Characterizing Field and Laboratory Performance of Cementitious Partial Depth Repair Materials

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Abstract

Partial depth repair (PDR) is an essential preventative maintenance treatment for concrete pavements. PDR process typically replaces spalled or deteriorated concrete when the damage does not extend beyond the top one-third of the slab and has not affected load transfer between slabs. PDR is a cost-effective preventative maintenance treatment when compared to traditional full depth repair but must be carried out during the proper time window. The repair material typically is a rapid setting cementitious concrete, polymer-based concrete or bituminous material. The repair material must be suitable for environmental and load conditions, provide adequate bond to existing concrete and if required, allow faster opening to traffic. PDR operations are generally labour and time intensive, thus high costs are associated with the procedure. This paper reports on a project to compare laboratory and field performance of several rapid setting cementitious concrete PDR materials and to establish selection criteria for materials and processes. A test section was selected on a major arterial in the City of Winnipeg in Manitoba to compare six candidate materials under the same environmental conditions and similar traffic loading. The field repairs were completed during the summer in 2010. Pre- and post installation condition surveys were conducted at the repair sites and the field evaluation will continue for the next two years. Laboratory tests were conducted at the University of Manitoba and include evaluation of thermal compatibility and the impact of freeze-thaw and wet-dry cycling on bond strength between repair materials and regular concrete. Results of laboratory and field evaluation will be used to develop performance-based selection criteria for PDR materials. The selection criteria will provide a cost-effective accelerated alternative to full-scale field studies, and provide a timely response to progressive market changes and the availability of new products.

Introduction

Spalling is a surface distress in Portland Cement Concrete (PCC) pavements that reduces the service life of the pavement and decreases the quality of ride. Incompressible debris lodged in unsealed joints, or cracks, prevent the pavement from expanding during warm weather and produces high compressive stresses along the joint or crack faces. These high compressive stresses cause spalling of PCC pavement slabs. Partial depth repair is a rehabilitation method for PCC pavements which is commonly used to repair spalls and shallow deteriorations of pavement slabs. Partial depth repair consists of removing the deteriorated and unsound concrete and replacing it with new repair material.

Partial depth repairs are mainly located along the joints of the slab, but can be placed anywhere in the slab to replace deteriorated concrete. Replacing the deteriorated concrete with new and durable material helps to restore the structure integrity, improve the quality of ride, and reduce moisture infiltration to subsurface layers of the pavement. PDR when properly installed with good quality control can have good performance for more than 5 years of service [1]. However, improper construction practices and improper design of PDR can result in poor performance and failures. The most common causes of PDR failure are due to the improper selection of the repair material and the incompatibility between the repair material and original concrete [4].

There are limitations to using PDR when trying to ensure good performance and cost effectiveness of repairs. The adequacy of using PDR is governed by the cause and depth of the spall. Full-depth repairs should be used instead of PDR when spalling is deeper than the top third of the slab thickness. It is also not recommended to use PDR for spalls caused by misaligned dowels or D-cracking due to high shear stresses [1]. PDR should not be used if a pavement has large amounts of fatigue cracking or deterioration which are signs that the pavement has little service life left.

The behaviour of PDR depends on the properties of the repair material and the compatibility between the repair material and substrate concrete [5]. A significant difference in the coefficient of thermal expansion (CTE) between the repair material and the original concrete will result in high shear and tensile stresses along the interface. The bond strength should be considered based on the CTE of the repair material and its ability to resist the propagation of cracks. The difference between the CTE of the concrete and the repair material may cause an existing transverse crack to open or close with changing temperature conditions [2].

There are five different repair procedures used for preparation of repair area: saw and patch, chip and patch, mill and patch, waterblast and patch, and clean and patch. The saw and patch is the most commonly used procedure. The difference between these five procedures is in the method used for removal of the deteriorated concrete. The spall repair study conducted under the Strategic Highway Research Program (SHRP) concluded that there is no significant difference in the performance of repair areas prepared with the saw and patch, chip and patch, mill and patch, and waterblast and patch methods [1].

