PERFORMANCE OF AN INNOVATIVE IN-SITU CONCRETE PAVEMENT REPAIR PATCH

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Abstract

Concrete pavement cracks and deteriorate due to severe service loading, de-icing materials, freeze-thaw cycles, and other factors. The replacement cost of existing deficient concrete pavement is expensive. Moreover, the design of maintenance materials requires the use of energy-efficient materials with a low environmental impact. Facca Incorporated, in collaboration with Dura Concrete Canada Inc., located in Ontario has been developing an innovative and proprietary cementitious composite for different construction applications. One of these applications is the use of Ultra-High-Performance Fibre Reinforced Concrete (UHPFRC) and High-Performance Fibre Reinforced Concrete (HPFRC) as a partial patch repair for concrete pavements. The mechanical and durability performance of the UHPFRC and HPFRC mixtures were investigated. In order to compare the mixture's performance in the field, a location in the City of Windsor was selected. These innovative in-situ repair materials were applied in thickness varying from 40 to 60 mm. The selected concrete pavement was closed, milled, prepared, repair materials applied and completed within 72 hours. The strength gain of both UHPFRC and HPFRC were acceptable to open the roads to traffic after 48 hours from casting. Laboratory and in-field results and observations for the road repair materials showed superior mechanical and durability characteristics and will be presented in detail.

1. Introduction

Severe physical loadings and harsh weather conditions are the main reason for concrete pavement deterioration. This deterioration has resulted in poor conditions of North American infrastructure and is a growing concern for engineers, contractors and public officials for quite some time now. It is unfortunate that patch repairs for concrete pavement is usually considered as a simple task that everyone can do it. Moreover, the mixture design and the necessary performance tests of the repair materials are overlooked. Such views resulted in an endless “repair of repairs” that is ruining the reputation of concrete repairs (Vaysburd et al. 2004). The poor condition and performance of repair materials can also be due to poor practices partly to outdated specifications which are not helpful to the selection of the material for specific job situations. For instance, cementitious materials are usually chosen based on their minimum compressive strength, rather than properties that are more relevant in specific conditions such as plastic and drying shrinkage limit.

It is well-known that there are many repair materials and techniques that are available to mitigate and stop the damage to infrastructure. However, only a few of these materials satisfy the requirements for a durable repair. Among these materials, fibre reinforced cementitious materials that have been developed rapidly in recent years. Two proprietary high-ductile and environmentally friendly materials were developed by Facca Incorporated, in collaboration with Dura Concrete Canada Inc. These materials are High-Performance Fibre Reinforced Concrete (HPFRC) and Ultra-High-Performance Concrete (UHPFRC). The work presented in this paper is to evaluate the mechanical, durability and stability characteristics of these materials for concrete pavement patch repair. The work was completed at both laboratory and in-situ conditions.

2. Repair Materials

2.1. Materials

General use cement (C) type conforming to Canadian standard, CSA A3001 was used as a binder in all mixtures. Commercially available fly ash (FA), silica fume (SF), and slag (SG) were used as supplementary cementitious materials (SCMs). The physical and chemical properties of the SCM and cement satisfied the recommendations of ASTM C1240, ASTM C618, ASTM C989, and CSA A3001 standards. Lake sand with a maximum grain size of 600 µm was used in the production of the HPFRC and UHPFRC mixtures. High range water reducing (HRWR) and workability modifying admixtures (WM) as per ASTM C494, was employed to achieve workable cementitious mixture. Polyvinyl fibres of 8 mm length and 39 µm diameter were used for HPFRC mixtures andinibars high stiffness PVA fibres of 19 mm length and 200 µm diameter were used for UHPFRC mixtures. Both PVA fibres are monofilaments and had an average tensile strength and a specific gravity of 1600 MPa and 1.3, respectively and meets the requirement of ASTM C1116.

2.2. Mixture Design and Proportioning

High-Performance Fibre Reinforced Concrete (HPFRC) and Ultra-High-Performance Concrete (UHPFRC) with a minimum 28-day strength of 60 MPa and 120 MPa, respectively, were designed and implemented as repair materials. The mixture proportions with respect to cement mass are listed in Table 1. The fibres content was 2 percent by volume in both mixtures. As per the road conditions and specific requirements, the mixtures were designed to have thixotropic consistency. Thixotropic cementitious mixtures are known to be thick and viscous in normal condition but flow when subjected to vibration or agitation.

The procedure of mixing for the fibre reinforced HPFRC and UHPFRC followed several steps. First, sand, cement, and SCM were added to high shear mixer and dry mixed for two minutes. Then, the water and the specified amount of chemical admixtures (HRWR, and WM) were mixed separately and then were slowly added to the dry mixture. After about 8-10 minutes, a consistent paste was obtained. Next, the fibres were added slowly to reduce balling and clumping and to provide a better dispersion of the fibres. This step took approximately two to four minutes. To complete the mixing procedure, two more minutes of mixing was provided.

