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Preparation of modified asphalt emulsion concrete for steel bridge protection

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ABSTRACT

The study investigates the effect of modified asphalt emulsion on concrete protective course for steel bridges. Modified asphalt emulsion concrete protective course (MAECPC) is a mixture of asphalt emulsion, latex emulsion polymer and aggregates. The strength performances of the MAEC were tested through laboratory experiments. The results show that the MAEC has better performance, cracking resistance, bending strength, abrasion resistance and the linear contraction coefficient compared with Portland cement concrete (PCC), and stone mastic asphalt (SMA). It could be concluded that MAEC is a good material for protective course of railway bridge deck.

INTRODUCTION

Because of the savings and advantages, thousands of orthotropic deck bridges have been or are being built throughout the world. However, because of their flexibility, the durability of the surfacing structure on orthotropic steel bridges remains a big problem. Fatigue cracks in the overlay at right angles of the orthotropic plate stiffeners and shear cracks at the interface between the overlay and steel plate are the frequently reported damage[1]. Frequent resurfacing results in huge costs and thus in reduced road network availability. The Merwedebrug Bridge in the Netherlands and Wuhan Baishazhou Yangzi River Bridge in China are good examples. The past performance of the Merwedebrug Bridge showed that the asphalt overlay structures on average required reconstruction every six years. Between reconstruction works, smaller repairs were frequently required to keep these structures operational[2]. In order to improve the durability of overlay structure on bridge, a large research project has been carried out by Delft University of Technology[3]. This project combined laboratory test, finite element modeling and validation by means of accelerated pavement testing. Focus was on the effect of membrane performance. A similar research project was also initiated to lengthen the service life of the overlay structures by Wuhan University of Technology[4]. Because of unsuccessful experiences on asphalt concrete overlay and epoxy asphalt concrete[5], epoxy polymer concrete, which comprises a series of epoxy binder and aggregate broadcast applications, was introduced[6]. Thin epoxy polymer concrete overlays were reported to be successfully applied on concrete and steel bridge decks in USA[7]. Li et al.[8] found out that cement – asphalt emulsion composite (CAEC) had most of the features of both cement and asphalt, that is increased fatigue life, higher toughness, enhanced strain ability, lower temperature susceptibility. It is a known the application of asphalt emulsion for cement asphalt mortar (CAM) which is key engineering material in the slab track system of high-speed railways in Japan, Germany or China[9-11]. The dosage of asphalt in CAM is much higher than the specified dosage for admixtures in concrete[12,13]. Song et al.[12] recommend limiting asphalt – cement ratio to 20%. Waterproofness, carbonation resistance and chloride ion penetration resistance of CAM increased with increased asphalt dosage. In contrast, their compressive strength and adhesion in tension decrease with asphalt–cement ratio increase[12]. Nowadays, almost all steel bridges decks use the AC as their wearing course. In this case, the flexible protective course is drawing more and more attentions.

Modified asphalt emulsion concrete (EAC) has been proven to be an excellent material. Given the good mechanical performance of the EAC, it is considered to be the material of protective course on the railway bridge.

The main objective of this work is to assess the feasibility of using MAEC as the protective course on the railway steel bridge. In doing so, this paper presents the experimental and numerical analyses to evaluate the material characteristics and the structural performances of this flexible protective course. The material characteristics of the MAEC were assessed through a laboratory experiment; and the structural performances of the MAECPC were investigated by a numerical analysis of a typical railroad bridge with an MAECPC.

MODIFIED ASPHALT EMULSION CONCRETE PROTECTIVE COURSE

Modified asphalt emulsion concrete protective course (MAECPC) is a mixture of asphalt emulsion, latex emulsion polymer and aggregates. The polymer modified asphalt emulsion, a material has brought improved properties and better performances to the concrete. Modified asphalt emulsion concrete has good strength performances when used as the pavement material.

Modified asphalt emulsion concrete is selected to build the modified asphalt emulsion protective course for the orthotropic steel bridges. The typical structure of the bridge deck system is shown in Figure 1, where the modified asphalt emulsion protective course is acting as both the protective layer and a part of the steel deck system. Following are some technical requirements for the protective course: (1) to protect the waterproof membrane, (2) it must have good cooperative workability with other components of the system; and (3) it must have good structural performance when used in the bridge deck system.