Several factors must be considered when selecting a repair material for a particular project. These factors are the time available until opening to traffic, temperature during construction, cost of materials and labour, service life, and volume of the patches. Before approving the repair material, the bond strength, time for strength gain, modulus of elasticity, freezing and thawing durability, scaling resistance, sulphate resistance, abrasion resistance, CTE, and shrinkage should be evaluated and taken into account [3]. There are three main types of repair materials: cementitious, polymer, and bituminous repair materials. The agency responsible for choosing the repair material should select the one that fits the necessary performance criteria.

This paper studies the performance of six repair materials in the field and conducting laboratory testing in order to establish selection criteria for partial depth repair materials. Only cementitious based repair materials were considered for the field and laboratory components of the project. Once testing is completed, the overall effectiveness of each of the repair materials will be evaluated for their compatibility with the environmental conditions, the construction practices, and the construction materials used in Manitoba.

Field Evaluation of Repair Materials

Field evaluation of 6 PDR materials was carried out along two sections of Portage Avenue in Winnipeg, Manitoba. The first test section was situated along westbound Portage Ave. between Garry St. and Smith St. while the second was along westbound Portage Ave. between Donald St. and Hargrave St. as seen in Figure 1. Both test sections consisted of a two way divided road with 3 traffic lanes and one parking lane in each direction. The middle lane of the 3 traffic lanes was selected for both test sections. All of the PDR areas situated within each test section were 6 m away from the adjacent intersection in order to eliminate vehicles from performing turning maneuvers on the repair areas.