For each mixture, prisms, and cylinders of varying dimensions were prepared and cast for different mechanical and durability tests as listed in Table 2. The mechanical performance of the mixtures was assessed by means of compressive, and flexural strength. While, the durability of the mixtures was investigated and evaluated by the means of rapid chloride penetration, freeze-thaw, and drying shrinkage.

2.3. Laboratory Test Methods

One of the well-known drawbacks of cementitious materials is its tendency to shrink, which results in cracks when the material is restrained. This problem is more evident in large concrete structures such as pavement, slabs, overlays, and walls. Plastic shrinkage is a volumetric contraction of cement-based materials (Booya et al. 2019). Hence, mixtures were tested for restrained plastic shrinkage and potential early age cracking. For this, the testing method by Booya et al. and Gorospe et al. (Booya et al. 2019, and

Gorospe et al. 2019) was followed with few modifications. Restrained plastic shrinkage was performed in an environmental chamber operating at a temperature of 40°C (± 2°C) and relative humidity of 15% (± 3%) to accelerate the development of shrinkage cracks. A heater fan connected to a temperature and humidity controller was used to produce uniform airflow over the test specimens and to maintain the set environmental conditions. Furthermore, a plexiglass cover was also used to sustain the heat and uniform airflow, and to allow for observation of cracks during testing. The operating conditions resulted in an evaporation rate of 0.75 kg/m2/h.

As shown in Figure 1, two concrete elements of 40 x 350 x 550 mm in dimension, with hemispherical protrusions were used to provide internal restraint to 30 mm of patch repair materials. The concrete elements were put adjacent to each other with a 5 mm gap to simulate a crack. Moreover, the two components were surrounded by a wooden form, with 25 mm gap concrete elements and the form sides. The designed material was poured over the concrete elements and was surfaced with a trowel. Forms were carefully removed after two hours in the environmental chamber to increase exposure to airflow. Testing resumed for a total test period of 24 hours.

2.4. In-situ Repair Methodology

After consulting with officials at the City of Windsor, three concrete road pavement slabs were chosen for patch repair. The cracked pavement slabs are located on Walker Rd in Windsor, Ontario as shown in Figure 2. This road is known for its high traffic volume with an estimated Average Daily Traffic (ADT) count of 40,000 vehicles per day (10,000 vehicles/lane/day). Figure 3 shows the original condition of these concrete pavement slabs with their crack widths.

The repair operations started by traffic control and lane closure activities on a weekday morning (In November 2019). After, the surface was milled and grinded using a concrete milling machine as can be seen in Figure 4. Each repaired slab had a different milling dimension and shape than the other. However, the milling was positioned over the cracks with an average width of 600 mm and a depth of 45 mm (Figure 4). The length for each slab was between 3 and 4 meters. After milling, the saw cut was used to square the milled concrete edges.

ACI RAP Bulletin 7 recommendations were followed for surface preparations. High-pressure air was used to blow the dust and debris from the surfaces. These surfaces were then soaked with water for about an hour and excess water removed as can be seen in Figure 4.

A mobile pan mixer unit with skilled crew individuals from Dura Concrete Canada Inc. (Figure 5) started producing the two proprietary repair materials on-site (HPFRC and UHPFRC). The produced materials were sequenced in multiple batches of 130 litres each.

The produced materials were poured directly on to the concrete surface that was in a saturated surface dry (SSD) condition (Figure 5). Afterward, the material was levelled and surfaced with a trowel and a spiked roller. Testing cylinders were sampled from both materials to verify the compressive strength of the designed materials. Few cylinders were put beside the repaired patches and few others were sent to the laboratory for testing at a moist curing condition.

Winter curing protection was followed by the pouring and placement activities as can be seen in Figure 6. Hence, the surfaced materials were covered with wet burlaps and thick heat insulating tarps. Due to the sudden decrease in temperature after about 12 hours from the placement, it was recommended that radiant heating pipes be used. This ensured that the repair materials are exposed to an average temperature of 22°C± 3°C. After verifying the compressive strength of the field cured specimens, the lane was reopened to traffic (after about 48 hours from materials placement). The field cured cylinder specimens had a strength comparable to the ones tested at the laboratory.

3. Results Discussion and Conclusions

3.1. Laboratory Testing Results

Experimental laboratory testing results are listed in Table 3. As can be seen from the table, the designed materials have excellent mechanical and durability performance.

The restrained plastic shrinkage testing showed no visible cracks on the surface after 24 hours of exposure to blowing hot air. This suggests that both used materials (HPFRC and UHPFRC) have excellent volume stability and resistance to cracking despite the high amount of supplementary cementitious materials content. This favourable performance is believed to be due to the frictional force induced in the fibre-cement interface, which restrains the movement of the cementitious matrix (Manget and Azari).

