10th International Conference on Composite Science and Technology
ICCST/10
A.L. Araújo, J.R. Correia, C.M. Mota Soares, et al. (Editors)

RESEARCH ON CEAC LONG-LIFE COMPOSITE PAVEMENT

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Key words: CEAC, Long-life composite pavement, FEM analysis, Stress parameters, Test road.

Summary：*Based on the multifunctional long-life pavement design concept, the cold mix cement - emulsified asphalt concrete (CEAC) is applied to high compression zone, meanwhile the large stone asphalt mixes is set to form the composite base with Cement Treated Macadam (CTM). A three-dimensional finite element model of CEAC composite pavement is established for stress parameters analysis. Then the CEAC long-life composite pavement combination is discussed for the thickness of each layer. The CEAC long-life composite pavement in Yichang city is put forward to test road. The tests show that CEAC and the composite base are suitable for multifunctional long-life pavement. The maximum tensile stress and the maximum shear stress are suggested as strength design parameters for pavement.*

0 Introduction

Multifunctional long-life pavement is the development trend of the road. Based on the reasonable combination design of the structure and materials, the damage of long-life pavement is controlled in the surface, and the main structure of the pavement can be still service well. It is required that the surface layer of pavement should be drainage、noise reduction、slippery resistance. Meanwhile the binder course is located at compressive stress area, which requires a good bearing capacity、rutting resistance and durability. The structural fracture mode of pavement substantially eliminates the traditionally widespread fatigue damage of pavement, advoiding the top-down cracking, and extends the service life of road. The design pattern of the long-life pavement is shown in Figure 1[1].

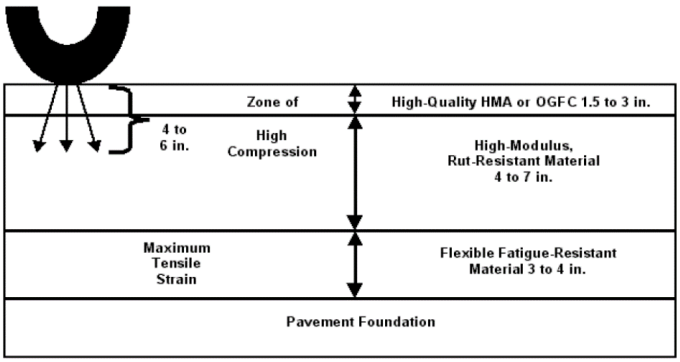

Figure 1: International long-life pavement design pattern

Researches and applications of long-life asphalt pavement in Europe and America have been reported in literature. The main idea is increasing the thickness of the asphalt layer for long-life pavement [2-6]. The average thickness of asphalt layer is 17.4cm-35.3cm in US [7], while it is almost more than 20cm in Europe[8]. However the research of long-life asphalt pavement is still on the way in China. The thickness of asphalt layer in long-life test road in Guangzhou-Shenzhen Highway is 32cm [9]. The total thickness of long-life test road is 76cm and the thickness of asphalt concrete layer is 25cm in the highway of Jiangsu Province. The thickness of asphalt concrete layer is 27cm at reconstructive test long-life section in Huning highway from south Jiangsu to Shanghai[10]. But the thickness of typical asphalt concrete layer in semi-rigid asphalt pavement is generally 10cm in China. So it is hard to completely copy the idea of long-life pavement in Europe and America. It is necessary to seek the suitable structure and material of long-life pavement in China.

1 Conceptual design of CEAC long-life composite pavement

Cold mix cement emulsified asphalt concrete (CEAC) is a semi-flexible composite material. It is a mixture of cement, asphalt, aggregates water and additives. Related experiments[11] show that it is high modulus(7d, 2500~3600MPa),good rutting resistance(dynamic stability 20000 times/mm),good water stability(immersion residual stability≥90%),high ratio of freeze-thaw splitting strength (≥90%), and long fatigue life. CEAC can works as the waterproof membrane to avoid rainwater infiltrating into roadbed. Besides, there is not necessary to set expansion joints, which contributes to the smoothness of pavement. So CEAC is suitable for the binder course of multifunctional long-life pavement. In addition, in order to solve the common reflective cracks of semi-rigid pavement in China, the large stone asphalt mixes interlayer is set to form the composite base with Cement Treated Macadam (CTM). The combination of pavement structure and materials is hoped to meet with requirement for multifunctional long-life pavement.

