Construction and Building Materials 75 (2015) 275–282

Contents lists available at ScienceDirect

Construction and Building Materials

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

Field validation of recycled cold mixes viscoelastic properties

Pietro Leandri [a,*], Massimo Losa [a], Andrea Di Natale [b]

[a] University of Pisa, Department of Civil and Industrial Engineering (DICI), Largo Lazzarino, 1, 56122 Pisa, Italy
[b] NEXT Ltd., Via Rinaldo Piaggio, 32, 56025 Pontedera, Italy

HIGHLIGHTS

- Mechanical and performance properties of recycled cold mixes to be used in design of pavement sections.
- Evaluation of mechanical properties and performance of recycled cold mixes by laboratory tests.
- Evaluation of visco-elastic properties of recycled cold mixes by tests carried out on cores.
- Comparison between predicted and recorded visco-elastic response of recycled cold mixes.

ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form 7 October 2014
Accepted 12 November 2014

Keywords:
Recycled cold mixes
Bitumen emulsion recycled cold mixes
Foam bitumen recycled cold mixes
Visco-elastic properties
Fatigue resistance

ABSTRACT

Visco-elastic properties of recycled cold mixes are analyzed in this paper by tests carried out in laboratory; the aim of the paper is to evaluate how reliable are these properties to be used for the prediction of visco-elastic response of pavement layers containing recycled cold mixes.

The paper focuses on both bitumen emulsion and foam bitumen recycled cold mixes; two different mixtures were designed in laboratory to achieve specific mechanical properties and used to build two instrumented test sections. Visco-elastic properties and fatigue resistance of these mixtures were determined on cores extracted from the test sections and compared with those determined on a conventional hot asphalt mixture for base layer. This comparison allowed to highlight the reduced thermo-sensitive and time-dependant behavior of these mixtures.

Visco-elastic properties of the recycled cold mixtures determined in laboratory, then were used to predict strains in the base layer of the test pavements by using the ViscoRoute 2.0 software. The comparison between measured and predicted strain pulses allowed to evaluate the reliability of visco-elastic parameters determined in laboratory to predict response of layers composed of recycled cold mixes. The obtained results show that visco-elastic parameters of bitumen emulsion recycled cold layers exhibit a satisfactorily capacity to accurately reproduce the pavement response; the same reliability cannot be found for foam bitumen recycled cold layers, whose behavior diverges significantly from that of a continuum.

1. State of the art

Recycled Cold Mixes (RCM) are currently used in base and subbase layers, principally for their recognized benefits in terms of pavement sustainability [1]; a lot of papers are available in literature about this subject, nevertheless some issues still need to be investigated and particularly those related to modeling their effective visco-elastic behavior which can be significantly different from that of conventional Hot Mix Asphalt (HMA). The role of active fillers in RCM has been investigated by many Authors [2], confirming that RCM containing a low percentage of active filler perform better than conventional RCM, particularly in soaked conditions; for the specific case of Bitumen Emulsion Recycled Cold (BERC) mixtures, it has been shown that cement can increase the mix stiffness, its resistance against permanent deformation and can decrease its moisture sensitivity and temperature susceptibility [3]. Increased curing time and cement content and decreased testing temperature on BERC mixtures lead to increased Indirect Tensile Strength (ITS) and Resilient Modulus (RM) values [4,5]. Nevertheless, the resistance to repeated loading is a significant

Abbreviations: HMA, Hot Mix Asphalt; RCM, Recycled Cold Mixes; BERC, Bitumen Emulsion Recycled Cold mixes; FBRC, Foam Bitumen Recycled Cold mixes; ITS, Indirect Tensile Strength; RM, Resilient Modulus.

* Corresponding author. Tel.: +39 0502218298; fax: +39 0502217762.
E-mail address: pietro.leandri@ing.unipi.it (P. Leandri).

http://dx.doi.org/10.1016/j.conbuildmat.2014.11.028
0950-0618/© 2014 Published by Elsevier Ltd.

factor for the mechanical characterization of these materials. The addition of cement can make these mixtures more brittle than conventional HMA [6], reducing the flexibility and fatigue life of RCM. Particularly, it appears Foam Bitumen Recycled Cold (FBRC) mixes display a longer fatigue life at low strain levels, while BERC mixes display a longer fatigue life at higher strain levels. Qualitative analyses indicate that BERC mixes show a diffused damaged, due to its visco-elastic characteristics, while fatigue damage of FBRC mixes shows a brittle fracture [7]. At low initial strain levels, the fatigue life of RCM with cement is longer than mixtures without cement, whereas at high initial strain levels, the fatigue life is less than mixtures without cement [8]; this is due to the fact that the cement has the effect of increasing the fatigue life at lower strains and reducing the fatigue life at higher strains.

The different visco-elastic behavior has been highlighted also recently [9], confirming that RCM provide lower stiffness modulus and lower resistance to repeated loading, but better resistance to permanent deformation when compared with HMA. This behavior can be explained due to the presence of cement bonds that reduce thermal sensitivity and viscous response.

Despite the numerous laboratory studies, only few researches have been carried out to monitor effectively the behavior of RCM in the field, and they are limited to FBRC mixes [10–12]; particularly, in the two latter, a fiber optic sensor system was used for in situ strain measurements, asserting that the material could be characterized as durable against fatigue failure. The analysis of results did not indicate an in situ stress dependent behavior.