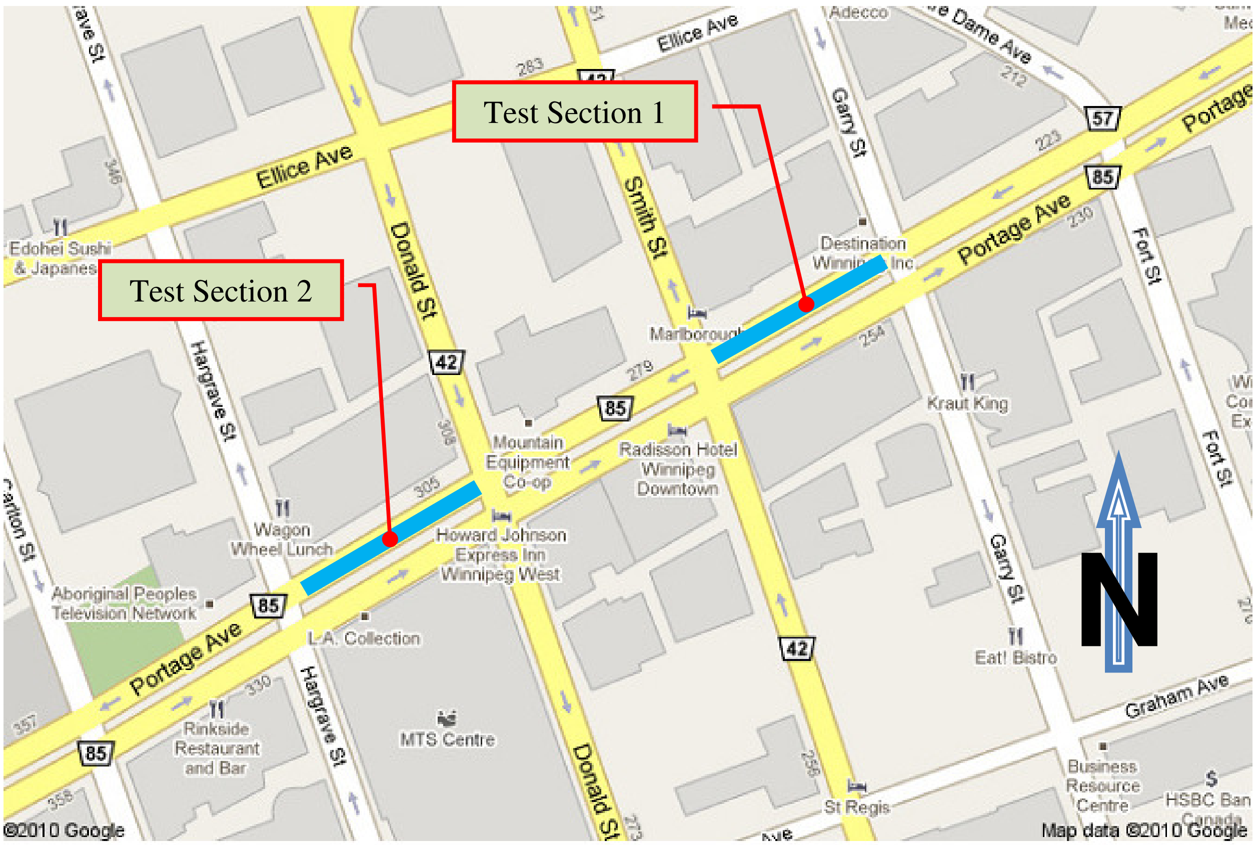


Figure 1: Location of Test Sections

The posted speed limit along the test sections is 60 km/h and the average weekday daily traffic is 34,800 vehicles over the six lanes of traffic. The type of traffic observed along both test sections during installation of the repairs was predominantly passenger cars (91% of observed vehicles). The existing pavement consisted of a Jointed Plain Concrete Pavement with a width of 3.70 m, a thickness of 255 mm, and an apparent maximum aggregate size of 25 mm. The pavement was placed on a limestone base. A total of 18 and 21 transverse joints along test section 1 and 2, respectively, were selected for PDR.

All repairs along both test sections were located along the longitudinal or transverse joints. Before commencing concrete removal of deteriorated concrete the soundness of the spalls was evaluated within and along the repair boundary. The severity level of the spalls was more significant along transverse joints than longitudinal joints, as seen in Table 1, with a number of 'moderate' transverse joints. The severity level of the spalls along longitudinal joints was predominantly low for both test sections. On the other hand, the majority of transverse joints along test section 1 had low severity while test section 2 had predominantly moderate severity.

Table 1: Number of Spalls Grouped According to Severity Level

Test Section	Joint Type	Number of Spalls		
		Low[1]	Moderate[2]	High[3]
1	Transverse	27	12	1
	Longitudinal	26	1	-
2	Transverse	4	18	-
	Longitudinal	25	1	-

[1]Low: Spalls less than 75 mm wide, measured to the center of the joint, with loss of material, or spalls with no loss of material and no patching.
[2]Moderate: Spalls 75 mm to 150 mm wide, measured to the center of the joint, with loss of material.
[3]High: Spall greater than 150 mm wide, measured to the center of the joint, with loss of material.

Along both test sections the transverse and longitudinal joints had an average depth of 34 mm and 26 mm, respectively. The length of spalls along transverse and longitudinal joints varied between test sections according to Table 2. For test section 1, the length of spalls along transverse and longitudinal joints was predominantly less than 750 mm. For test section 2, the length of spalls along transverse joints was predominantly between 1600 mm and 3700 mm, while the length of spalls along longitudinal joints was predominantly between 1600 and 3700mm and less than 750mm in length.

Table 2: Number of Spalls Grouped According to Their Length

Test Section	Joint Type	Number of Spalls		
		$L < 750$ [mm]	$750 < L < 1600$ [mm]	$1600 < L < 3700$ [mm]
1	Transverse	23	12	5
	Longitudinal	20	3	4
2	Transverse	2	2	18
	Longitudinal	12	6	8

The deteriorated concrete marked within the repair area was removed by the saw and patch method. This method consisted of saw cutting the marked edges of the repair to a depth of 40 mm from the pavement surface using a concrete cut-off saw mounted on a cutting cart. Once the repair boundaries were cut, the concrete was removed by a 11.3 kg jackhammer. The concrete was removed by first jackhammering near the center of the repair area and working outwards to the saw-cut. Then the repair surface along the bottom edge of the saw-cut was jackhammered in order to fully expose the vertical surface of the cut. The concrete within the repair area was removed to the bottom of the saw cut or 10 mm below visually sound and clean concrete [3,4]. Once finished, the repair surface was at a typical 10 to 45 degrees angle from the horizontal as shown in Figure 2.

