Fire-Spalling Resistant Dry-Mix Shotcrete

FOR THE REHABILITATION OF THE LOUIS-HIPPOLYTE-LA FONTAINE TUNNEL

By Christine Poulin and Cody Fournier

INTRODUCTION

Since 1967, the bridge-tunnel Louis-Hippolyte-La Fontaine has been one of the most critical transportation arteries for one of Canada's busiest cities. Located in Montreal, Quebec, this unique structure combines a 1500 ft (460 m) bridge and an immersed tunnel almost a mile long (1.5 km), passing over Charron Island and then under the St. Lawrence River (Fig. 1) (La Presse Canadienne, 2017). This crucial artery has played a central role in supporting daily mobility, economic activity, and regional connectivity with up to 120,000 daily commuters (La Presse Canadienne, 2022).

Fig. 1 (ABOVE and BELOW): Drone captures of the bridge-tunnel Louis-Hippolyte-La Fontaine. Photo credit: OIQ (n.d.).

With over 50 years in service, the *Ministère des Transports et de la Mobilité Durable* of Quebec (MTMD) has initiated a major rehabilitation program to extend the Louis-Hippolyte-La Fontaine tunnel's service life by approximately 40 years. The Renouveau La Fontaine consortium, formed by Pomerleau and Vinci Construction (Dodin QC and Eurovia QC), was awarded the contract. Construction began in 2021 and is scheduled for completion in 2027 (Gouvernement du Québec, 2026).

The rehabilitation includes full structural restoration of the tunnel and upgrades to meet current fire protection standards. To satisfy performance requirements for road tunnel fire resistance, the MTMD and Renouveau La Fontaine selected fire and spalling resistant concrete as the primary protective solution.

Sika Canada played a significant role in meeting these specifications, particularly in the refurbishment work inside the tunnel's two ventilation towers, each consisting of two reinforced concrete shafts (Fig. 2). Dry-mix shotcrete placement with fire induced spalling resistance was selected as the optimal solution due to the towers' complex geometry, their constrained location within the tunnel, and the required sequencing of repair operations.

Thanks to the collaboration of the various project stakeholders, including the specialized shotcrete contractor Groupe LB (formerly known as FDDF), Sika Canada succeeded in developing the only fire resistant dry-mix

Fig. 2: Ventilation towers of the Louis-Hippolyte-La Fontaine tunnel. Photo credit: La Presse (2024).

shotcrete capable of meeting the project's stringent fire protection requirements. This article examines in detail the project's specific challenges, the technical requirements, the materials and technologies deployed, and the results achieved to satisfy the owner's criteria.

PLACEMENT METHOD SELECTION

The ventilation towers of the Louis-Hippolyte-La Fontaine tunnel were among the most challenging components to rehabilitate within the project. Their curved geometry, dense reinforcement, and the limited clearance inside the shafts significantly increased the complexity of the repairs (Fig. 3).

One of the initial repair approaches involved the use of a conventional form-and-pour approach together with the addition of a passive protection panel to ensure fire-spalling resistance of the structure. However, due to the irregular shapes of the structures, the very limited working space on the scaffolding, and the tight schedule for completing the rehabilitation, this approach was deemed impossible. Shotcrete placement was the only viable solution for carrying out the work successfully.

The wet-mix process was first considered by Renouveau La Fontaine. However, the low volumes per sequence, the heavy equipment required, and the restricted access

Fig. 3 (ABOVE and BELOW): Views of one of the severely damaged shafts undergoing repair inside the tunnel. Photo credits: La Presse (2024) and Sika Canada (2024).

Fig. 4 (ABOVE and BELOW): Preconstruction mock-ups with dry-mix shotcrete for the encapsulation of reinforcement and Sika® Galvashield® galvanic anodes. Photo credit: Sika Canada (2023).

within the tunnel significantly constrained work inside the shafts and limited the use of ready-mix concrete. A small on-site batching plant with smaller pumping equipment and pre-packaged wet-mix shotcrete could have been an alternative. However, the wet-mix process using a rapid-set accelerator for overhead applications, including those at the base of the shafts on this project, was not permitted by MTMD due to concerns related to durability and placement quality. Given these constraints, dry-mix shotcrete was the only placement method capable of meeting the project's requirements.

Upon selecting this placement method, several preconstruction mock-ups were requested during the preliminary phase of the project by the MTMD and Renouveau La Fontaine to demonstrate the effectiveness of shotcrete placement in encapsulating the heavy reinforcement and the cathodic protection system integrated into the rehabilitation design (Fig. 4).