2. Objectives

This paper focuses on both BERC and FBRC mixes. The principal objective is to analyze the visco-elastic behavior of RCM by tests carried out in laboratory; two different mixtures were designed in laboratory to achieve specific strength requirements and were used for construction of two test sections. Visco-elastic properties and fatigue resistance of the mixes were determined by dynamic tests carried out on cores extracted from the pavements, and were compared with those determined on a conventional HMA for base layers.

In order to evaluate field performance of these mixtures, the two test sections were instrumented and monitored under on service traffic loads. Visco-elastic properties of the RCM determined in laboratory were used to predict visco-elastic strains in the base layer by using the ViscoRoute 2.0 software. The comparison between measured and simulated strain pulses allowed to evaluate the reliability of the visco-elastic parameters determined in laboratory to predict the field behavior of the RCM for constructing.

3. Mix design of BERC and FBRC mixtures

Mix design was carried out with a Superpave gyratory compactor [13]. Given the absence of technical standards concerning volumetric parameters to be observed for this type of mixes, the optimum contents of cement, and of both bitumen emulsion and foam bitumen were identified by optimizing both the bulk density of the compacted mixture (G_{mb}) and the ITS.

Fig. 1 shows the aggregate size gradations after the bitumen recovery of both the BERC and the FBRC mixes. The maximum aggregate size is equal to 16.0 mm and to 25.0 mm for the BERC and the FBRC mix respectively, being the related base layer thickness equal to 10 and 15 cm respectively.

In order to determine the optimum water content, samples were compacted at a number of gyrations N_{max} equal to 180, with a cement content equal to 2% and different water contents. The optimum content of total liquids was determined as the value

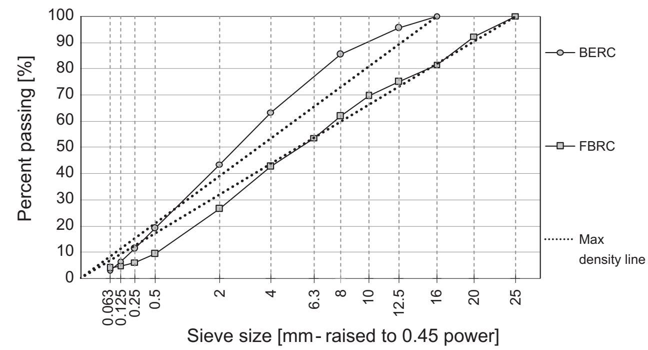

Fig. 1. Aggregate size gradations and composition characteristics of BERC and FBRC mixes.

which maximizes the bulk density (G_{mb}). After that, in order to determine the optimum binder content, specimens were compacted at a number of gyrations equal to 180 with different emulsion (3.3%, 4.2%, 5.0%) or foam bitumen content (2%, 3%, 4%), as well as with different cement (1.5%, 2%) and a water content which allows to obtain a total liquid content equal to the value previously determined. In order to avoid that the mixtures become significantly more brittle than conventional HMA, the maximum percentage of cement was equal to 2% [6,14]. After a period of accelerated curing (72 h) @ $T = 40$ °C, specimens were tested to determine ITS. The optimum content of cement, and of both bitumen emulsion and foam bitumen were identified by optimizing the ITS values; the selected mixture compositions are reported in Table 1.

The two gyratory compaction curves of the design mixtures (Fig. 2) show a linear increase of compaction degree for both the mixtures; this highlights that the two mixtures show similar compaction and volumetric properties.

The results of the ITS tests carried out on the two design mixtures at $T = 25$ °C, according to UNI EN 12697-23, after a period of accelerated curing for 72 h at $T = 40$ °C, are similar for both the mixes, and they are equal to 0.34 and 0.38 N/mm^2 respectively for BERC and FBRC mixes, with a Coefficient of Variation (COV) ranging between 7.5% and 9.5%; they are greater than the minimum value required by the national standards for RCM (ITS $\geqslant$ 0.30 N/mm^2). In order to evaluate moisture susceptibility, the Indirect Tensile Strength Ratio (ITSR), according to UNI EN 12697-12, was determined. The results clearly show that no problems pertaining to moisture susceptibility arise for the two mixes [14]. Particularly, the BERC mix shows less moisture susceptibility than the FBRC mix [3], being the ITSR equal to 92% and 87% respectively, and greater than 75% required from national standards.

Table 1
Composition characteristics of the mixtures.

		Bitumen Emulsion Recycled Cold mix (BERC)	Foam Bitumen Recycled Cold mix (FBRC)
Recycled asphalt pavement	(%)	100.0	80.0
Virgin aggregates	(%)	0.0	20.0
Bitumen emulsion[a,e]	(%)	4.2	–
Foam bitumen[b,e]	(%)	–	3.0
Cement[c,e]	(%)	2.0	2.0
Optimum total liquids[d,e]	(%)	7.0	5.0

[a] Modified bitumen emulsion 60/40 with latexa.
[b] 70/100 Penetration grade pure bitumen for foam bitumen.
[c] Portland cement 32.5 *R*.
[d] Total liquids = bitumen emulsion/foam bitumen + water.
[e] Percentage by weight of total aggregates (RAP + virgin aggregates).