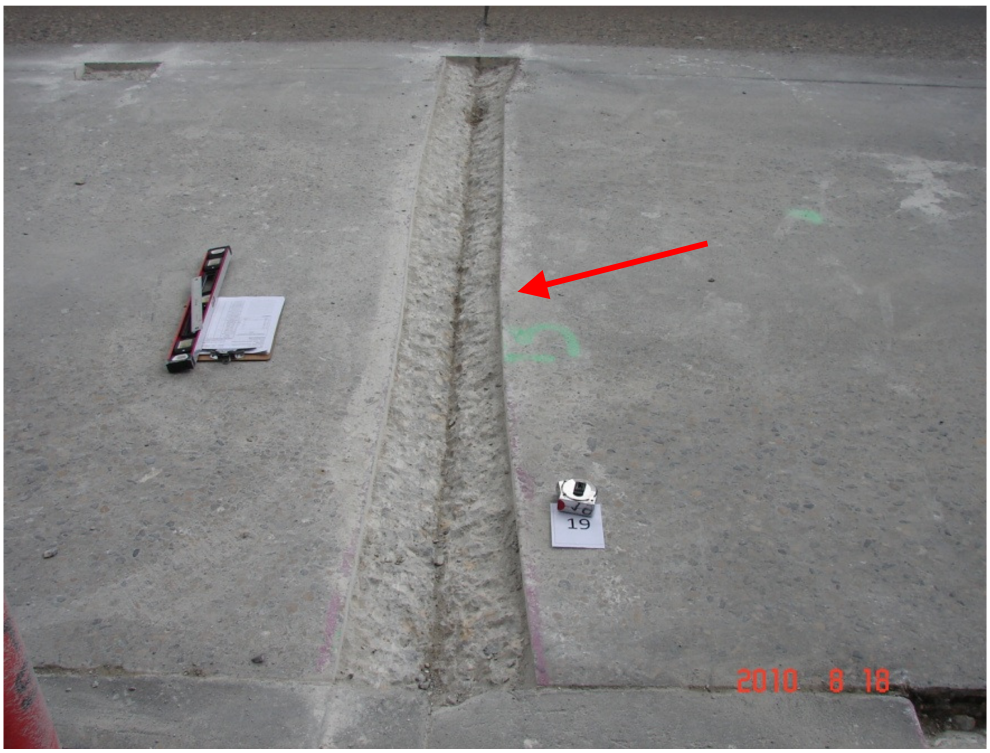


Figure 1: Typical Finalized Repair Surface

Six cementitious repair materials were used in this field evaluation. Three repair materials were placed along test section 1 and the other three materials were placed along test section 2. Table 3 shows the technical data of the six repair materials. Out of the six repair materials, aggregate extender was added to 4 repair materials as shown in Table 3. The aggregate extender consisted of well graded rounded gravel with low angularity as shown in Figure 3. Repair materials were mixed according to the manufacture's specifications and recommendations. Repair materials were poured into the repair area, made flush with the existing concrete surface with a shovel or trowel and then internally vibrated using a 25 mm head vibrator. The repair patch was finished using a trowel and a curing compound was applied.

Table 3: Summary of Technical Data of the Repair Material

Repair Product	Yield per Bag [m^3]	Water Content [L]	Mixing Time [min]	Recommended Mixing Technique		Extension*
				Small Quantities	Large Quantities	
A	0.0113 [22.7kg bag]	2.13 – 2.84	4 - 5	Jiffy or mortar mixer	Jiffy or mortar mixer	80%
B	0.017 [36.3kg bag]	2.60 – 2.84	8	Not specified	Not specified	–
C	0.0119 [22.7kg bag]	2.84	4	Jiffy mixer	Mortar mixer	100%
D	0.0116 [22.7kg bag]	2.84	4	Not specified	Not specified	80%
E	0.0113 [24.3kg bag]	1.89	7	Concrete mixer	Concrete mixer	–
F	0.0105 [22.7kg bag]	1.60 – 1.77	4	Jiffy mixer	Mortar mixer	50%