These successful tests demonstrated the ability of high velocity shotcrete placement to thoroughly encapsulate complex reinforcement configurations and the embedded galvanic anodes. The mock-ups clearly highlighted how the energy of the shotcrete impact produced full consolidation

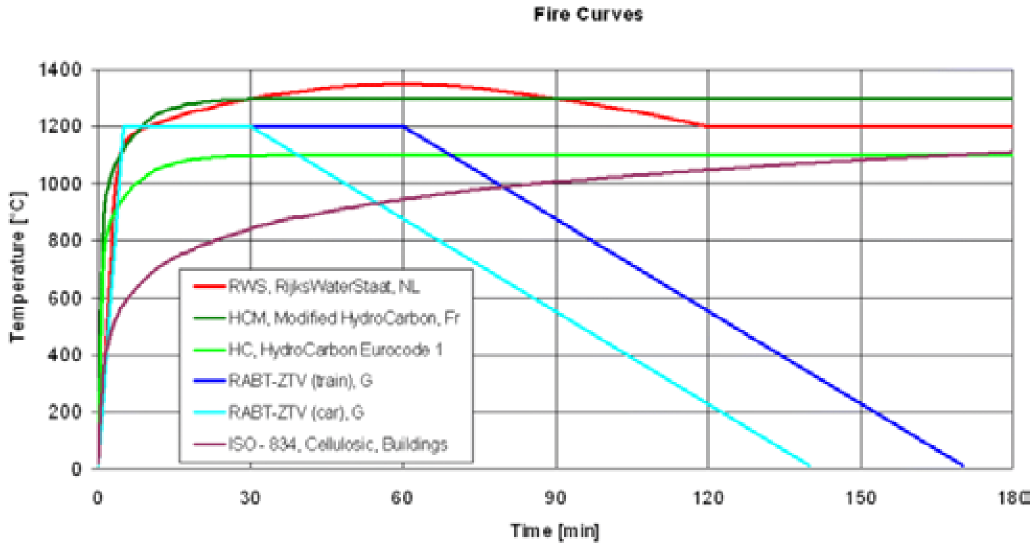

Fig. 5: Depiction of the various industry-recognized fire curves as a function of exposure time and test temperature. Figure credit: Promat (2020).

around both the reinforcing steel and the cathodic protection components, ensuring durable, continuous contact within the in place concrete.

PROJECT REQUIREMENTS

According to the design criteria established in the MTMD's material standard 3101 (2021), several key performance characteristics of the shotcrete material had to be validated to obtain approval from the MTMD, such as:

- Compressive strength of 5176 psi (35 MPa) at 28 days
- Air content between 3.5% and 7.0%
- Maximum air void spacing factor of 0.012 in. (300 µm)
- Chloride ion penetration below 1500 coulombs

In addition, to comply with fire-resistance requirements, the material also had to meet the Modified Hydrocarbon (HCM) fire curve performance criteria specified in the CETU Technical Guide (2017) and in accordance with standard NF EN 13381-3 (AFNOR, 2015). Mainly recognized and used in France for road tunnels, the HCM fire curve represents the evolution of temperature over a period of 120 minutes on elements that may be exposed to a fire reaching a maximum temperature of 2400°F (1300°C) due to the burning of petrochemical fuels (petrol, oil, chemical tankers, etc.). For this project, the exposure duration was increased to 180 minutes.

Several other fire scenario curves exist across various international standards and guidelines. The HCM curve is among the most stringent for fire protection requirements. Fig. 5 presents a comparison of several recognized fire curves as a function of time and temperature, including the HCM curve specified for this project.

As part of the rehabilitation project for the Louis-Hippolyte-La Fontaine tunnel, the laboratory appointed to perform the HCM fire curve tests was the *Centre d'Études et de Recherches de l'Industrie du Béton* (CERIB) established in France, in accordance with the recommendations of the CETU Technical Guide. CERIB operates as an industrial technical center specializing in research, innovation, and material qualification for infrastructure works (CERIB, 2026).

SHOTCRETE MATERIAL AND SAMPLING

The specific requirements of the project leveraged Sika Canada's expertise in developing a dry-mix shotcrete material optimized for fire performance and, more specifically, for mitigating explosive spalling. A dedicated mix was formulated to withstand the severe fire conditions anticipated in the Louis-Hippolyte-La Fontaine tunnel.

The dry-mix shotcrete mixture design included GU cement, silica fume, air entrainment, a maximum aggregate size of 0.375 in. (10 mm), conforming to ACI PRC-506 (2022) Grade 2, nonreactive aggregates, and microfiber designed to reduce fire-spalling, dosed at 5.77 lb/yd^3 (2 kg/m^3) (Fig. 6).

