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The long-term properties of mineral-cement-emulsion mixtures

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HIGHLIGHTS

- Nine different mineral-cement-emulsion mixtures were tested acc. to AASHTO TP79.
- The long term changes of dynamic moduli and phase angles were investigate.
- Mixtures were tested in periods of 28 days and 1.5 year.
- The mean change (increase) of dynamic moduli ranged from 9% to 14%.
- The mean change (decrease) of phase angles ranged from 4% to 8%.

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ABSTRACT

This publication presents evaluation of long-term behavior of mineral-cement-emulsion (MCE) mixtures. MCE mixtures are among the major products of cold recycling of old asphalt pavements. They are composed by binding of the old materials reclaimed from the pavement and new mineral aggregate using two different binding agents – cement and bituminous emulsion. While bituminous emulsion dissolutes and binds materials quite fast, it does not increase the stiffness modulus of the whole mixture. Opposite behavior occurs for cement. Its effects appear slowly and all construction materials that contain cement present the increase of strength and stiffness modulus with time. Usually the increase of strength or modulus is similar for all tested materials for the same curing periods.

This article investigates the impact of combination of two binding agents and their different amounts on the increase in strength and stiffness modulus of mineral-cement-emulsion mixtures with curing time. Conducted literature and laboratory studies showed that regarding the short term changes of modulus and phase angle, mineral-cement-emulsion mixtures present similar behavior to other cement-bound materials, such as cement concrete or cement-bound mixtures. In the case of long-term behavior similarities to the cement-treated materials were found as well: an increase in moduli and a decrease in phase angles were observed for longer curing times. This kind of behavior illustrates that hydraulic bonds affect both mechanical and rheological long-term properties of mineral-cement-emulsion mixtures.

1. Introduction

Presently full-depth cold in-place recycling of old asphalt pavements using cement and bituminous emulsion is one of the most popular recycling technologies, as it is quite fast and relatively inexpensive, with strongly reduced usage of new materials [1–6]. A mineral-cement-emulsion mixture base layer provides very good mechanical performance, even when the base material obtained from old deteriorated asphalt pavements is of inferior quality.

Mineral-cement-emulsion mixtures include two different binding agents – cement and bituminous emulsion – that allow to obtain properties stated in the requirements. Each of the binding agents is responsible for meeting specific requirements [7–10]. Bituminous emulsion is responsible for creation of bituminous bonds, and – as a result of increase in cohesion of the layer – resistance to moisture-induced damage. It also provides sufficient flexibility of the layer, which should lead to minimization of the risk of shrinkage cracking. Cement is responsible for creation of hydraulic bonds, and, as a result, a further increase in resistance to moisture-induced damage. It also provides sufficient preliminary strength and bearing capacity of an MCE base layer for the purpose of construction traffic. As a side effect – in contrast to the bituminous emulsion – it is also responsible for an increased risk of shrinkage cracking. The overall behavior of an MCE base layer is the result of interaction between both binding agents. Special effort should be taken during MCE mixture design to obtain more bituminous

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bonds, as the risk of reflective cracking on the surface of the pavement is quite high, due to high amount of cement in the mixture. Mechanical properties stated in the requirements [11] should be achieved for the lowest possible cement content.

Indirect tensile strength is used as a basic parameter for evaluation and description of materials treated with cement and bituminous emulsion, due to simple specimen preparation, simple laboratory procedure and repeatability of results. Recently for mineral-cement-emulsion mixtures and other materials treated with either cement or bituminous emulsion more emphasis is being put on stiffness moduli, both short- and long term. The main purpose of stiffness moduli research is to obtain the optimum combination of binding agents that would result in the maximum bearing capacity of constructed layer with simultaneous reduction of possible extensive shrinkage. As most studies described in the literature review were conducted for shorter times of curing, it is hard to predict the final increase in stiffness modulus with curing time, as the addition of cement will be still responsible for creation of hydraulic bonds.

Literature review shows that in most requirements and regulations [7,8,11–15] mineral-cement-emulsion mixtures are evaluated similarly to the hydraulically treated materials. Typical requirements – especially in terms of strength – are given for periods of 7 and 28 days, as cement is one of the two main binding agents, even if its amount is strongly reduced. There is only a single case of requirements based on the elastic or even viscoelastic properties of the mix.

The development of strength of mineral-cement-emulsion mixtures with time of curing has been quite extensively investigated in recent years: especially the early-stage strength – up to 7 days [16], and short-term strength – up to 60 days of curing [17–23]. The case of long-term performance of mineral-cement-emulsion mixtures has not been thoroughly described and up to now only a single study has been conducted.

