Construction and Building Materials 24 (2010) 2252–2259

Contents lists available at ScienceDirect

Construction and Building Materials

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

A model for resilient modulus determination of recycled mixes with bitumen emulsion and cement from ITS testing results

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ARTICLE INFO

Article history:
Received 3 October 2009
Received in revised form 16 March 2010
Accepted 1 April 2010
Available online 22 April 2010

Keywords:
Cold recycling
Bitumen emulsion
Type I cement
Pozzolanic cement
ITS
M_r

ABSTRACT

Typically, resilient modulus (M_r) of recycled mixes, containing bitumen emulsion and cement, will increase upon curing. Hence, assigning a design M_r for these mixes will be more complex than the case of conventional hot mixes. Furthermore, M_r testing facilities are not generally available in many project sites. Therefore, developing a model that could estimate M_r from ordinary testing methods would be quite appropriate. In this research, upon performing indirect tensile strength test (ITS) and determining M_r of specimens at different testing temperatures (−10, 5 and 25 °C) and curing times (7, 28 and 120 days), two models have been developed to estimate the M_r of recycled mixes with bitumen emulsion and two types of cements (type I and pozzolanic cement). The results showed that increased curing time and cement content and decreased testing temperature led to increased ITS and M_r values. For both tests the effect of temperature was more pronounced than two other parameters. The models were developed by two steps. First the relationship between ITS and M_r at similar testing conditions was determined for each cement type. This was done by a linear relationship. In the second step, the relationship was adjusted to consider the effects of temperature and curing time. Using the final model, M_r of studied mixes could be estimated from ITS testing results at similar or different testing conditions.

1. Introduction

Mechanical properties of cold recycled mixes with bitumen emulsion and cement are very much related to curing condition [1,2]. Extensive research works on emulsion–cement interaction confirmed that cement will accelerate the breaking of bitumen emulsion and setting of the mix [3–5]. However, because of cement hydration nature, the mechanical properties of the mix will be time dependent [3]. For recycled layers with bitumen emulsion it has been affirmed that at least one year curing is needed to achieve the final physical characteristics. Whereas for cold mixes containing bitumen emulsion and cement about 90% of the final stiffness was achieved after 90–120 days curing [3–6]. Several research works showed that after 120 days curing the stiffness will be almost two to three times greater than the initial value (e.g. 7 days) [4,6].

In recent years mechanistic approaches (based on elastic theory) that require elastic behavior for pavement materials as input have been widely used for pavement design applications. Resilient modulus (M_r) of bituminous mixes, measured with indirect tensile mode (ASTM D4123), is one of the stress–strain measurements that used to evaluate the elastic properties of bituminous mixes [5,7]. For a hot mix with specified mix design, testing temperature is the most effective parameter affecting the M_r value [3,4]. However, for the case of cold mixes, curing time is also an important parameter. Hence, for controlling the load bearing capacity it is necessary to measure the M_r of recycled specimens at different curing times. Due to inaccessibility of M_r test apparatus in many project sites, in this paper two models have been established to estimate the M_r value of recycled mixes (with bitumen emulsion containing type I and pozzolanic cements) with the results of indirect tensile strength testing method which is less expensive and more accessible than M_r testing equipments.

2. Cement–emulsion interaction

Reclaimed Asphalt Pavement (RAP) materials exhibit stress dependent behavior with an increase in resilient modulus under increasing confining stress and a reduction in resilient modulus under increased shear stress conditions [8,9]. In general, because of crystalline bonds formation, addition of cement increases the resilient modulus, shear strength and permanent deformation resistance and decreases the moisture sensitivity of the material and may reduce the ability of the material to sustain flexural bending [8–10].

The addition of bitumen emulsion results in the formation of pliable bituminous bonds in the RAP material, resulting in a higher

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doi:10.1016/j.conbuildmat.2010.04.031

cohesion and increased permanent deformation resistance [9,11]. However, due to the visco-elastic behavior and temperature dependency of bituminous bonds, the mixture may be prone to rutting under high service temperatures and slow moving traffic [11].

Emulsified mixes that are stabilized with cement, exhibit a combination of the stress dependent characteristics of the unbound RAP, the brittle but permanent deformation resisting characteristics of cement and the flexible characteristics of bitumen emulsion. The extent to which either of the above characteristics dominate the mix behavior depends on the proportions in which the constituents are mixed and the properties of the individual constituents [10].