These specially designed fibers play a critical role in reducing fire induced spalling. When exposed to elevated temperatures (approximately 328°F [165 °C]), the fibers melt and expand within the concrete. This process generates a network of microcracks that facilitates vapor movement and relieves internal moisture pressure. In addition, the melting of the fibers significantly increases the pore connectivity, allowing internal water vapor to dissipate more effectively through the cementitious matrix. As a result, the buildup of

Fig. 6: Close-up views of the fibers in Sika® Fibermesh® 150F, a fiber designed to prevent explosive fire spalling in concrete. Photo credit: Sika Canada (2023).

moisture pressure inside the concrete is mitigated, thereby enhancing the concrete's stability and integrity under extreme thermal loading (Smith & Atkinson, 2009).

The project specified tests were used to validate the performance of the shotcreted mixture and the effectiveness of the fiber technology. In accordance with NF EN 13381-3, a large flat panel 12.8 × 10.5 × 0.41 ft (3.9 × 3.2 × 0.125 m) was prepared on June 6, 2022, to serve as a full scale test specimen.

The panel seen in Fig. 7 incorporated a reinforcement configuration representative of in service conditions, along with twelve thermocouples positioned 4 in. (100

Fig. 7: Preparation of the panel with dry-mix shotcrete King® MS-D1 FSR for the HCM fire curve testing by the contractor Groupe LB. Photo credit: Sika Canada (2022).

Test	Standard	Age / Cycles	Units	Project Requirement	Result
Compressive Strength	CSA A23.2-14C	1 day	psi (MPa)	2176 (15.0)	3508 (24.2)
		7 days	psi (MPa)	3626 (25.0)	5221 (36.0)
		28 days	psi (MPa)	5076 (35.0)	6938 (47.8)
Bulk Resistivity	CSA A23.2 26C	28 days	ohm·ft (ohm·m)	1640 (500)	1221 (372)
Air Content	CSA A23.3-4C	—	%	3.5 – 7.0	6.7*
Spacing Factor	ASTM C457	—	in (μm)	0.012 (300)	0.008 (206)
Absorption (Immersion & Boiling)	ASTM C642	—	%	8.0	2.6
Permeable Void Volume	ASTM C642	—	%	17.0	5.9
Rapid Chloride Penetration	CSA A23.2-23C	56 days	Coulombs	1500	212 *(Very Low)*
Freeze–Thaw Resistance	ASTM C666	300 cycles	% durability factor	—	100
Salt-Scaling Resistance	ASTM C672	56 cycles	lb/ft^2 (kg/m^2)	—	0.02 (0.1)
Fire Resistance	CETU Technical Guide, and NF EN 13381-3	180 minutes, at 2372 °F (1300 °C)	—	HCM fire-curve	Passed

Table 1: Compilation of the test results obtained for the King® MS-D1 FSR shotcrete mix for the Louis-Hippolyte-La Fontaine tunnel project.
**Air content testing conducted in accordance with ASTM C457*

mm) from the exposed face to monitor the thermal evolution during testing.

After the panel was fabricated, it was shipped by sea to the CERIB laboratory in France, arriving on Sept. 2, 2022, to undergo the fire resistance test. The test setup consists of a furnace in which the panel, supported horizontally on two bearings, is exposed to a fire scenario representative of an HCM curve thermal loading.

RESULTS AND DISCUSSION

Based on the tests carried out for this project, the dry-mix shotcrete material formulated for fire spalling resistance met all project requirements, including the spalling resistance test under the HCM fire curve. The detailed results are presented in Table 1 (see previous page).

The mix achieved a 28-day compressive strength of 6938 psi (47.8 MPa) exceeding the minimum strength criteria established by the MTMD. The hardened concrete exhibited 6.7% entrained air, achieving a well-distributed air void structure with a spacing factor of 0.008 in. (206 μm). The absorption after boiling (2.6 %) and permeable void volume (5.9 %) were consistent with acceptable placement quality as defined by established in situ performance indicators, including those presented by Morgan & Jolin (2022).

Durability testing demonstrated compliance with project requirements. Chloride ion penetration was classified as *very low*, and the air entrainment system provided robust resistance to freeze–thaw cycling as well as to surface scaling in the presence of de icing salts. Additionally, the bulk resistivity of 1221 ohm-ft (372 ohm-m) supports compatibility with the cathodic protection systems implemented as part of the tunnel rehabilitation program.

The incorporation of an appropriate fiber was fundamental toward achieving the required fire spalling resistance under HCM curve thermal loading. As reported by CERIB (2023), a test is considered successful when the concrete exhibits no evidence of fire induced spalling, including delamination, surface breakout, or loss of cover concrete from the exposed face. Fig. 8 depicts the condition of the shotcrete panel before and after the fire exposure. The results confirm that this mixture produced the first dry-mix shotcrete system verified to meet the HCM fire spalling resistance criteria.