Figure 1 : The typical structure of the bridge deck system; 1. Substrate reinforced concrete 2. Waterproof coating 3. MAEC protective 4. Ballast

EXPERIMENTAL STUDIES

Materials and preparation

1. Materials

asphalt emulsion, latex emulsion, cement, sand and basalt aggregate were used in this work. The technique indices of latex emulsion and basalt aggregate are listed in TABLE 1. Ordinary Portland cement OPC complying with Egyptian Standard Specification E.S.S 373/1993 was applied. High rang water reducing chemical admixture Sikament 163 produced by Sika Egypt Company was used. It complies with ASTM C 494

TABLE 1 : Technique indices of latex emulsion and basalt aggregate

Latex emulsion		Basalt aggregate	
Properties	**Values**	**Properties**	**Values**
Solids Content, %	63	Los Angeles abrasion value (%)	11.5
Viscosity, Brookfield	800	Crushing value (%)	8.9
Monomer Ratio, (Styrene /Butadiene)	24/76	Apparent density (g/cm3)	2.91

type F and B.S. 5057 part 3 for Super plasticizer.

2. Preparation of asphalt emulsion

Asphalt emulsions are manufactured by passing hot asphalt and water containing emulsifying agents through a colloid mill under high pressure. The colloid mill produces extremely small (less than 5-10 μ) globules of asphalt, which are suspended in water. TABLE 2 presents the main properties of asphalt emulsion.

TABLE 2 : Main properties of asphalt emulsion

Physical properties	Value
Test on emulsion:	
- Viscosity – Saybolt Furol at 25°C.	25
- Settlement and storage stability test 24h %.	0.7
- Sieve test %.	0.15
- Residue by Evaporation of Emulsified Asphalt at 163 °C. %	62.6
- Residue from distillation to 360 °C, %	63
- Drying time, min.	26
- Solubility in water.	good
Test on residue from distillation:	
- Penetration at 25°C 100 g, 5 seconds, 0.1 mm	43
- Ductility at 25 °C, 5 cm/min, cm.	+100
- Solubility in trichloroethylene, %.	98

3. Preparation of modified asphalt emulsion concrete (MAEC)

Cement, sand, gravel, and water were first mixed for 2 min at 350 rpm, and then, the amount of asphalt and latex emulsions (1:1 by weight) were added at 8% based on the weight of cement. The amounts of water in the polymer solution were included in the water-to-cement ratios. Super plasticizer was added to the fresh concrete during mixing to achieve a uniform mix with about 180 mm slump.

Strength tests program

The strong compressive strength is the main reason of the extensive use of the Portland cement concrete protective course (PCCPC). Therefore, to replace the PCCPC, the MAECPC should have good compressive strength. In addition, cracking is the main distress of the PCCPC, the cracking resistance of MAECPC should be evaluated to ensure the MAECPC would not fail like the PCCPC.

In this study, the compressive test and the wheel tracking test were conducted to examine the compressive strength of the MAEC. Meanwhile, the bending beam test was adopted to evaluate its cracking resistance performance. The strength performances of the MAEC and PCC (28 day of curing 25 $^{\pm 2}$ °C and 98 $^{\pm 1}$ % of temperature and relative humidity, respectively.) and stone mastic asphalt (SMA) which is a widely used pavement material were also tested for comparison.

1. Compressive strength test

Compressive strength test of MAEC was conducted following the test method in BS 1881[14]. During the test, three cylindrical specimens, measuring 100 mm diameter by 100 mm height, were tested using a universal test machine at 25 °C, with a load rate of 2 mm/min.

2. Three – point bending fracture test

The tensile strength is an important index to evaluate the crack resistance of the paving material. As shown in Figure 2, the three-point bending beam samples with a dimension of 250 mm x 50 mm x 50 mm were made of the same batches of as the compression samples, slabs were firstly cut into 250 x 30 x 35 mm beams, and then tested by universal testing machine. The loading rate was 5 mm min^{-1} at 25 °C.

