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Evaluation of the Bending Properties of Cement-Asphalt Mortars by a New 4PB Test Method

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ABSTRACT

As a cushion layer in nonballasted or slab tracks, cement-asphalt mortar (CAM) has been widely applied in high-speed railway networks in Japan, Germany, and China. Traditionally, the compression test method is used in the laboratory to characterise its static mechanical properties at room temperature, for the purpose of quality control and formulation design. However, the validity of this test method has been challenged since the CAM layer is mostly subjected to bending in the track structure. In this paper, the bending properties of two typical CAMs, namely CAM-I and CAM-II, were studied by a newly-developed mini-4PB test apparatus, in comparison to their compressive properties obtained from the traditional test method. It was confirmed that the 4PB test method was suitable for characterising the bending properties of CAM-I or CAM-II, especially for measuring the modulus of elasticity. Irrespective of the test methods used, nonetheless, CAM-I and CAM-II were found to be distinctively different in their mechanical properties and behaviour at room temperature. In addition, all bending parameters of these two CAMs had a decreasing trend with the increase of temperature, but the best deformation capacity or resistance to fracture was observed at around 0 °C.

KEY WORDS: cement asphalt mortar (CAM); 4-point bending (4PB); modulus of elasticity;

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1. INTRODUCTION

As a cushion layer in nonballasted or slab tracks, cement-asphalt mortar (CAM) has been widely applied in high-speed railway networks in Japan, Germany, and China [1-3]. In the CRTS (**C**hina **R**ailway **T**rack **S**ystem) I and the CRTS II of China's high-speed railway network, for instance, there are two typical CAMs in service [4, 5], one with relatively low strength and modulus of elasticity and the other with high ones, termed hereinafter as CAM-I and CAM-II, respectively.

For quality control and formulation design, like concrete materials, the traditional compression test method is generally used in testing the static mechanical properties and behaviour of CAMs at room temperature. However, it has been recognised that, in the new railway track structure, the CAM layer is mostly subjected to bending [6, 7] and hence the validity of this test method is challenged. On the other hand, unlike concrete materials, it has been reported that CAMs are typically viscoelastic materials and their mechanical properties obtained in the laboratory, such as strength and modulus of elasticity, are significantly influenced by the test temperature [8]. Therefore, it is of necessity and vital importance to propose a new test method to characterise the bending properties of different CAMs and, meantime, to study the influence of temperature, in order to get a good understanding of such cushion materials.

In this paper, the bending properties of two typical CAMs, namely, CAM-I and CAM-II, were studied by a 4-point bending (4PB) test method, in comparison to their compressive properties using the traditional compression test method, and the influence of temperature was also evaluated.

2. EXPERIMENTAL

2.1 Raw materials

As composite materials, CAMs are made up primarily of Portland cement, asphalt emulsion, fine aggregate, water and chemical admixtures. In the experimental work, a Portland cement, P·O 42.5, supplied by Beijing Jinyu Cement Corporation and an anionic asphalt emulsion was used. Manufactured sands, with a size range from 40 to 70 meshes, was used as fine aggregates. To reduce or dissipate foams in the mixture, a siloxane-type defoaming agent, DF642, was added. Tap water was used for all the mixes.

2.2 Sample manufacturing

Two typical CAMs with the A/C (i.e. m(A)/m(C), the ratio of asphalt binder in the emulsion to Portland cement by mass) of 0.2 and 1.0 and a control Portland cement mortar were prepared according to the mix proportions in **Table 1**. Mini-slump tests were performed and it was recommended that the spread diameter should exceed 280 mm, in order to ensure the self-compacting ability [9].

Table 1. Mix proportions of CAM-I and CAM-II (by mass)

Type	A/C	C	AE		A+C	S	Tap water	W/C
			A	Water				
CAM-I	1.0	1260	1260	809	2520	3780	199	0.8
CAM-II	0.2	2100	420	270	2520	3780	780	0.5
Control	0	2520	0	0	2520	3780	1260	0.5

Note: AE, A, C, S and W represents asphalt emulsion, asphalt binder, Portland cement, sands, total water.