3.2. Assessment and Observations

The visual observations and inspections after more than five months revealed that there were no signs or indications of deterioration to the repaired patches (Figure 7). The repaired patches were subjected to heavy traffic volume at about 48 hours after placement and exhibited several freeze-thaw cycles and dry-wet cycles. Figure 8 shows the minimum and maximum temperature profiles in Windsor, Ontario for the months of

November 2019 through April 2020. From this figure, the maximum temperature recorded was 21.1 °C, while the lowest recorded temperature was -14.8 °C. This concludes that these patches can sustain heavy traffic loading and extreme weathering exposure despite the age of the patch repair (maturity of hydration process). It is also worth noting that these patches were subjected to snow removal activities which include salting and/or plowing.

On the other hand, the in-situ casting method and the surfacing procedure (trowelling) were reported as beneficial by the contractor. It allowed the materials to fill the cracks in the deteriorated concrete easily and be placed quickly.

The experimental and in-field observations of this work indicate the usefulness of using innovative high-performance fibre reinforced cementitious composites as repair materials. Hence, this work confirms that the mixture design of the two patch materials are durable and have superior mechanical and durability, and volume stability characteristics.

4. Acknowledgement

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5. References

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6. Tables

Table 1 – Mixture design and proportioning with respect to cement mass

Material ID	Cement	SCM	Sand	Water	HRWR	WM
HPFRC	1	1.1	0.87	0.55	0.013	0.006
DURA® UHPC	1	0.23	0.67	0.23	0.04	0.007

Table 2 – Summary of the laboratory testing methods

Test Name	Standard	Specimen Dimensions	Testing age/Duration
Compressive Strength	ASTM C39	Ø75×150 mm	1,2, 7, and 28 days
Flexural Strength	ASTM C1202	75 mm X75 mm X355 mm prisms	1, and 28 days
Rapid Chloride Penetration	ASTM C1609	Ø100×50 mm disc specimen	28 days
Freeze and Thaw	ASTM C666	75 mm x 75 mm x 280 mm prisms	Up to 300 cycles
Linear Shrinkage	ASTM C596	25 mm x 25 mm x 285 mm specimens	Up to 56 days

Table 3 – Laboratory results

Mixture ID	Compressive Strength (MPa)				Flexural Strength (MPa)		RCPT (coulombs)	Linear Shrinkage (Strain)	Freeze /Thaw (DF %)
	1 day	2 day	7 day	28 day	1 day	28 day	28 day	56 day	After 300 cycles
HPFRC	30.7	35.6	52.1	76.8	5.1	>7.5	<1000	2000x10^{-6}	-
DURA® UHPC	56.4	62.6	85.9	122	-	>15	<200	8000x10^{-6}	98.3

7. Figures

Figure 1 – Restrained plastic shrinkage

Figure 2 - Location of the repaired concrete pavement (Circled)

Figure 3 – Original condition of the concrete pavement

Figure 4 – Concrete pavement condition after milling and surface preparations

Figure 5 – Production and pouring of the patching repair materials

Figure 6 – Curing and protection procedure

Figure 7 – Heavy traffic load and volume on the repaired concrete pavement

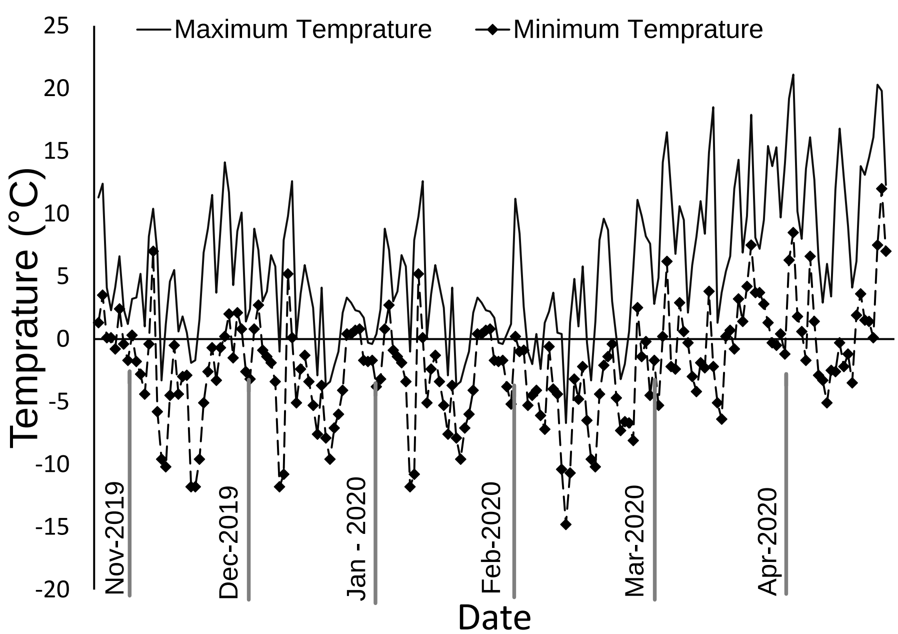

Figure 8– Temperature profile