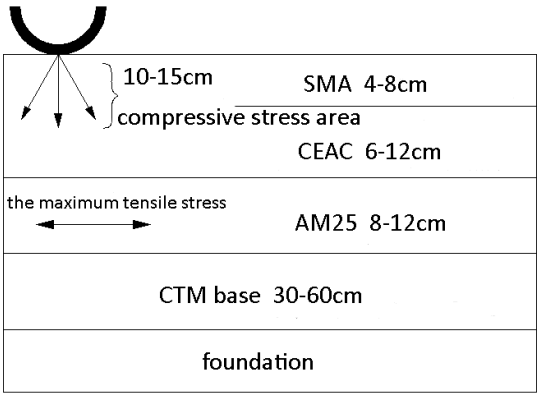

Figure 2: CEAC Long-life composite pavement

2 Specimen preparation and properties for CEAC

The material used in the CEAC study is emulsified asphalt, Portland cement, fly ash, aggregates, water and additives. The CEAC mix design is shown in Table 1. The emulsion type is anionic. Aggregates, cement and fly ash are prepared by first mixing for three minutes. Then emulsified asphalt and water reducer are added to the dry mixture and mixed for five minutes. The material properties of CEAC are shown in Table 1 and Table 2. Table 3 is the fatigue test of CEAC (7d).

Material	Cement	Aggregates	Emulsified Asphalt	Water reducer	Reference	
Specifications	P.O42.5	AC-20C	Anionic	Poly carboxylic acid	Asphalt aggregates ratio by weight	Cement content by weight
Content of mixture（kg/m³)	150	2000	140	1.5	7%	5%

Table 1: CEAC Mix Design

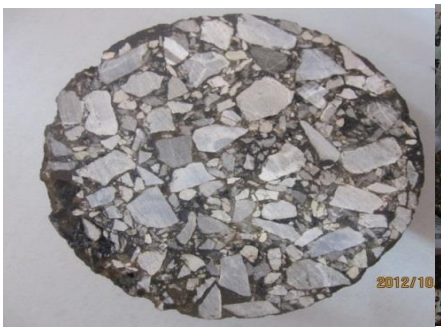

Figure 3: Specimen of CEAC

Figure 4: Interface of CEAC

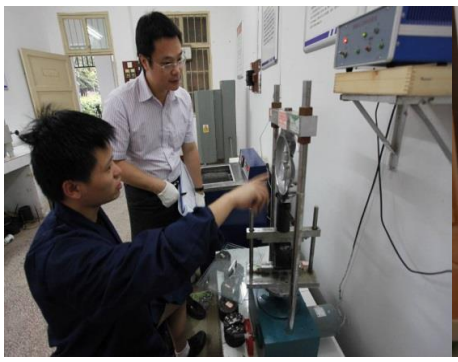

Figure 5: Marshall test of CEAC

Figure 6: Fatigue test of CEAC

Elastic modulus (7d) [MPa] 15 ℃	Poisson's ratio (7d) 15 ℃	Splitting tensile strength（MPa） (7d) 15 ℃	Splitting tensile strength（MPa） (7d) -10 ℃	Immersion residual stability (%) (28d)	Freeze-thaw splitting tensile strength（MPa）(28d)
2566	0.27	1.25	2.62	91.1	1.71

Table 2: Material Properties of CEAC

Test conditions	Stress level	Stress (MPa)	Fatigue life (times)
15 ℃ Loading rate 1mm/min	0.3	0.4135	76685

Table 3: Fatigue test of CEAC (7d)

3 Stress analysis of the CEAC long-life composite pavement

3.1 The three-dimensional finite element model

A Finite element model based on ANSYS is used to analyze the stress field of CEAC composite pavement and the CEAC Long-life composite pavement material parameters are shown in Table 4. All materials are considered to be linear elastic and subjected to the continuum assumption method, satisfying the continuity conditions between the layers. The boundary conditions is no displacement in Z-direction on the bottom surface, no displacement in Y-direction on the left and right sides, no displacement in X-direction on the front and back sides, and the surface is free. In addition, X-direction is driving direction, while Y-direction is transverse direction of pavement and Z-direction is vertical direction. The element of Solid 45 is chosen for FEM analysis. The load for FEM is standard axial load BZZ-100, in which the tire pressure is 0.7MPa. Single wheel load can be simplified into rectangularity 18.9cm×18.9cm and the contacted area is 357.21cm^2. The gap between the edges of wheel is 13.1cm and the distance between two wheels is 138.1cm[12]. The most unfavorable position under wheel load is shown in Figure 7. The example FEM of CEAC pavement is shown in Figure 8.

