Construction and Building Materials 70 (2014) 148–157

Contents lists available at ScienceDirect

Construction and Building Materials

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

Characterizing the performance of cementitious partial-depth repair materials in cold climates

Haithem Soliman *, Ahmed Shalaby [1]

Department of Civil Engineering, University of Manitoba, Room E1-368A Engineering, 15 Gillson St., Winnipeg, Manitoba R3T 5V6, Canada

HIGHLIGHTS

- Laboratory criteria is proposed to evaluate PDR materials in cold climates.
- PDR materials showed high sensitivity to changes in water–cement ratio.
- Field surveys showed signs of degradation of PDR materials after winter.
- The mode of failure was used to indicate the effectiveness of PDR materials.
- Some PDR materials showed bond improvement after conditioning.

ARTICLE INFO

Article history:
Received 21 February 2014
Received in revised form 25 July 2014
Accepted 29 July 2014
Available online 20 August 2014

Keywords:
Pavement rehabilitation
Joint spalling
Thermal compatibility
Bond strength
Freeze–thaw durability
Wet–dry durability

ABSTRACT

This paper examines the performance of partial-depth repair materials for concrete pavements in laboratory and field conditions. A laboratory evaluation method based on evaluating the compatibility between partial-depth repair material and concrete substrate was examined. Bond between repair material and concrete substrate; wet–dry and freeze–thaw durability of bond; and thermal compatibility were used to evaluate the performance of repair materials in cold climates. Materials were ranked based on the calculation of a score which combines the proposed evaluation criteria. Condition surveys were conducted to evaluate the field performance of the repair materials from an ongoing 3-year field study. The laboratory performance of the repair materials was validated by the results of the field study.

1. Introduction

Spalling is a surface distress in Jointed Plain Concrete Pavements (JPCP) that reduces the service life of the pavement and decreases the quality of ride. Partial-depth repair (PDR) materials are used to replace the deteriorated concrete which helps to restore the structural integrity, improve the quality of ride, and reduce moisture infiltration to subsurface layers of the pavement. PDR materials, when properly installed with good quality control, can have good performance for more than 5 years of service [1,2]. However, improper selection of the repair material or construction practices can result in poor performance and premature failures.

Before approving a repair material for use, bond strength, time for strength gain, modulus of elasticity, freezing and thawing durability, scaling resistance, sulfate resistance, abrasion resistance, coefficient of thermal expansion, and shrinkage should be evaluated [3]. The Performance of a repaired slab depends on the properties of the repair material and the compatibility between the repair material and the concrete substrate. A significant difference in the coefficient of thermal expansion (CTE) between the repair material and the concrete substrate can result in high shear and normal stresses along the interface surface [4]. The difference between the CTE of the concrete substrate and the repair material may cause an existing transverse crack to open or close with changing temperatures. The opening of the crack can cause it to propagate into the repair material and through the pavement surface [4].

Pattnaik and Rangaraju [5] investigated the compatibility between cementitious repair materials and concrete using a modified ASTM C 78 test procedure [6]. Composite simple beams were prepared from the repair materials and regular concrete. Analysis

* Corresponding author. Tel.: +1 204 474 9220; fax: +1 204 474 7513.
E-mail addresses: umsolimh@cc.umanitoba.ca (H. Soliman), ahmed.shalaby@umanitoba.ca (A. Shalaby).
[1] Tel.: +1 204 474 6818; fax: +1 204 474 7513.

http://dx.doi.org/10.1016/j.conbuildmat.2014.07.114
0950-0618/

of flexural strength and load–deflection curves obtained from third point loading showed that significant differences in the strength between the repair material and concrete substrate cause incompatibility failures. High drying shrinkage of the repair materials was also found to cause incompatible failure.

Al-Ostaz et al. [7] used the slant shear test to evaluate the bond strength between repair material and concrete. The slant shear test was conducted in accordance with British Standard BS EN 12615:1999 [8]. Two types of repair materials were evaluated, cementitious and polymer materials. Slant shear tests were conducted on unconditioned specimens and specimens that were subjected to thermal cycling from +12.8 °C to +51.7 °C which simulates fluctuations of temperature in extreme hot temperatures. For unconditioned specimens, polymer-based repair materials had higher bond strength to concrete than cementitious repair materials. After being subjected to thermal cycling, polymer-based repair materials showed greater reduction of bond strength than cementitious repair materials.