Based on microscopic studies made using scanning electron microscope (SEM), the products of recycled mixes (with bitumen emulsion and cement) could be similar to hydration reaction products in normal concrete mixes [4]. SEM photos showed that mixes that contain cement are quite rough in texture, having a pock marked surface [4,12]. Photographs of mixes, containing pozzolanic cements, exhibited some differences at initial days of curing [13,14]. Based on several research works, the pozzolanic compounds have no considerable activity before lime production from hydration reaction. Reaction between pozzolan and lime initiates soon after hydration. However, pozzolanic reaction effects will appear after several days [15,16]. It has been shown that at initial curing period the stiffness of mixes containing pozzolanic cement will be less than those containing type I cement. The Research works have shown that the final stiffness of pozzolanic systems will be equal or even more than type I cement [15,16].

3. Materials

3.1. Aggregates

RAP materials, were taken from Tehran West Depot. After crushing the lumps the materials greater than 25 mm were removed and the gradation was determined. The gradation of the processed RAP is shown in Fig. 1.

ASTM D2172 procedure was followed and the bitumen content of the RAP was determined. RAP materials contained 3.3% bitumen by total weight of the material. The gradation of extracted aggregates was then obtained as shown in Fig. 1. No virgin aggregate were added.

3.2. Bitumen emulsion

Cationic slow setting emulsion (CSS-1h) was used in the experimental program. The formulation and properties of bitumen emulsion are shown in Table 1.

3.3. Cement

Type I and type I(PM) pozzolanic cements were used in this research. Pozzolanic cement were combination of 85% type I cement clinker and 15% natural pozzolan. The components and physical properties of cements are reported in Table 2. The amounts of cement used in the mixture were 1%, 2% and 3% of total mixture weight.

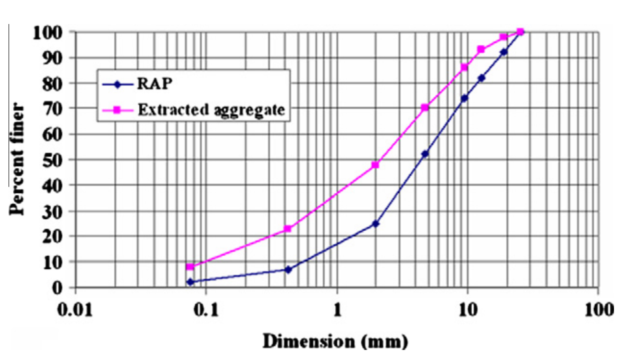

Fig. 1. The gradation of RAP materials and extracted aggregates.

Table 1
Bitumen emulsion formulation and properties.

Property	Value
Viscosity (s)	40
Particle surface electric charge	Positive
Binder level (%)	60.0
Water level (%)	35.0
Emulsifier level (%)	1.0
Solvent level (%)	3.5
HCl level (%)	0.5

Table 2
Component materials and physical properties of I(PM) pozzolanic and type I cements.

Component	Average (by weight)%	
	I(PM)	Type I
a – Component materials		
C_3S	40.0	49.0
C_2S	23.0	25.0
C_3A	9.0	12.0
C_4AF	7.0	8.0
$CaSo_4$	2.5	2.9
CaO	0.7	0.8
MgO	0.8	1.2
Loss of ignition	3.0	1.5
Natural pozzolan (tuff)	15.0	0.0

Property		I(PM)	Type I
b – Physical properties			
Min. specific surface (cm^2/gr)	3000	2800	
Setting time	Initial (min)	60	45
	Final (h)	7	6
Min. compressive strength (kg/cm^2)	7 days	175	–
	28 days	315	425

4. Mix design

Several procedures are available to determine the optimum bitumen emulsion and water content for cold recycled mixtures [9,17,18]. In this research modified Marshall method was used. According to this method, first mixtures without cement were prepared containing 3% water (consisting of emulsion water, RAP water content (0.3%) and additional water added to the mixture). Bitumen emulsion was added to mixture at different amounts (from 2.5% to 4.5% by total weight of the mixture) at 0.5% increments. Then samples were compacted applying 50 blows per side with Marshall hammer. After compaction, all samples were kept in the molds and were oven cured for 6 h at 60 °C. Then after removing from molds, samples were kept for 48 h at room temperature. These were then tested for maximum and bulk specific gravities and Marshall stability. The results of these tests are presented in Table 3a. The only design criterion for optimum bitumen emulsion content in this method is the void content that should be within 9–14% [9]. Using this criterion, and considering the maximum of bulk specific gravities and maximum stability, the optimum emulsion content was assigned to be 4% [9]. In the second step, the optimum moisture content (OMC) was determined for specimens containing different amounts of cements at optimum bitumen emulsion. The details of results which obtained for specimens containing 3% cement are presented in Table 3b. As reported in this table, the air voids of specimens for both cements were more than 14%. With determination of the maximum bulk specific gravity, maximum stability and minimum air void, optimum moisture content (OMC) values were determined for different mixes. OMC values of all specimens are presented in Table 4. As seen, OMC values increased upon adding the cements. The more cement content, the more will be OMC value.