On the other hand, not much interest was given to the investigation of elastic modulus of mineral-cement-emulsion mixtures. Bocci et al. [17] investigated the influence of different curing conditions on the development of stiffness modulus. It was also found that curing in 40 °C strongly increases the development of stiffness modulus, probably due to increased hydration of cement. Meocci et al. [18] compared laboratory-prepared specimens with cores obtained from existing pavements. Stimilli et al. [24] investigated ITSM and complex modulus of both laboratory and field specimens. Kavussi & Modarres [20] investigated ITSM at three different temperatures (−10, 5 and 25 °C) for three curing periods (7, 28, 120 days). Valentin et al. [21] tested the stiffness modulus of both mineral-cement-emulsion mixtures and foamed bitumen mixtures. The test included influence of several factors on the value of stiffness modulus, e.g. proportions of the binding agents and curing time. Graziani et al. [22,23] tested the stiffness modulus of two different cold-recycled mixtures – mineral-emulsion mixture, with small addition of cement, and mineral-cement-emulsion mixture, for curing times of up to 120 days. Lin et al. [10] tested viscoelastic properties of mineral-cement-emulsion mixtures in the temperature range from −10 °C to 50 °C, but only for curing times of up to 28 days.

The assessment of change in the stiffness modulus of mineral-cement-emulsion mixtures is important for the pavement design process, as it influences the mechanical and fatigue behavior of the whole structure. An increase in stiffness modulus will result in an improvement of fatigue properties and bearing capacity of the pavement structure [25]. On the other hand, as the mixture contains cement as one of the binding agents, an increase in modulus can lead to shrinkage cracking of the mineral-cement-emulsion mixture base, and, consequently, to reflective cracking at the surface of the asphalt courses. The assessment of change in stiffness modulus and phase angle can indicate whether the impact of the increase in stiffness modulus of mineral-cement-emulsion mixtures is relevant to the comprehensive assessment of pavement fatigue life and failure mechanisms.

Fig. 1 presents comparison of the development of strength of mineral-cement-emulsion mixtures and hydraulically treated materials, such as hydraulically treated mixtures and concrete cement. Fig. 2 presents comparison of development of stiffness or elastic modulus over time for the aforementioned materials. To compare the processes, the values of strength and stiffness or elastic modulus were normalized. The period of 28 days of curing for each material was set as reference and the results for other curing periods were presented as a fraction or multiplication of the reference value. This method of analysis was chosen in order to compare the behavior of cement-treated mixtures in a very wide range of strength or modulus. Results for mineral-cement-emulsion mixtures were compared with those obtained for cement concrete [26]. A brief summary of the literature review is presented in Table 1.

2. Experimental program

2.1. Materials

The MCE mixture for research was designed according to the Polish requirements [11] and its mineral skeleton comprised of reclaimed asphalt, unbound crushed aggregate 0/31.5 and fine aggregate 0/2. CEM I 32.5R and cationic bituminous emulsion C60B5R were used as binding agents. The amounts of each binding agent used were set to 2, 4 and 6%, to create a matrix of 9 different combinations of binding agents in MCE mixtures (from 2% of cement and 2% of bituminous emulsion up to 6% of cement and 6% of bituminous emulsion). Grading curves of the designed MCE mixtures are presented in Fig. 3. Basic data regarding composition and mechanical properties of the selected mixtures is presented in Table 2. According to the requirements [11], samples for assessment of basic properties of MCE mixtures were compacted in a Marshall compactor with 75 blows per side. The amount of water added to the mixture was assumed on the basis of the following equation:

$$W_{dod} = W_{opt} - W_{nat} - W_{em} - 0.5 \times B \quad (1)$$

where: W_{dod} – the amount of added water [%], W_{opt} – optimum moisture content, determined from Proctor method [%], W_{nat} – natural moisture of MCE mixture (both reclaimed asphalt and additional aggregate) [%], W_{em} – water included in the bituminous emulsion [%], B – the amount of bitumen in the bituminous emulsion [%].

MCE mixtures were mixed using a standard laboratory mixer. First cement and water were added to the reclaimed asphalt and aggregate in the form of suspension with w/c ratio of 1. Next the bituminous emulsion was added and all components were mixed for 2 min at an ambient temperature of +25 °C.

Samples for the dynamic modulus test were compacted in a Superpave Gyratory Compactor to achieve 99% of the Marshall samples compaction. Vertical stress of 600 kPa, angle 1.25° and gyration rate of 30 gyrations per minute were used.

Indirect tensile strength (ITS) was tested according to the EN 12697-23 standard, indirect tensile stiffness modulus (ITSM) was tested according to the EN 12697-26 standard (IT-CY, method C). In the case of C6E2, C6E4 and C6E6 MCE mixtures, basic mechanical parameters were not assessed, as specified mixtures do not comply with the Polish requirements, and were not planned in the preliminary part of the research.