During the process of mixing, Portland cement and fine sands were in sequence added into a liquid mixture of asphalt emulsion and water first, which was then followed by a small addition of some defoaming agent. The whole mixture was mixed in a 2.5-litre stirring mixer for about 5 min. Then without vibration, the fresh CAM paste was poured into two groups of moulds to manufacture test cylinders (with a dimension of Φ 50.00 mm × 50.0 mm) and prisms (40 mm × 40 mm × 160 mm) as required by two different test methods. After being cured in a standard curing room for 7 days at 20 °C and a relative humidity (RH) of 95%, these samples were placed in another room with constant temperature (23±2) °C and constant humidity (65±5) % and cured for at least 180 days.

2.3 Test methods used

Two test methods, namely, the traditional compression test method and the 4PB test method, were used to test CAMs on a Material Testing System, MTS 810.

Uniaxial compressive tests of CAM cylinders were carried out at room temperature. The loading rate is controlled by the displacement of two grips and the standard rate is 1.0 mm/min [9]. Prior to loading, the two loading surfaces were polished and coated with French chalk, to reduce the surface restraint effect. At least 3 samples were used for each test. Thus, force-displacement curves of CAMs could be directly obtained. By dividing the displacement by the height (ε_c = Displacement / Height) and the force by the area of section (σ_c = Force / Area), strains and stresses, ε_c and σ_c, could be calculated to establish stress-strain curves. On a stress-strain curve, the peak stress value is defined as peak stress $\boldsymbol{\sigma_{cp}}$, i.e. compressive strength, and the tangent modulus at the original point, $\boldsymbol{E_c}$, was used as the modulus of elasticity.

A 4PB test apparatus was developed as shown in **Figure 1** for bending tests. At least 3 prisms were used for each test. According to the classical beam theory, stress-strain curves could be established and four mechanical parameters, namely, bending strength ($\boldsymbol{\sigma_b}$), bending modulus of elasticity ($\boldsymbol{E_b}$), failure strain ($\boldsymbol{\varepsilon_f}$) and failure energy ($\mathbf{G_f}$), could be calculated. Amongst them, failure strain could be defined as the peak strain when the stress reached the peak and failure energy could be defined as the strain energy density to the failure strain, i.e. the integral area before the peak on the stress-strain curve.

Figure 1. A newly-developed mini-4PB test apparatus on the MTS for CAMs

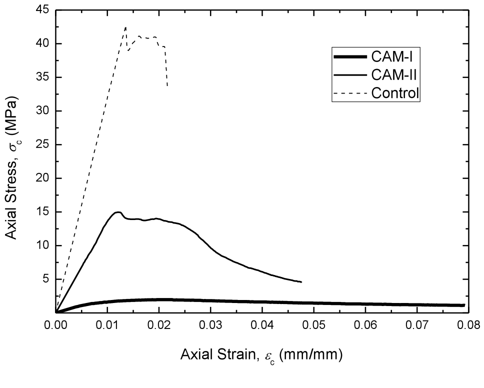
To achieve low or high temperatures, a self-made environmental chamber was attached to the MTS 810 machine. With the consideration of the softening temperature, $T_{R\&B}$, of asphalt binder, high temperatures up to 40 °C and 60 °C and low temperatures down to 0 °C and -20 °C were chosen for testing. Before 4PB tests, CAM specimens were stored at the same temperature as the targeted test temperature in another environmental chamber for at least 24 hours to stabilise the core temperature of the test specimens.