* Coarse aggregate extension by weight of repair material per bag

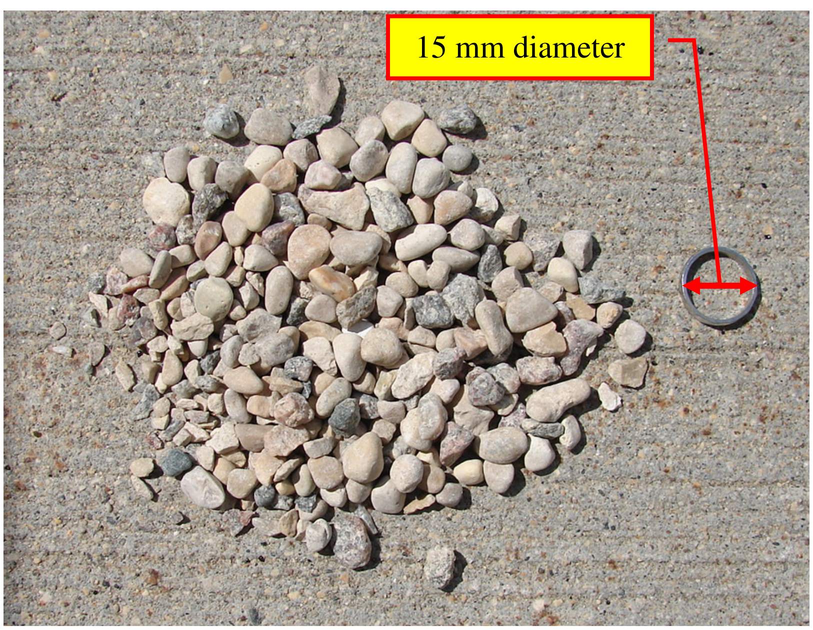


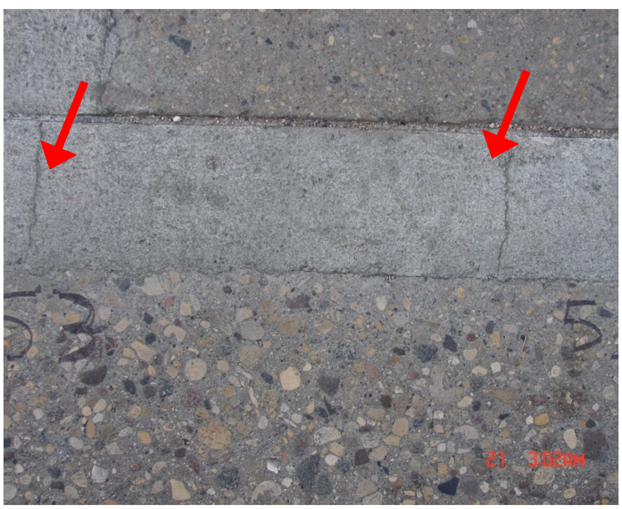
Figure 3: Sample of Aggregate Extender

Field Performance of Repair Materials

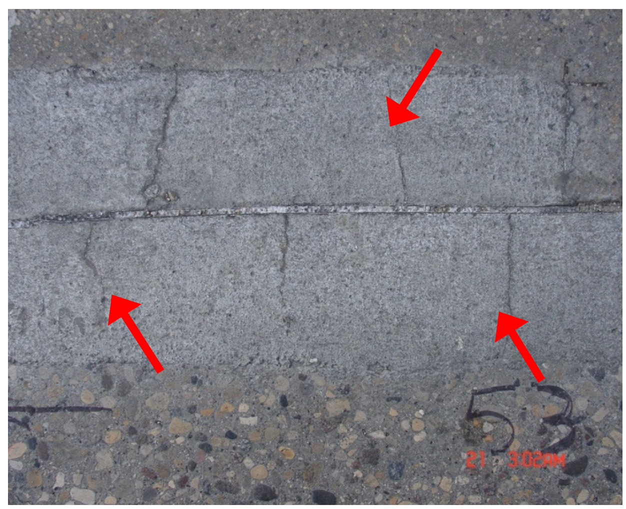
The performance of the repair materials were evaluated one month after installation. Four criteria were used to evaluate the repair areas:

