Construction and Building Materials 155 (2017) 531–541

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Analysis on the fatigue properties of vertical vibration compacted lime–fly ash-stabilized macadam

Jinshun Xue *, Yingjun Jiang

Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang'an University, Xi'an 710064, Shaanxi, China

HIGHLIGHTS

- Fatigue performances of the LFASM compacted by Vibration Testing Method are evaluated.
- Fatigue equations of LFASM are established.
- Suggested values of tensile strength structure coefficient of the LFASM are proposed.

ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form 23 July 2017
Accepted 10 August 2017

Keywords:
Road engineering
Lime fly-ash stabilized macadam
Vibration Testing Method
Splitting strength
Fatigue equation
Tensile strength structure coefficient

ABSTRACT

Although lime–fly ash-stabilized macadam (LFASM) is a common material for the road base course of semi-rigid pavements, the fatigue performance of compacted LFASM has been rarely studied through the vibration testing method (VTM). In this work, LFASM was designed using the VTM instead of the quasi-static testing method. The vibration compaction test method was used to determine optimum water content and maximum dry density, and cast specimens were analyzed through the vibration pressure producing specimen method. The fatigue performances of the LFASM specimens were evaluated, and the fatigue equations of LFASM were then established. The suggested values for the coefficients of the tensile strength structure of LFASM were proposed on the basis of the derived fatigue equations. Results show that the splitting strength of LFASM increased with increasing lime and fly ash contents. However, the rates of the increase in the splitting strength of LFASM gradually declined. The splitting strength of LFASM with skeleton-dense (SD) gradation was higher than that of LFASM with gradation of specification (SG). The fatigue life of LFASM conformed to the two-parameter Weibull distribution, and the established fatigue equations accurately reflected the fatigue life of CRPMs. LFASM with SD gradation showed potentially better fatigue resistance than LFASM with SG. As the contents of lime and fly ash increased, the effect of gradation on the fatigue performance of LFASM became negligible. The failure probability based on the fatigue equations was 50%, the values of the regression coefficient a of the fatigue equations ranged from 1.198 to 1.278, and the values of coefficient b ranged from 0.051 to 0.059. The formula of the tensile strength structure coefficient K_s was proposed. The coefficients for tensile strength structure were recommended after considering various factors. The value of K_s obtained in this work can be used to effectively guide the design of pavement structures. The pavement designed with VTM offers many advantages in terms of crack resistance and durability.

1. Introduction

Fly ash, a waste material of coal-fired power stations, is widely used in civil engineering [1–4]. Conventional construction materials are mainly replaced with fly ash because of economic considerations and waste utilization. Additionally, the strength of materials that contain fly ash may continue to increase over long periods due to pozzolanic reactivity [5]. Lime–fly ash-stabilized macadam (LFASM) is a common semi-rigid base material that is extensively applied in highway base courses because of its good pavement performance [6–8].

The physical and mechanical behaviors of LFASM, including maximum dry density, optimal water content, compressive strength, splitting strength, resilient modulus, shrinkage performance, and fatigue performance, have been extensively studied [9–13]. The fatigue cracking of LFASM in response to seasonal changes in ambient temperature and repeated vehicle load is a

* Corresponding author.
E-mail address: jinshunx@chd.edu.cn (J. Xue).

http://dx.doi.org/10.1016/j.conbuildmat.2017.08.057
0950-0618/

Nomenclature

LFASM	lime fly-ash stabilized macadam	MTS	material testing system
LFA	lime fly-ash	Ri	splitting strength
VTM	vibration testing method	σ_m	tensile stress
QSTM	quasi-static testing method	σ_S	limit splitting strength
SG	specification gradation	K_S	tensile strength structure coefficient
SD	skeleton dense gradation	N_e	cumulative equivalent axle loads
VVTE	vertical vibration test equipment	A_c	coefficient of highway classification
VCTM	vibration compaction testing method		
VPSM	vibration pressure producing specimen method		

common issue. Thus, the fatigue performance of LFASM should be studied for material evaluation and pavement design. Mallela et al. optimized the design method of LFASM layers on the basis of fatigue properties [14]. Panda analyzed the fatigue fracture standards of LFASM by conducting laboratory tests and then applied the obtained results to the reconstruction of pavement design [15]. Judycki established fatigue formulas in accordance with specific criteria and compared the fatigue curves of flexible and semi-rigid pavement [16]. Lav et al. utilized accelerated full-scale road test data for the fatigue performance of cement-stabilized fly ash and then performed a mechanistic empirical design procedure to obtain the appropriate layer thicknesses for pavement with different amounts of cement content to improve service life [17]. The effects of structure type and flexural tensile strength on the fatigue life of LFASM have been experimentally studied with the aim of improving the service life of pavement structure [18]. Li studied the fatigue damage forecast model of LFASM [19]. Gao studied the fatigue performance and fatigue fracture mechanism of LFASM on the basis of linear fatigue–damage accumulation theory and fracture mechanics [20].