Figure 2 : Three-point bending fracture test setup

3. Wheel tracking test

The Wheel Tracking Test (WTT)[15] was used to characterize the asphalt mixture rutting performance under laboratory controlled conditions. Wheel tracking tests were conducted at 60°C to evaluate the high temperature performance of the MAEC. The dynamic stability (DS) can be calculated according to Eq. (1). The curve of deformation vs. time is shown in Figure 3.

$$DS = (t_2 - t_1) \times N / (d_2 - d_1) \quad (1)$$

Where: N, number of wheel passes.

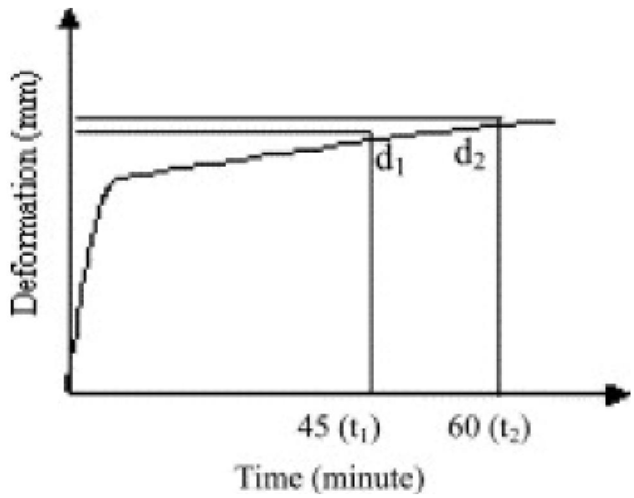

Figure 3 : Curve of deformation vs. time

Cooperative performance tests

In addition to the good strength performances, as a part of the bridge deck system, the MAEC should also have good cooperative performance with the other parts of the system. In this section, the abrasion resistance test and the linear contraction coefficient test will be adopted to evaluate the cooperative performance of MAECPC with other parts of the system under construction loads and environmental loads.

1. Abrasion resistance test

During the construction of the ballast layer, vibrations will be applied onto the ballast layer. The vibrations and loads will bring some negative influences to the performance of the protective course under the ballast layer, such as the abrasion to the protective course. If the protective course does not have good abrasion resistance, it will lose lots of mass during the vibration, bringing severe damage to the MAEC. Therefore, to ensure that the protective course can work well with the ballast layer, a good abrasion resistance is required for the protective course material. For this purpose, the abrasion resistance test was employed to evaluate the resistance performance of the MAEC to the abrasion. In this paper the cement concrete and stone mastic asphalt (SMA) were also tested for comparison.

Surface abrasion was measured on the top surface of the saw-cut cube specimens from the slab in accordance with ASTM C944[10]. Three cubes were extracted per mixture in order to produce three areas of representative surface in accordance with the standard. First, the specimen was placed in the rotating-cutter drill press shown in Figure 4a. The device was set to rotate for two minutes at a speed of 200 rpm exerting a constant load of 98 N (22 lbf). The total diameter of the cutter shown in Fig. 4b was 82.5 mm (3.5 in). After each cycle of abrasion, loose material was removed, and then the mass of the specimen was measured to the nearest 0.1 g. The three results of mass loss were averaged, and the abrasion resistance was determined using Eq. (2):

$$SA = (W_1 - W_2) \times 100 / W_1 \quad \text{Eq.} \qquad (2)$$

Where: SA (Surface abrasion, %.), W_1 (Initial weight of test specimen, gram) W_2 (Final weight of test specimen, gram).

