base course paving increased (1–3). Because the strength, rigidity, and water stability of asphalt emulsion mix

Communicated by F.W. Locher.
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TABLE 1
Portland cement properties.

Water content for standard consistence (%)	Initial setting time	Final setting time	Soundness	Compressive strength (MPa)			Flexure strength (MPa)		
				3 days	7 days	28 days	3 days	7 days	28 days
27.6	1.3h	3.2h	Satisfied	15.9	24.9	42.1	3.4	4.7	6.4

were too low to satisfy the traffic load and pavement performance requirements, ordinary Portland cement was added to asphalt emulsion mix to improve its early mechanical properties. Test results obtained by Terrel and Wang (1971) and Head (1974) showed that the early strength, resilient modulus, and water stability of CAEC were increased (1,2), but its fatigue life was not extended as expected and even reduced when cement content was more than 3% (3). In recent years, CAEC has gained even more interest, as it can reduce shrinkage cracking of cement-treated base course and enhance cold recycling of asphalt base course (4). However, it was also verified that cement content had to be confined within a certain extent, otherwise, transverse cracking and fatigue cracking of the pavement would be inevitable (4–6).

Like other types of thermoplastic polymer modified cement concrete, the mechanical properties of CAEC are intimately related to its microstructures. The microstructure of CAEC suggested by literature was a two-phase composite with cement phase dispersed in asphalt phase, i.e., hard inclusions in soft matrix. Such a microstructure would likely result in debonding and cracking at the interface and worsen fatigue resistance (7,8). Experiments and mechanism analysis showed that when polymer emulsion was incorporated into cement concrete, it formed a thin film at the interface of cement mortar and coarse aggregates, which was one of the most important mechanisms for performance improvement of polymer modified concrete (9–11). In the light of these observations, it is reasonable to expect that if asphalt emulsions (a type of low-cost thermoplastic polymer emulsion) are directly coated onto the surface of coarse aggregates, the performance of CAEC would be improved. The purpose of this paper is to present some experimental results on the new microstructure CAEC.

Test Procedures

Raw Materials

Ordinary Portland cement was used as a binder, whose fundamental properties were shown in Table 1. The asphalt emulsion used was CSS-1h type, with its properties of residue on

TABLE 2
Asphalt emulsion residue on evaporation test results.

Penetration (25°C, 100 g, 0.1 mm)	Softening point ($T_{R\&B}$)	Ductility (25°C, 5 cm/min.)	Penetration Index
88	48.5°C	86 cm	−0.8

TABLE 3
Aggregate properties.

Bulk specific gravity	Fine aggregate	2.72
	Coarse aggregate	2.69
Water absorption (%)	Fine aggregate	0.7
	Coarse aggregate	1.2
Coarse aggregates	Crushing value (%)	15
	Lots of Los Angeles abrasion test (%)	18
	Content of flat aggregate (%)	12
Filler retained on 0.074 mm sieve (%)		9

evaporation shown in Table 2. Crushed limestone, natural sand, and ground limestone were used as coarse aggregates (grain size between No. 4 ~ 3/4 inch sieve), fine aggregate (grain size between No. 200 ~ No. 4 sieve), and filler (grain size ≤ No. 200 sieve), respectively. Their properties and gradation were shown in Tables 3 and 4, respectively. The superplasticizer incorporated was commercially available with a brand name of Goldstar #9.

Specimen Preparation

CAEC mixture was formed by three steps. In the first step, coarse aggregates were mixed with asphalt emulsion to form asphalt emulsion coated coarse aggregates. In the second step, fine aggregates, filler, cement, additional water, and superplasticizer were mixed up to form cement mortar. In the final step, asphalt coated coarse aggregates and cement mortar were further mixed up to uniform to obtain CAEC mixture.

Beam specimens with the dimension 15 × 15 × 55 cm were used for fatigue test and flexure strength test. These specimens were prepared with concrete vibrator controlled by compactness of up to 96% or more. Cylindrical specimens of Φ10 × 10 cm were used for compressive strength testing and resilient modulus testing, while the small beam specimens of 5 × 5 × 24 cm were for load-displacement testing from which a stress-strain diagram could be obtained. Both cylindrical specimens and small beam specimens were cut from the 15 × 15 × 55 cm beam specimens. The composition of CAEC by weight in these specimens was: cement: asphalt: water: coarse aggregates: fine aggregates: filler: superplasticizer = 1: 0.367: 0.8: 8.417: 5.25: 0.8: 0.005. Obviously, CAEC specimens are lean cement based composite so as to agree with the cement content usually used in pavement base layer of around 6%.

For the purpose of comparison, control lean cement concrete specimens were also prepared with the same composition (except without asphalt), and the same test procedures were followed as that of CAEC. The curing of specimens was carried out by sealing the specimens with plastic film in room temperature up to 1 day before test.

TABLE 4
Aggregate gradation.