Layers	Elastic modulus [MPa] 15 ℃	Poisson's ratio 15 ℃
SMA13	1385(1200-1600)	0.28
CEAC	2566	0.27
AM25	720	0.30
CTM base	1550(1300-1700)	0.15
CTM subbase	1480(1300-1700)	0.15
Subgrade	50	0.35

Table 4: The CEAC long-life composite pavement material parameters

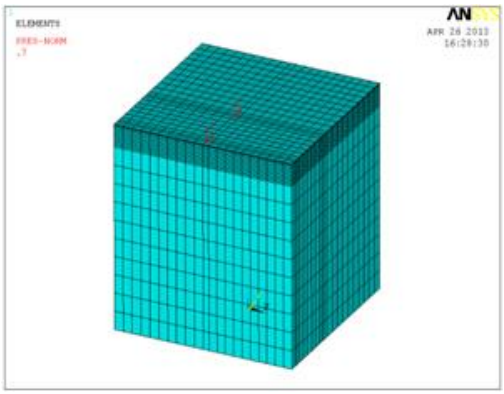

Figure 7: the BZZ-100 axle loading

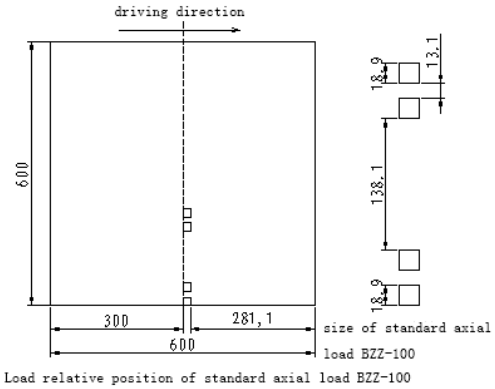

Figure 8: the FEM of CEAC pavement

3.2. Discussion of stresses index in three-dimensional model

The theory of elastic layered system is the base of asphalt pavement design specifications in China[13]. The layer's tensile stress is the very important control index in the design of asphalt pavement from Figure 9. That is to say, it is controlled by σ_x under plane stress state. Pavement shear stress index is controlled by τ_{xy} .

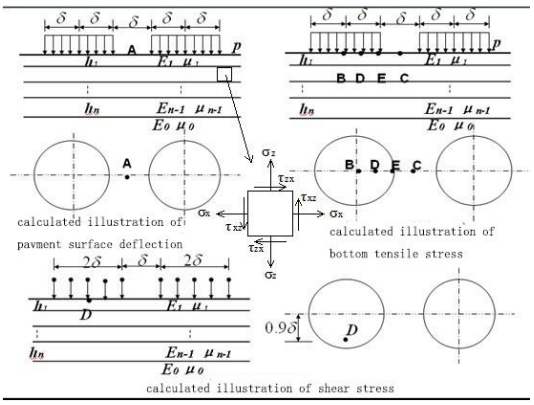

Figure 9: asphalt pavement design index

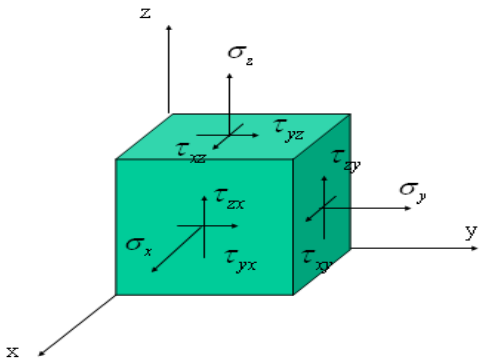

Figure 10: the state of stress at a point

But in three-dimensional model, the stress state of a point is complex. Figure 10 shows all the stresses at a point in a three-dimensional of pavement, which is sufficient and necessary to represent the state of stress at the point. However, it is not clear how to determine the control design index when analyzing a three-dimensional FEM of asphalt pavement. The influence of normal stresses σ_x、σ_y、σ_z and maximum tensile stress σ_1 are discussed. Formula (1) is stresses state matrix, as well as formula (2) are principal stresses and the maximum shear stress. Stress components of pavement structure were analyzed through the three-dimensional CEAC long-life FEM (Table 4).

$$\text{Stress state matrix } [\sigma] = \begin{bmatrix} \sigma_x & \tau_{yx} & \tau_{zx} \\ \tau_{xy} & \sigma_y & \tau_{zy} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix} \tag{1}$$

$$\text{Principal stresses and the maximum shear stress } \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{\max} \end{Bmatrix} \tag{2}$$