3. RESULTS AND DISCUSSION

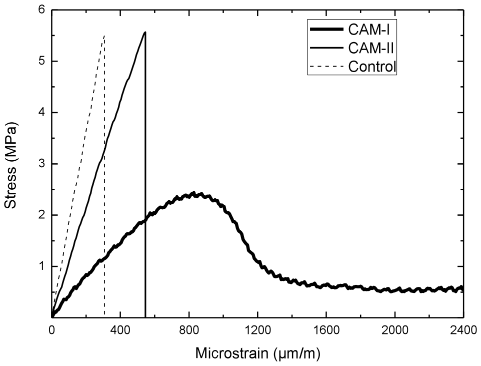
3.1 Mechanical properties of CAM-I and CAM-II using two different test methods

Figure 2 showed typical stress-strain curves of the control Portland cement mortar, CAM-II and CAM-I, obtained under compression and 4PB at room temperature.

It is well known that Portland cement mortar is typically a quasi-brittle solid, and this is more than evident from its stress-strain curves shown in **Figure 2**. When some small amount of asphalt emulsion was incorporated into the Portland cement mortar (i.e. CAM-II, A/C=0.2), a significant reduction in the compressive strength happened but it was interestingly noticed that the bending strength of CAM-II was not reduced. On the contrary, a slight improvement has been achieved, which was probably due to the modification of asphalt emulsion in the cement mortar. Additionally, CAM-II deformed and failed more like the control cement mortar in a quasi-brittle manner. When A/C was increased to 1.0, in contrast, CAM-I was capable of undergoing a large amount of deformation under both compression and bending at room temperature in spite of its lowest strength and modulus of elasticity. Moreover, the after peak softening portion showed that CAM-I is more like a ductile material which has a high deformability.



(a)



(b)

Figure 2. Stress-strain curves of CAM-I and CAM-II under room temperature (a) compression; (b) bending

Based on the comparison from the two test methods as shown in **Table 2**, it was found that the traditional test method underestimated one order of magnitude the modulus of elasticity for both CAMs. That is to say, the 4PB test method can give more reliable results, especially on the modulus of elasticity, therefore considered to be suitable for characterising their bending properties. Irrespective of the test methods used, nevertheless, CAM-I and CAM-II were distinctively different in their mechanical properties and behaviour.

Table 2. Comparison between CAM-I and CAM-II at room temperature

Items		**CAM-I**	**CAM-II**
A/C		1.0	0.2
Compressive Parameters	σ_{cp} (MPa)	2.04	14.58
	E_c (MPa)	286.60	1293.71
Bending Parameters	σ_b (MPa)	2.32	5.66
	E_t (GPa)	3.80	10.59
	ε_f (μm/m)	881	539
	G_f (J/m^3)	1,223.04	1,489.36
Failure Mode		Ductile	Quasi-brittle

3.2 Influence of temperature on the 4PB properties of CAM-I and CAM-II

Within a temperature range from 0 to 40 °C, all bending parameters of CAM-I decreased as the temperature increased (**Table 3**) but remained ductile (**Figure 3**). However, it was destabilised during testing if the temperature increased to

60 °C. In contrast, a ductile-to-brittle transition was observed when the temperature was reduced from 0 °C to -20 °C as clearly shown in **Figure 3**.

Table 1. Bending parameters of CAM-I at intermediate temperatures (0-40 °C)

Tem. (°C)	σ_b (MPa)	E_b (GPa)	ε_f (μm/m)	G_f (J/m^3)
0	2.75	4.64	889	1456.64
20	2.32	3.80	881	1223.04
40	1.47	2.77	679	562.83

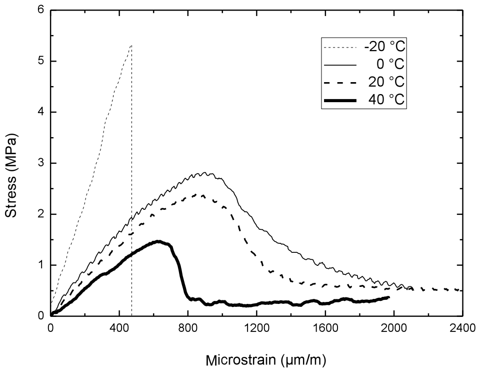


Figure 3. Stress-strain curves of CAM-I under various temperatures

For CAM-II, similarly, its bending parameters (**Table 4**) tended to decrease with the rising temperature but the best deformation capacity (**G_f**) or resistance to fracture (**ε_f**) was observed at around 0 °C.