In practice, inorganic-binder-stabilized materials are compacted through the vibration testing method (VTM) and quasi-static testing method (QSTM) [21–24]. The QSTM is commonly used to compact LFASM because it is easy to employ and it does not require the use of expensive equipment. However, the correlation between laboratory specimens prepared using the QSTM with in-field specimens is less than 40% because the static pressure that acts on aggregates during QSPM prevents aggregate motion. As static pressure increases, the friction force between the aggregates increases. The aggregates are thus crushed, which consequently affects the mechanical property of the specimens. The VTM was proposed to meet the rapid growth of traffic volumes, axle loads, and field compaction conditions [25,26]. Aggregate rearrangement is favored given the high-frequency liquefaction that acts on the aggregates during VTM compaction. Given that the VTM decreases aggregate breakage and can be used to simulate vibrational compaction in practical engineering [27,28], the mechanical property that results from compaction by this method is representative, reliable, and accurate. The correlation between specimens prepared in the laboratory using the VTM with in-field specimens reaches up to 90% [22,23]. The mechanism of the VTM is similar to that of gyratory compaction initially developed by the Texas Highway Department in 1939 to aid the design and control of asphalt mixtures [29]. In contrast to gyratory compaction, however, the VTM is aimed at improving the simulation of practical field compaction [13–15].

Most studies on LFASM are based on the QSTM; thus, information about the fatigue performance of LFASM designed with the VTM is limited. However, previous studies have also indicated that LFASM behaves differently under different compaction methods even at the same compaction level [23]. Therefore, the fatigue performance of LFASM based on the VTM should be evaluated. In the current work, LFASM with different gradations and contents of lime–fly ash (LFA) were prepared and compacted in the laboratory using the VTM. Then, the fatigue performances of the LFASM specimens were evaluated, and the fatigue equations of LFASM were established. The suggested values for the coefficients of the tensile strength structure of LFASM were proposed on the basis of the derived fatigue equations.

2. Materials and experiment program

2.1. Raw materials

2.1.1. Lime and fly ash

Lime and fly ash was obtained from Tongchuan city, Shaanxi province, China. The chemical and physical properties of these materials and the requirements of *the Technical Guidelines for the Construction of Highway Road Bases* (JTG/TF20-2015) are shown in Tables 1–3.

2.1.2. Aggregate

The macadam was composed of four types of aggregates with different size ranges. The aggregates were graded into four types of coarse and fine aggregates as follows: 37.5–19 mm, 19–9.5 mm, 9.5–4.75 mm, and less than 4.75 mm. The technical performances of the aggregates were tested in accordance with *The Test Methods of Aggregate for Highway Engineering* (JTG E42-2005). The test results are shown in Table 4.

2.1.3. Mixtures

LFASM is multi-phase composite material that is composed of lime, fly ash, and aggregates. Thus, LFASM is composed of two dispersed systems: the LFA (lime–fly ash) mortar microdispersed system and the aggregate dispersed system. The LFA specimens exhibit the optimal mechanical and shrinkage ratios when the mass ratio of lime to fly ash is 2:5; thus, this ratio of lime to fly ash was selected in this research.

As shown in Table 5, two aggregate gradations were selected in the test: the gradation of specification (SG) [30] and skeleton-dense gradation (SD) [31]. The mass ratio of the aggregates with particle sizes of 19–37.5 mm, 9.5–19 mm, 4.75–9.5 mm, and less than 4.75 mm was 45:30:18:7 with SD and 38:32:20:10 with SG. Three contents (17%, 19%, and 21%) of lime and fly ash for each gradation were selected.

2.2. Specimen preparation methods

In this work, the fatigue properties of LFASM were studied using specimens cast through the VTM.

The vertical vibration test equipment (VVTE) is the core of the VTM. The VVTE used in the VTM was manufactured in accordance with the principle of a directional vibratory roller. The VVTE for indoor testing was designed to imitate the working

Table 1
Test results of lime character.

Test index	Fineness/%		Mass fraction of CaO and MgO/%
	Residue of the sieve of 0.71 mm	Residue of the sieve of 0.125 mm	
Results	0	2.3	61.0