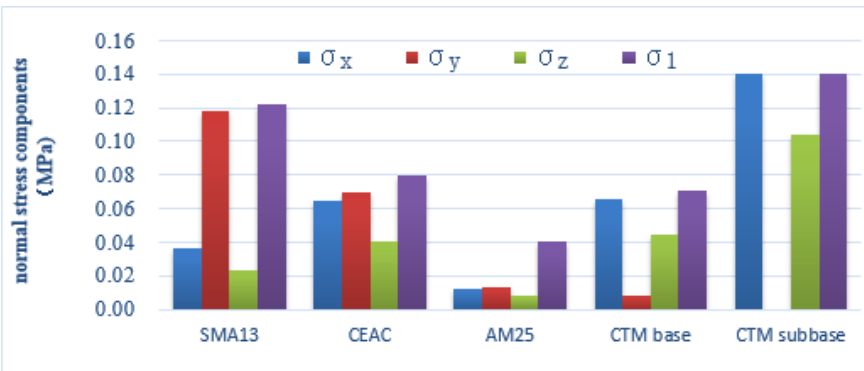

Figure 11: Comparison of normal stress components in pavement layers

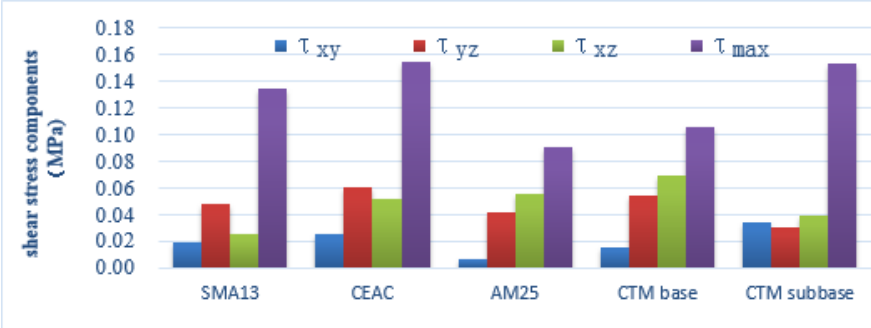

Figure 12: Comparison of shear stress components in pavement layers

Figure 11 shows that the normal stress σ_x、σ_y、σ_z are obviously different in different layers. In base and subbase(CTM), the order is $\sigma_x > \sigma_z > \sigma_y$. In surface (SMA13), binder layer (CEAC) and upper base (AM25), the order is $\sigma_y > \sigma_x > \sigma_z$. So normal stress $\{\sigma_x, \sigma_y, \sigma_z\}$ could not be regarded as strength index when analyzing the three-dimensional element model. However, σ_1 is always the maximum stress in three-dimensional analysis. That is to say, there is always $\sigma_1 > \max\{\sigma_x, \sigma_y, \sigma_z\}$ in each layer of pavement structure. Therefore, it would be more appropriately to apply σ_1 as strength design index in asphalt pavement. The failure criteria is $\sigma_1 \le [\sigma]$, and here $[\sigma]$ is allowable tensile strength. From Figure 12, in each layer $\tau_{\max} \ge \max\{\tau_{xy}, \tau_{yz}, \tau_{xz}\}$, so the maximum shear stress can be used as shear strength index. The shear failure criteria is $\tau_{\max} \le [\tau]$, and here the $[\tau]$ is allowable shear strength. The surface deflection of pavement is still used as integrated design control index over stiffness control index.

4 The thickness design on the CEAC long-life composite pavement

When the initial structure and materials of composite long-life pavement is confirmed, the thickness design on the CEAC long-life composite pavement should be focused on. The combination of thickness for pavement structure is shown in Table 5. According to the analysis of CEAC FEM, the influence of thickness of each layer is discussed from Figure13~Figure 16.

layers	length [cm]	width[cm]	thickness[cm]
SMA13	600	600	4
CEAC	600	600	4，6，8，10
AM25	600	600	4，6，8，10
CTM base	600	600	36
CTM subbase	600	600	18
Subgrade	600	600	600