Table 4. Bending parameters of CAM-II at different temperatures (-20-60 °C)

Tem. (°C)	σ_b (MPa)	E_b (GPa)	ε_f (μm/m)	G_f (J/m^3)
-20	7.63	15.41	503	2192.50
0	7.29	12.60	616	2370.22
20	5.66	10.59	539	1489.36
40	3.06	10.17	308	518.57
60	2.13	10.09	269	338.14

When the temperature was as low as -20 °C, the mechanical properties and behaviour of CAM-I and CAM-II were close to each other, implying that the glass transformation of the asphalt binder used might occur around this temperature. When the temperature rose up to 60 °C, which is higher than $T_{R\&B}$ (48 °C for the asphalt binder used in this study), only CAM-I was destabilised as a solid material, implying that the primary binding phase in this CAM system was the asphalt binder and $T_{R\&B}$ was probably the upper limit for CAM-I in service temperatures.

4. CONCLUSIONS

This paper is aimed at evaluating the static bending properties of two typical CAMs using a newly-developed 4PB test method under different temperatures. Based on the results, conclusions could be drawn as follows.

(a) The 4PB test method was suitable for characterising the bending properties of CAM-I or CAM-II, especially for measuring the modulus of elasticity;
(b) Irrespective of the test methods, CAM-I and CAM-II were found to be distinctively different in their mechanical properties and behaviour at room temperature;
(c) All bending parameters of these two CAMs had a decreasing trend with the increase of temperature. The best deformation capacity or resistance to fracture was observed at around 0 °C for both CAMs.

REFERENCES

[1] Ando, K., Sunaga, M., Aoki, H and Haga, O., Development of slab tracks for Hokuriku Shinkansen line. *Quarterly Report of RTRI*, 2001. 42(1): p. 35-41.
[2] Bastin, R., Development of German non-ballasted track forms. *Proceedings of the ICE, Transport*, 2006. 159: p. 25-39.
[3] Jin, S., X. Chen, and J. Yang, Key technologies of CA mortar for slab track. *China Railway Science*, 2006. 27(2): p. 20-25.
[4] Liu, Y., Kong, X., Yan, P., Bai, Y, Basheer, P. A. M. and Robinson, D., Comparison between two typical cement-asphalt mortars used in slab tracks of high-speed railways, in 31st Cement and Concrete Science Conference: *Novel Developments and Innovation in Cementitious Materials*. 2011: London, UK.
[5] Wang, F. and Y. Liu, The compatibility and preparation of the key components for cement and asphalt mortar in high-speed railway, in Reliability and Safety in Railway, X. Perpinya, Editor. 2012, InTech.
[6] Zhao, P., Analysis of slab track's dynamic performance and study of the parameter, in Civil Engineering. 2003, Southwest Jiaotong University: Chengdu, Sichuan, P. R. China.
[7] Liu, X., Zhao, P., Yang, R. and Wang, P., Theory and method for ballastless track design in passenger dedicated lines. 2010, Chengdu, Sichuan Province. China: Southwest Jiaotong University Press.
[8] Kong, X. Liu, Y., Zhang, Y., Zhang, Z. and Bai, Y.,Influences of temperature on mechanical properties of cement asphalt mortars. *Mater. Struct.*, 2014. 47(1): p. 285-292.
[9] Liu, Y., Kong, X., Zhang, Y. and Yan, P., Static and dynamic mechanical properties of cement-asphalt composites. *J. Mat. Civ. Eng.*, 2013. 25(10): p. 1489-1497.