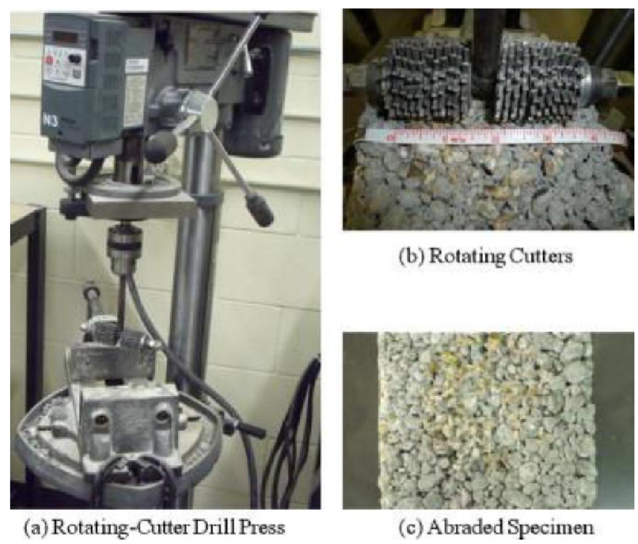

Figure 4 : Surface abrasion test

2. Linear contraction coefficient test

A linear contraction coefficient test device was developed and the linear contraction coefficient of MAEC was tested using the device shown in Figure 5. The test device was put into a temperature chamber, and the 250 x 30 x 35 mm, MAEC beam was placed on a glass plane, fixed by two dial gauges. In the beginning, the temperature chamber was set to 5 °C and hold for 4 h. Then after recording the value of the dial gauges, the temperature dropped to the temperatures of 0°C, -5°C, -10°C, and -15°C, respectively, with all temperatures lasting for 4 h and the deformations ΔT of the specimen were recorded from the dial gauge. According to the definition of the linear contraction coefficient stated in Eq. (3), the linear contraction coefficient during every temperature drop can be calculated.

$$\alpha = \varepsilon / \Delta T = \Delta L / L.\Delta T \quad (3)$$

Where:

α is a contraction coefficient ε is the thermo-strain of the specimen

L is a length specimen ΔT is a temperature change

ΔL is a change in length

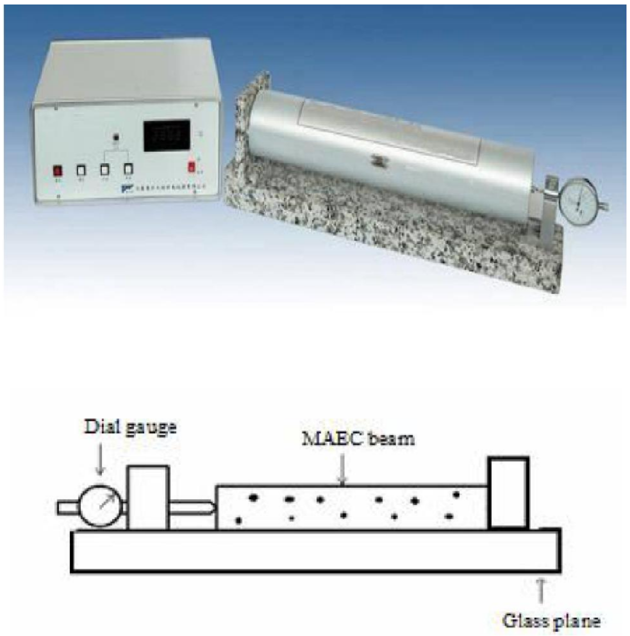

Figure 5 : Linear contraction coefficient test

RESULTS AND DISCUSSION

Compressive strength test

The result of the compressive test is listed in TABLE 3 and Figure 6. It can be seen that the compressive strength of MAEC is (41.2MPa) higher than that of PCC (35.5MPa). However, it is over three times than that of SMA (11.4MPa). The compressive strengths of both MAEC and PCC can meet the requirements of the protective course well, and the SMA does not qualify as the protective course material.

Tensile strength test

As shown in TABLE 3 and Figure 7, the tensile strengths of all the three materials could meet the criteria. Moreover, among the three materials, MAEC has the largest indirect tensile strength (6.4 MPa) while the PCC has the smallest one (4.8 MPa). It can be found that MAEC has much better cracking resistance than PCC, meaning that MAECPC can reduce the chance of cracking and increase the service life of the protective course. On the other hand, the maximum strain of MAEC at 25 °C is 0.98 x10^{-2} mm, while the strain of the PCC can be hardly measured. This means that under load, when the steel deck deformed, the MAEC can deform with the deck within a certain range while the PCC can barely do this. This deformation ability of MAEC can reduce the interior stress of the waterproof layer and hence reduce the chance of de-bonding. So it can be inferred that the MAECPC has better cooperative workability with the steel deck than the PCCPC.