Table 5: The FEM geometric parameters

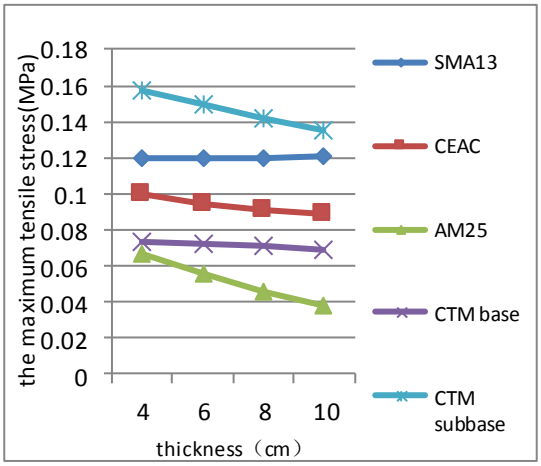

Figure 13: influence of CEAC thickness on σ_{max}

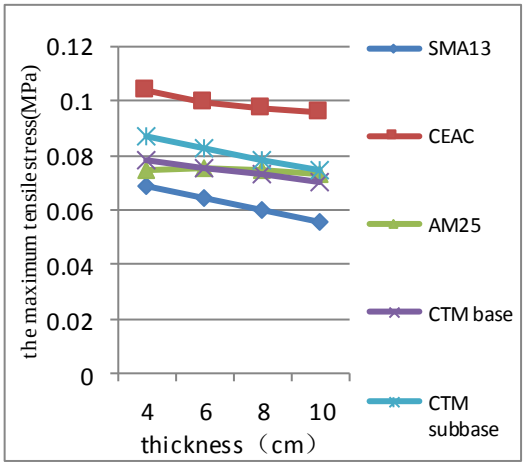

Figure 14: influence of CEAC thickness on τ_{max}

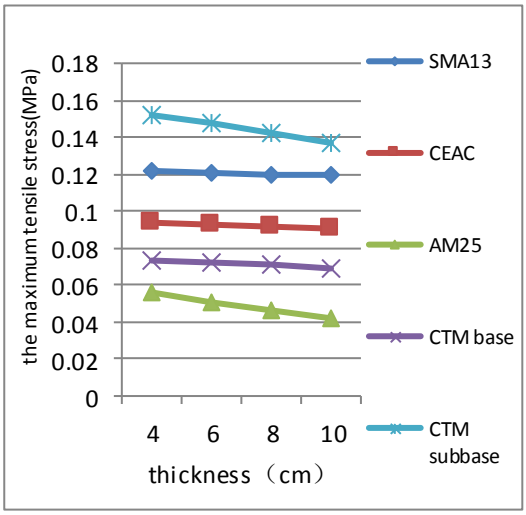

Figure 15: influence of AM25 thickness on σ_{max}

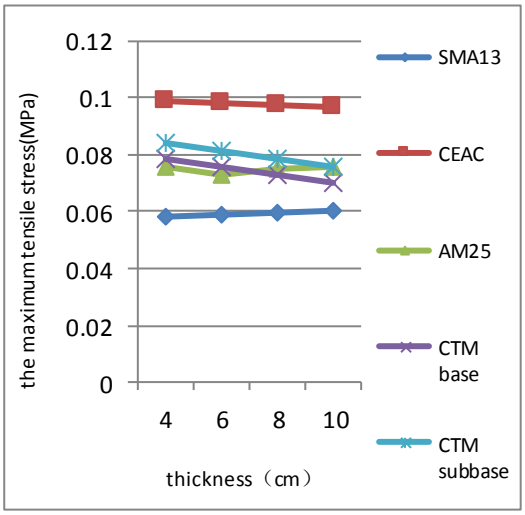

Figure 16: influence of AM25 thickness τ_{max}

Figure 13 and Figure 14 show that it decreases the stresses of each layer in the pavement when CEAC thickness is up, though the effects to the maximum shear stress are very small. Figure 15 and Figure 16 show the same trend about the AM25 thickness. Obviously, it is good for the CEAC pavement by increasing the thickness of CEAC and AM25.But after the analysis of cost and construction technology, there should be a suitable thickness combination for the CEAC long-life composite pavement. Figure 17 shows the CEAC long-life composite pavement combination and the test road (Figure 18) is successfully applied in Yichang city, Hubei Province, China.P.R

SMA13	4cm 1385MPa
CEAC	8cm 2800MPa
AM25	8cm 720MPa
CTM base	2×18cm 1550MPa
CTM subbase	18cm 1480MPa
subgrade	

Figure 17: the Yichang CEAC long-life composite pavement

Figure 18: the construction of Yichang CEAC long-life composite pavement test road

5. Conclusion

The CEAC, as a potential pavement material with good mechanic properties, can be applied in the compressive stress zone as the binder course into a long-life composite pavement. And the large-stone asphalt mix with cement treated macadam will be suitable composite base for long –life pavement. The maximum tensile stress and maximum shear stress of each layer are recommended as strength control index in the three-dimensional analysis of long-life composite pavement. The thickness analysis of each layer in the CEAC long-life pavement would prompt the

pavement. The test road of CEAC pavement in Yichang city has been a reference for the long-life composite pavement. However, the interaction between different layers, the viscoelastic of CEAC and the damage mechanism of CEAC composite pavement will be further studied in future.

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