Sieve	3/4 in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
Passing (%)	100	64.8	41.9	30.9	22.2	16.1	11.5	8.1	5.5

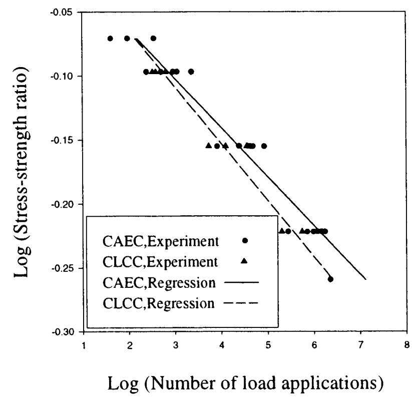

FIG. 1.
Fatique properties of CAEC and CLCC.

Test Procedure

Controlled-stress fatigue test was carried out with 15 × 15 × 55 cm simply supported three-point loading beam specimens. The load was sinusoid with frequency of 5 Hz. The characteristic parameter of cyclic load was $\rho = 0.1$. The test temperature was 15°C, and the age of specimens was 90 days.

Load-displacement test was conducted with 5 × 5 × 24 cm simply supported three-point loading beam specimens. The rate of displacement was 2 mm/min. and the load-deflection curve was recorded by LVDT. Flexure strength tests with 15 × 15 × 55 cm beam specimens, and compressive strength and resilient modulus tests with Φ10 × 10 cm cylindrical specimens were conducted by abiding by Chinese National Standards of JTJ053–94 (12) and JTJ057–94 (13) for concrete and semi-rigid base course materials, respectively. The test age was 28 days and temperature 20°C except for special circumstances noted. The values obtained are the average of at least three specimens.

Results and Discussion

The fatigue test results of CAEC and control lean cement concrete (CLCC) are shown in Figure 1 in which the fatigue equation curves with reliability of 50% are also presented. It can be seen that CAEC has significantly improved fatigue properties compared with CLCC, demonstrating lower fatigue damage rate and longer fatigue life at the same stress-strength ratio. This positive fatigue result suggests that, if the base course material CLCC were replaced by the same thickness CAEC in flexible pavement, the service life of pavement would be greatly extended. This result also verifies the proposed three-phase microstructure of CAEC can obtain positive result as expected, which further confirms the "thin film forming" mechanism by forerunner researchers (9–11).

Figure 2 shows microcracking propagation process of CAEC beams in fatigue test by tenfold optical microscopic observations. The coordinate is the distance between the microcracking tip and the bottom of the test beam, and the abscissa is the number of load applications. It can be seen from Figure 2 that the fatigue fracture of CAEC is "ductile," showing a long

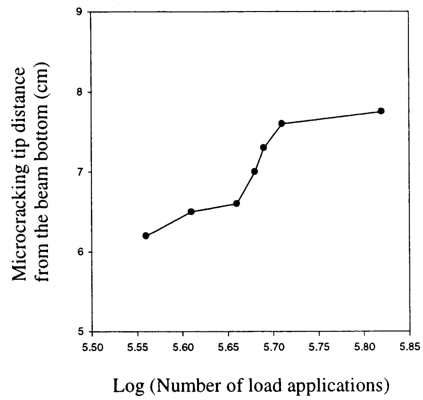

FIG. 2.
Test results pf microtracking propagation.

period time of visible cracking propagation. In contrast, it is observed in fatigue testing of CLCC that the fatigue fracture of CLCC is almost brittle, showing no visible cracking propagation. This result shows that the asphalt interphase layer can blunt the microcracking tip and delay the widening and propagating of the microcrackings due to the flexibility and strain ability of asphalt. It is known that when semi-rigid base course materials such as CLCC are used in flexible pavement, the reflective cracking has been a major problem that remains unsolved. This study shows that, if CAEC were used as a base course material in flexible

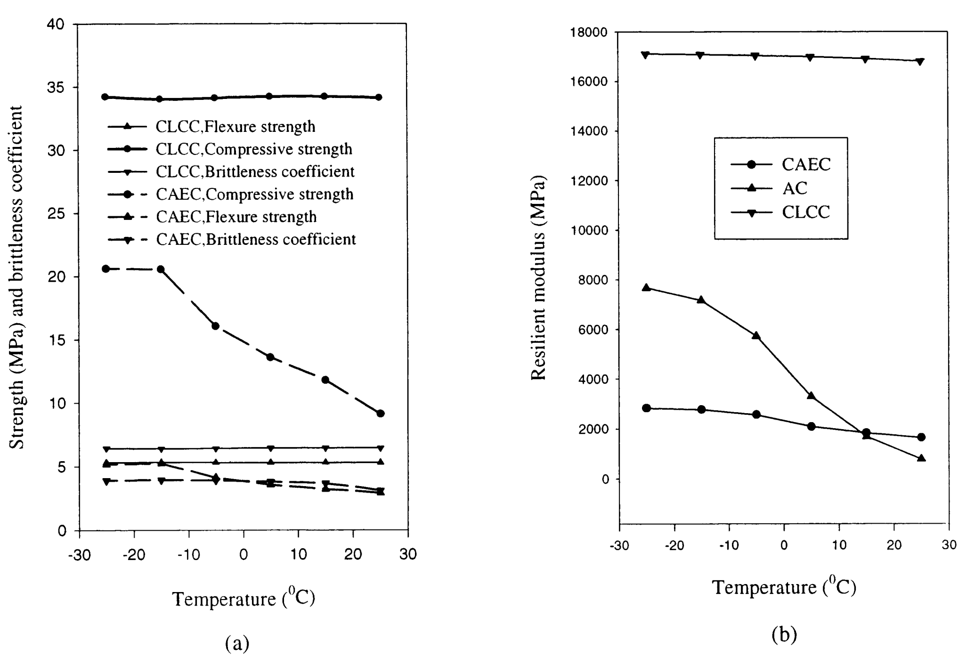

FIG. 3.
Test results of strength, regidity, and toughness.