TABLE 3 : Strength performance

Strength performance	Temperature °C	MAEC	PCC	SMA
Compressive strength (Mpa)	25	41.2	35.5	11.4
Tensile strength (Mpa)	25	6.4	4.8	5.4
Dynamic stability (Cycles/mm)	60	--	--	5215

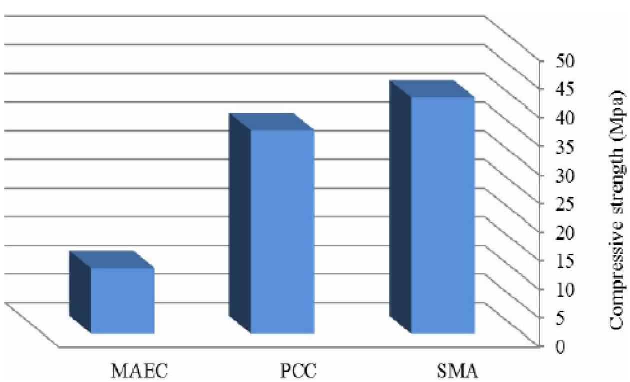

Figure 6 : Effect of compressive strength on different materials

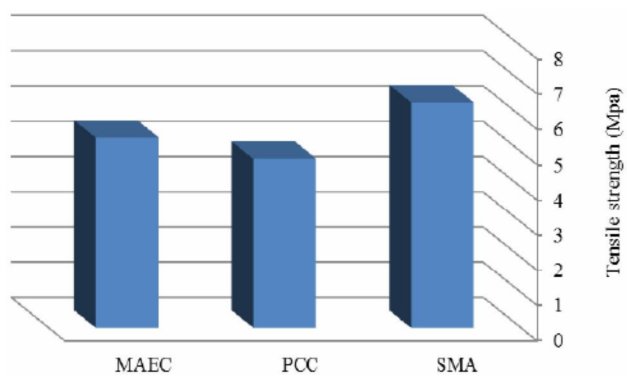

Figure 7 : Effect of tensile strength on different materials

The wheel tracking test (Dynamic stability)

The wheel tracking test results can be also seen in TABLE 3, where the dynamic stability is an index to evaluate the permanent deformation resistance of the asphalt mixture. The permanent deformation resistance is considered to be good when the DS greater than 3000 cycles/mm. It can be observed that the DS of the both MAEC and PCC is higher than that of the SMA, indicating that MAEC has a very good high temperature performance. This may be due to the not rutting depth for both MAEC and PCC.

Abrasion resistance

As seen in TABLE 4 and Figure 8, the mass loss of MAEC was smaller than commonly used concrete PCC and SMA (2325 g/m^2, 3115 g/m^2 and 3986 g/m^2 respectively), meaning that the MAEC has better abrasion resistance. This difference may be associated with the specific latex emulsion used in this study and also partially explained by the slightly lower porosity of MAEC mixtures; the results are very encouraging in terms of the potential of MAEC when it comes to surface durability. Since the PCCPC has been proved to meet the abrasion requirement well, it can be concluded that the MAECPC has better abrasion resistance to withstand the construction loads, meaning that the MAECPC has good cooperative performances with the ballast layer.

The linear contraction coefficient test

According to the definition of the linear contraction coefficient stated in Eq. (1), the linear contraction coefficient during every temperature drop can be calculated as listed in TABLE 5 and Figure 9, as can be seen that the linear contraction coefficient of MAEC is 1.74 x 10^{-5} °C^{-1} that is a little larger than that of the steel and the cement concrete. Suppose the temperature drops 40 °C in a day and the average tensile modulus of MAEC is 3800 MPa, then according to Eq. (4), the thermo-stress in MAECPC will be

(1.64 – 1.20) x 10^{-5} °C^{-1} x 40 °C x 3800 MPa = 0.67 MPa **(4)**

Since the tensile strength of MAEC is 6.4 MPa according to the indirect tensile strength test, no thermo-cracking will occur in the MAECPC.