- Transverse (shrinkage) cracking
- Longitudinal cracking
- Cracking at the saw-cut surface
- Surface finish

Transverse cracking, shown in Figure 4, represents the cracks in the transverse direction of the repair area. The severity of transverse cracking was categorized as low, medium, or high according to the spacing between cracks along the repair area. Longitudinal cracking, as shown in Figure 5, represents the cracks in the longitudinal direction of the repair area. Cracking at the saw-cut surface, as shown in Figure 6, represents the initiation of separation between the repair material and the original concrete. Surface finish, as shown in Figure 7, represents the regularity of the repair surface after installation of the repair material.



a) Low severity cracking



b) High severity cracking

Figure 4: Transverse Cracking in the Repair Area

The frequency of the distresses for each repair material one month after installation is shown in Table 4. Areas repaired with materials E and F had lower percentage of transverse cracking than the remaining materials. Repair materials that had high water content during mixing experienced higher percentage of transverse cracking. All of the repair material had no or very small percentage of longitudinal cracking except for repair material B. The longitudinal cracking near the wheel path can be attributed to the structural instability of the patched area and are not related to the type of repair material. For cracking at a saw-cut surface, materials D and F had the lowest percentage of cracking, while material B the highest percentage of cracking. All the repair materials had good surface finish except material A, where 32% of these patches had a poor surface finish.

Figure 5: Longitudinal Cracking in the Repair Area

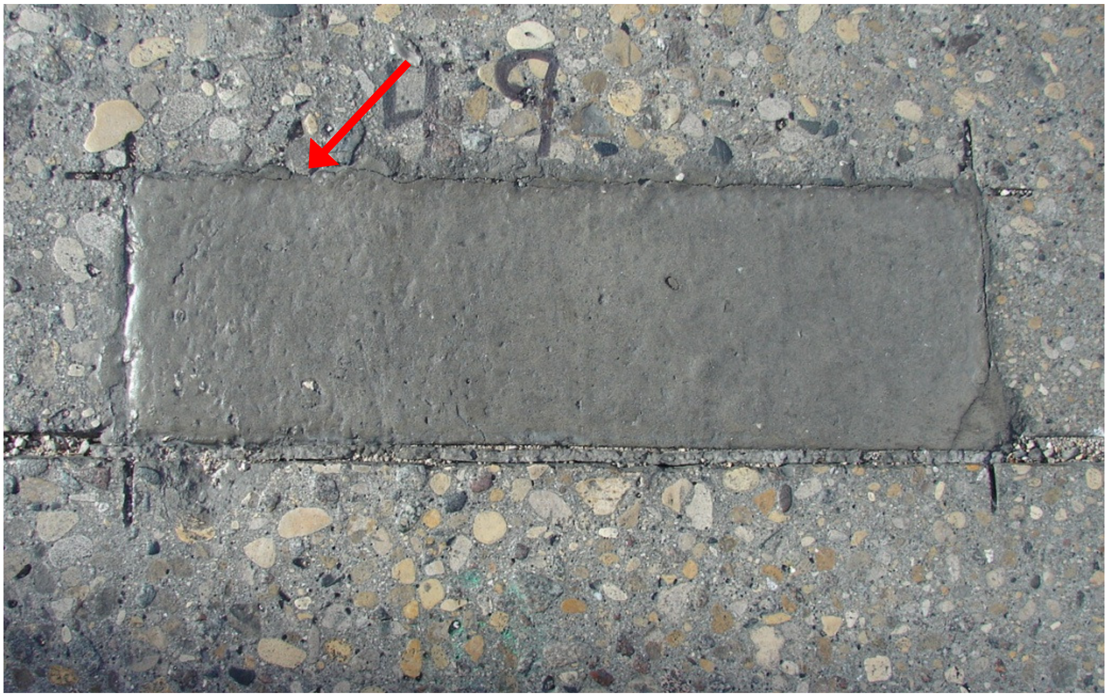


Figure 6: Cracking at the Saw-Cut Surface in the Repair Area

Figure 7: Repair Areas with Poor Surface Finish

Table 4: Frequency of Distresses One Month after Installation of the Repair Materials (%)