CONCLUSION

The Louis-Hippolyte-La Fontaine tunnel in Montreal is still today currently undergoing work to extend its service life by an additional 40 years. For this project, the two ventilation towers composed of two reinforced concrete shafts presented significant challenges due to their complex geometry and a constrained workspace. These constraints necessitated the use of dry-mix shotcrete as both a repair and fire protection material (Fig. 9 - see next page).

Upgrading the fire resistance performance of these structures required the application of a shotcrete capable of mitigating fire induced spalling under the severe thermal conditions represented by the HCM fire curve (180 minutes, at 2400°F [1300°C]). The incorporation of properly engineered microfibers was essential for reducing the risk of explosive spalling by enabling vapor pressure relief within the concrete matrix during rapid heating.

The coordinated efforts of the Renouveau La Fontaine consortium, the contractor Groupe LB, and the MTMD ensured the successful execution of this project. The fire resistance tests conducted by CERIB confirmed that the dry-mix shotcrete material used in this project is, to date, the only mixture of its type verified to meet HCM fire curve performance criteria. The shotcrete material developed for the Louis-Hippolyte-La Fontaine Tunnel, in accordance with MTMD requirements, constitutes today a proven new technology for future infrastructure projects requiring comparable fire protection performance.

Fig. 8: HCM testing panel before (LEFT) and after (RIGHT) being exposed to 2372°F (1300°C) for 180 minutes. No visible damage was reported after testing. Photo credit: CERIB (2023).

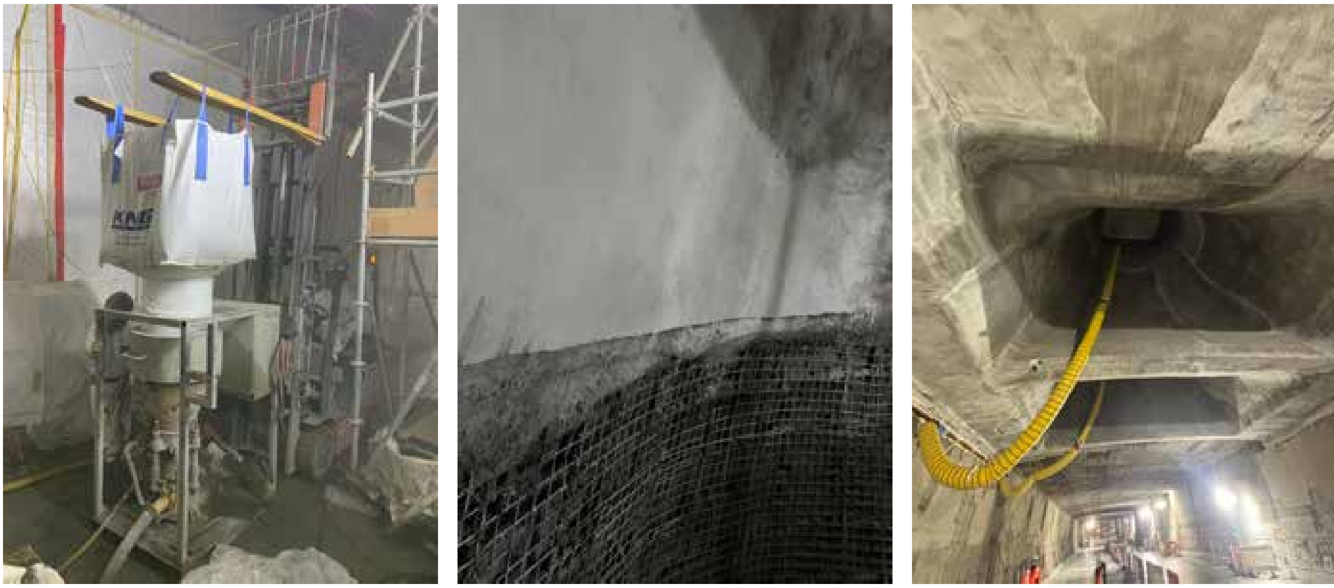

Fig. 9: Result of the rehabilitation of one of the towers using fire-spalling resistant dry-mix shotcrete King® MS-D1 FSR. Photo credits: Sika Canada (2024) and Groupe LB (2026).

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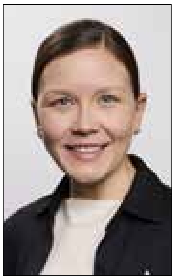

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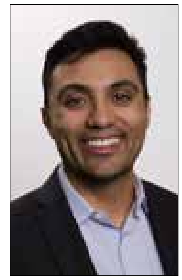

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