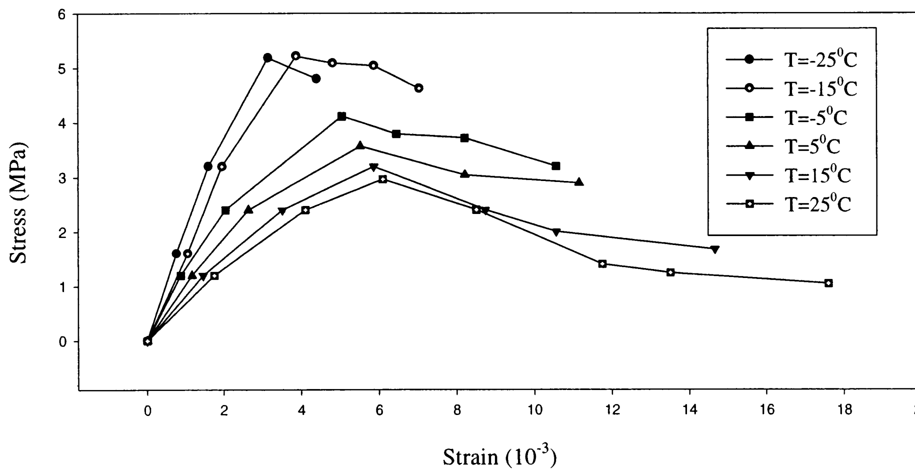

FIG. 4.
Stress-strain diagram of CAEC.

pavement, the distress of reflective cracking would be greatly reduced due to its significant ability in blunting microcracking tip and delaying microcracking propagation.

The test results on flexure strength, compressive strength, and resilient modulus for CAEC, CLCC, and asphalt concrete (AC) (14) at different temperatures are shown in Figure 3. It is found from Figure 3a that, compared with CLCC, the flexure strength and compressive strength of CAEC are decreased, which might be caused by weak interfacial bonds between the cement mortar and asphalt layer. However, its brittleness coefficient (represented by the ratio of compressive strength to flexure strength) is noticeably decreased. Figure 3b shows that the resilient modulus of CAEC is decreased, which would result in the increase of its flexibility compared with CLCC. As compared with AC, the variation of resilient modulus of CACE with temperature is very small, which means the temperature susceptibility of CAEC is also improved to a great extent. It is known that the high brittleness of CLCC and the strong temperature susceptibility of AC have been contributing factors to transverse cracking and map cracking in flexible pavement. The experimental study shows that, if CAEC were used as a base course material instead of CLCC or AC, the high brittleness and strong temperature susceptibility induced distress in flexible pavement would be alleviated.

Figure 4 shows the stress-strain curves of CAEC at different temperatures derived from the load-displacement test. It can be seen that the stress-strain relationship mirrors the micro-structure and mechanical characteristics of CAEC. When the strain is smaller than ϵ_0 (corresponding to the peak stress value), the stress-strain characteristics of CAEC are similar to that of cement concrete, and the deformation and damage occur mainly in cement mortar matrix, showing that cement mortar matrix is the main bearing body at this stage. When the strain is greater than ϵ_0, the stress-strain characteristics of CAEC are similar to that of AC, and it does not rupture as cement concrete does; instead, the specimens withstand measurable post-failure load and undergo significant displacement without full disintegration. The reason may be that the effect of asphalt interphase layer becomes dominant at this stage, endowing CAEC with significant post-peak load deformation due to the strong strain ability of asphalt. When temperature drops, asphalt tends to harden, which results in the shortening of the post-peak load deformation period, increase in the peak load, and gradual loss of the asphalt characteristics.

Conclusion

Introducing a flexible asphalt cushion layer in between the coarse aggregates and cement mortar makes the resulting CAEC possess most of the characteristics and advantages of both cement and asphalt, verifying the microstructure dependent of the mechanical properties of composite materials. Based on the preliminary experiment results, the following conclusions are obtained:

1. Compared with control lean cement concrete, CAEC increases fatigue life, reinforce toughness, enhances strain ability, and delays microcracking propagation.
2. Compared with asphalt concrete, CAEC reduces temperature susceptibility.
3. CAEC has the potential of being used as a base course material in flexible pavement structures due to its long fatigue life, low susceptibility to temperature, high toughness, and proper flexibility.
4. The concept of CAEC could be applied to the cold recycling of asphalt treated base course due to the fact that the aggregates are already coated with asphalt, which would facilitate the paving technology and save the cost.
5. The interface bonds between asphalt and cement mortar need further reinforcement to increase the strength of CAEC.

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