Material	Transverse (Shrinkage) Cracking*				Longitudinal Cracking		Cracking at Saw-Cut Surface		Surface Finish		No. of Patches
	No cracking	Low	Medium	High	No	Yes	No	Yes	Good	Poor	
A	5	32	63	0	100	0	74	26	68	32	19
B	25	50	17	8	75	25	4	96	100	0	24
C	23	43	28	6	97	3	46	54	91	9	35
D	17	17	66	0	100	0	100	0	100	0	12
E	69	31	0	0	100	0	62	38	100	0	13
F	59	23	16	2	98	2	88	12	94	6	69

*Low: Spacing > 400 mm; Medium: Spacing 200 – 400 mm; High: Spacing < 200 mm`

Laboratory Evaluation of Repair Materials

The purpose of the laboratory testing is to develop a performance based selection criteria for PDR materials. The selection criteria are based on the compatibility between the repair material and the concrete substrate along with the resistance of the repair material to environmental conditioning. The laboratory evaluation includes the six repair materials installed in the field. The laboratory evaluation of repair materials includes evaluation of:

- Compressive strength
- Freeze-thaw durability of bond strength
- Wet-dry durability of bond strength
- Coefficient of thermal expansion

The compressive strength of each repair material was tested under compression failure adapted from *ASTM C 873: Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds* [6]. This test is carried out on field and laboratory specimens of the repair material in order to determine if the used mixing method produces a mixture that has similar compressive strengths as reported by the manufacture. In other words, this test is used as a quality control indicator of the repair material produced. Three 3×6 inches cylindrical samples of each repair material were cast and tested until failure. Table 5 shows the compressive strength of the six repair materials obtained from specimens prepared during field installation of the materials.

Table 5: Compressive Strength of Repair Materials Obtained from Field Specimens

Repair Product	Compressive Strength [MPa]				Standard Deviation [MPa]
	Sample 1	Sample 2	Sample 3	Average	
A	71.1	83.7	84.1	79.6	±0.3
B	43.2	52.4	48.3	48.0	±4.6
C	51.8	47.0	39.4	46.1	±6.3
D	58.8	56.1	54.1	56.3	±2.4
E	43.2	52.4	48.3	50.4	±4.6
F	80.4	84.8	46.7*	82.6	±3.1

* Compressive strength value was arbitrarily not included in average and standard deviation calculation

The bond strength between repair material and concrete is tested under compression failure adapted from *ASTM C 882: Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear* [6]. Bond strength tests are conducted on composite samples. A composite sample consist of repair material and concrete which are cast in a 3×6 inches cylinder with a joint region situated along a cylindrical section set at a slant of 30 degrees, as shown in Figure 8.