TABLE 4 : Abrasion resistance test results

Concrete type	Loss in mass (g/m^2)
Modified asphalt emulsion concrete	2325
Portland cement concrete	3115
Stone mastic asphalt	3986

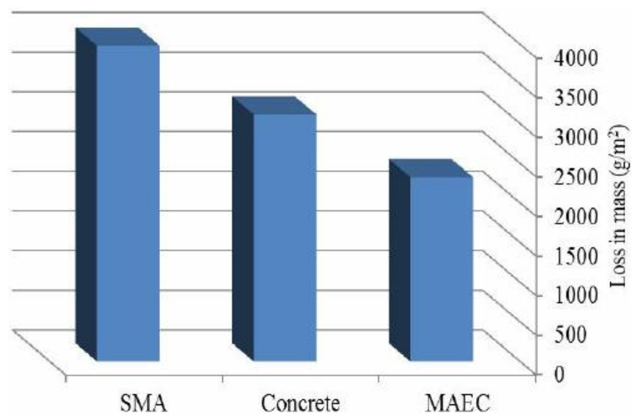

Figure 8 : Effect of different materials on abrasion resistance

TABLE 5 : Linear contraction coefficient test results

Concrete type	Coefficient of linear contraction (-°C^{-1})				Average
	0 °C	0 to -5°C	-5 to -10°C	-10 to -15°C	
MAEC	2.36 x10^{-5}	1.55x 10^{-5}	1.43x 10^{-5}	1.22x 10^{-5}	1.64 x 10^{-5}
SMA	3.40x 10^{-5}	3.15 x10^{-5}	2.35 x10^{-5}	2.10 x10^{-5}	2.75 x 10^{-5}
Concrete	----	----	----	----	1.0–1.5 x 10^{-5}
Steel	----	----	----	----	1.2 x 10^{-5}

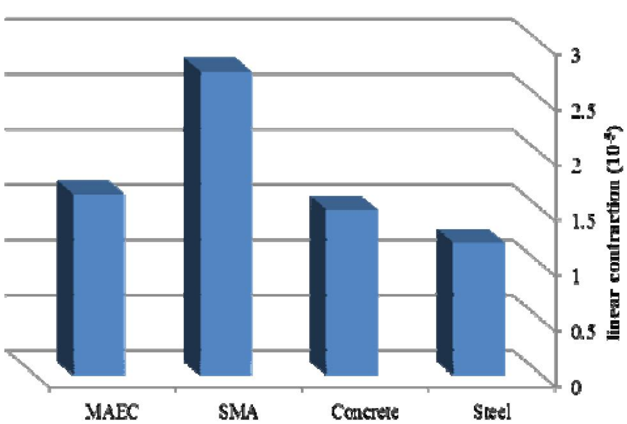

Figure 9 : Effect of different materials on linear contraction coefficient

CONCLUSION

- Compressive strength of MAEC is higher than that of PCC and SMA, The compressive strengths of both MAEC and PCC can meet the requirements of the protective course well, and the SMA does not qualify as the protective course material.

- Dynamic stability of the both MAEC and PCC is higher than that of the SMA, indicating that MAEC has a very good high temperature performance.
- MAEC has the largest indirect tensile strength. MAEC has much better cracking resistance than PCC, meaning that MAECPC can reduce the chance of cracking and increase the service life of the protective course. MAECPC has better cooperative workability with the steel deck.
- MAEC has better abrasion resistance than PCC. Since the PCCPC has been proved to meet the abrasion requirement well, it can be concluded that the MAECPC has better abrasion resistance to withstand the construction loads, meaning that the MAECPC has good cooperative performances with the ballast layer.
- Linear contraction coefficient of MAEC is slightly larger than that of the steel and the cement concrete, according to the indirect tensile strength test, no thermo-cracking will occur in the MAECPC.

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