2. Methodology

In cold climates, pavements may be subjected to a significant annual temperature differential of 75 °C or more [9]. The most common causes of PDR failure are poor bond between the repair material and original concrete; thermal incompatibility between the repair material and existing concrete; and unsuitability of the repair material to the climate conditions are among [1]. Field studies are conducted to evaluate the performance of partial-depth repair materials in-place, and to select the most successful material. However, field studies do not provide a timely response to dynamic market changes and the availability of new products. Currently there are no standard specifications for PDR materials. Having a performance-based specifications for PDR materials will potentially provide a cost-effective and rapid alternative to field studies.

In this paper, the laboratory performance of several cementitious PDR materials was evaluated. Bond strength, wet–dry and freeze–thaw durability of bond strength, and coefficient of thermal expansion were evaluated for a range of repair materials. A ranking method was proposed to compare the repair materials based on their laboratory performance. Laboratory evaluation results were validated by field performance of repaired slabs that incorporated the same repair materials. This work is part of a research study which aims to develop performance-based specifications for partial-depth repair materials and processes in cold climates.

3. Tested materials

A list of repair products along with their composition and physical properties is presented in Table 1 according to the datasheets received from each manufacturer. The repair products listed in Table 1 are pre-packed commercial products. Limited information was provided by the manufacturers about the materials composition. An aggregate extender was added to materials A, C, D, and F; while materials B and E had the coarse aggregate pre-mixed with the material. The aggregate extender consisted of 9.5 mm well-graded rounded pea gravel. Table 2 shows the strength properties of the repair materials according to each manufacturer's datasheets. Except material B, the repair materials show compressive strength higher than 30 MPa after one day.

4. Field study

4.1. Installation of repair materials

A field study was conducted to evaluate the field performance of six cementitious PDR materials. The repair materials were installed at the same time on side-by-side pavement sections located in a concrete urban arterial road in Winnipeg, Manitoba. The pavement in the test section consists of a 255 mm thick jointed plain concrete pavement (JPCP) with a slab width of 3.70 m on a granular base. The JPCP was first constructed in 1980s. The test sections consist of a two way divided road with 3 traffic lanes and one parking lane in each direction. The middle lane of the westbound direction was selected for installation of the repair materials. The posted speed limit is 60 km/h and the average weekday daily traffic is 34,800 vehicles over the six lanes of traffic with 9% trucks and buses. Pavement in the test location is subject to large temperature changes, where the maximum and the minimum air temperatures during the last 10 years were +36 °C and −36 °C, respectively.

Repair materials were applied to pavement deteriorations and spalls along the longitudinal and transverse joints of the test section in 2010. Fig. 1 shows examples of deteriorated joints before repair. The saw-and-patch method was used to remove the deteriorated concrete [10]. To minimize the influence of human factors, one work crew was used to prepare and install repair materials. All manufacturer's recommendations for surface preparation and installation were followed.

Table 1
Summary of the composition and physical properties of the repair materials.

Repair material	A	B	C	D	E	F
Composition (% by weight)						
Hydraulic cement	✓	✓	30–60	5–10	10–30	7–13
Alumina cement	–	–	–	10–30	–	–
Silica sand, crystalline	✓	✓	40–70	30–60	–	>60
Silicon dioxide	✓	–	–	–	–	–
Titanium dioxide	–	–	–	–	–	0.1–1
Formaldehyde	–	–	<0.1	–	–	–
Calcium sulfate	–	–	–	1–5	–	–
Tricalcium aluminate	–	–	–	0.5–1.5	–	–
Borax	–	–	–	–	–	1–5
Various oxides (Al, Ca, and/or Mg)	–	–	–	–	5–10	–
Physical and chemical properties						
pH	–	–	12	11–13	8.5	–
Specific gravity	2.7	2.6–3.2	2.7	2.0–2.3	2.63	2.75
Water content (L)	2.13–2.84	2.60–2.84	2.84	2.84	1.89	1.60–1.77
Mixing time (min)	4–5	8	4	4	7	4
Extension[a]	80%	–	100%	80%	–	50%
Recommended type of mixer	Jiffy or mortar mixer	Not specified	Jiffy or mortar mixer	Not specified	Concrete mixer	Jiffy or mortar mixer

✓ Chemical composition by weight not provided but stated.
[a] Coarse aggregate extension by weight of repair material per bag.