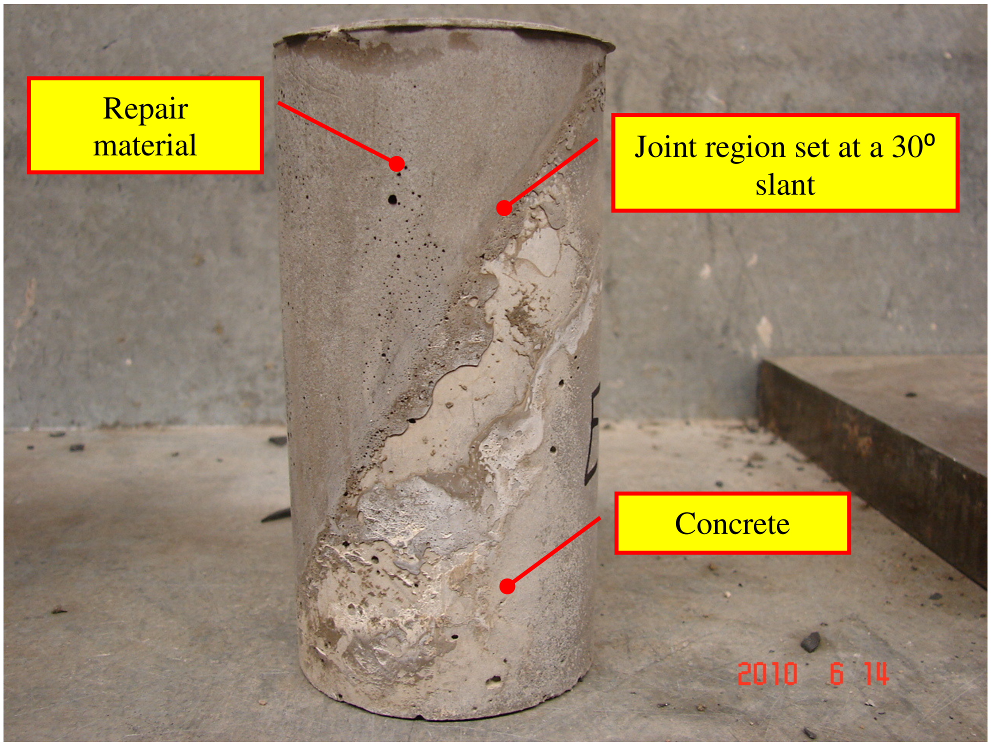


Figure 8: 3×6 Inches Composite Cylinder for Bond Strength Test

The bond strength of each repair material is evaluated on unconditioned and conditioned samples subjected to freeze-thaw and wet-drying cycling. For freeze-thaw durability, bond strength is tested after 10, 30, 60, and 90 cycles of freeze-thaw conditioning with each cycle 36 hours to complete. An environmental chamber was used to subject the samples to freeze-thaw cycling. For wet-dry durability, bond strength is tested after 4 and 8 cycles of wet-dry conditioning with each cycle 48 hours to complete.

The coefficient of thermal expansion of each repair material is conducted on 3×6 inches cylinders of each repair material. The test method is adapted from *ASTM E 831: Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis* [6]. This test is performed in order to establish the thermal compatibility between the repair material and concrete substrate. The thermal properties of the two materials must complement each other in order to prevent large differences in volumetric changes that can induce unwanted stresses along the bond surface due to thermal expansion or contraction.

Summary and Conclusions

PDR is a rehabilitation practice for PCC pavements which is commonly used to repair spalls and shallow deteriorations of pavement slabs. The selected repair material must be suitable for environmental and load conditions, provide adequate bond to existing concrete and if required, allow faster opening to traffic. Replacing the deteriorated concrete with new and durable material helps to restore the structure integrity, improve the quality of ride, and reduce moisture infiltration to subsurface layers of the pavement.

The objective of this research is to investigate the field and laboratory performance of six cementitious repair materials. A test section was selected on a major arterial in the City of Winnipeg in Manitoba to compare the six candidate materials under the same environmental conditions and similar traffic loading. The field repairs were completed during the summer in 2010. The performance of the repair materials were evaluated one month after installation. Four criteria were used to evaluate the repair areas: transverse (shrinkage) cracking, longitudinal cracking, cracking at the saw-cut surface, and surface finish.

Areas repaired with materials E and F had lower percentage of transverse cracking than the remaining materials. Repair materials that had high water content during mixing experienced higher percentage of transverse cracking. All of the repair material had no or very small percentage of longitudinal cracking except for repair material B. Longitudinal cracking near the wheel path can be attributed to the structural instability of the patched area and are not related to the type of repair material. For cracking at a saw-cut surface, materials D and F had the lowest percentage of cracking, while material B the highest percentage of cracking. All the repair materials had good surface finish except material A, where 32% of these patches had a poor surface finish.

The laboratory evaluation includes the six repair materials installed in the field. Compressive stress is measured for field and laboratory specimens of the repair material as a quality control indicator of the produced repair material. Freeze-thaw and wet-dry durability tests are conducted on 3×6 inches composite cylinders to evaluated durability of the bond strength between repair material and concrete. The coefficient of thermal expansion test is performed in order to establish the thermal compatibility between the repair material and concrete substrate. The thermal properties of the two materials must complement each other in order to prevent large differences in volumetric changes that can induce unwanted stresses along the bond surface due to thermal expansion or contraction. The laboratory testing and conditioning of specimens are still in progress.

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