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An experimental study of electrochemical incompatibility between repaired patch concrete and existing old concrete

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HIGHLIGHTS

- Electrochemical incompatibility exists between repaired concrete and old concrete.
- Performance of the patch repair strategies for concrete bridge deck slabs is examined.
- Increased corrosion at the periphery of the repair and progressed into the repaired zone.
- Different measures are proposed to increase the service life of the repair system.

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ABSTRACT

This research program examines the performance of different patch repair strategies for repairing concrete bridge deck slabs, damaged due to premature corrosion of embedded reinforcing steel bars (rebars). The electrochemical compatibility between the repaired patch concrete and the existing old concrete in fifteen (1000 mm × 1000 mm × 200 mm) specimens was examined using half-cell potential, chloride content, rebar mass loss and corrosion penetration rate tests. The experimental results showed that the potential difference between the repaired patch concrete and the existing old concrete local corrosion increased significantly at the periphery of the patch, and gradually progressed into the repaired zone. This effect varied from one repair technique to another. Different measures to increase the service life of the repair system are also proposed, such as incorporating a sacrificial embedded anode, an impressed current cathodic protection system, along with the use of surface coating or membrane as an additional line of defence.

1. Introduction

Sustainable and durable civil infrastructure requires planning, design, construction, operation, maintenance, repair/rehabilitation to ensure a healthy economy and a high quality of life in any community [1]. Bridges and overpasses comprise a major component of the transportation infrastructure. More than 40% of the existing bridges use in Canada were built over 50 years ago, and a considerable number of these structures need strengthening, rehabilitation, or replacement, using the limited maintenance budgets [2]. According to the Report Card for America's Infrastructure [3], the average age of over 600,000 bridges in the United States is currently 42 years and more than 30% of existing bridges have exceeded their 50-year design life, with an overall grading of "C+", which means that maintenance, repair, and rehabilitation programs will require significant investment in the immediate future. This Report Card also suggested an annual investment of $20.5 billion for repair, reconstruction, and renovation of the existing bridges [3]. Structural concrete is the primary construction material for these bridges, followed by steel. The level of deterioration of concrete bridges and other infrastructure is significant, and the rehabilitation costs are growing exponentially. Corrosion of rebars embedded in concrete, due to chloride-contamination, is the principal cause of this deterioration [1,4,5]. The field observations, specifically the detailed testing program on Dickson Bridge, Montreal, Canada, showed that the conventional patch-repair of concrete deck systems is ineffective, and it is unable to provide an adequate service life, basically because of the electrochemical incompatibility between the chloride-free concrete in the patch and the chloride-contaminated concrete in the peripheral region around the repaired patch [5–8]. The nature and consequence of the electrochemical activities in a repair system, as compared with new construction, are still not well understood, which results in an

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Table 1
Different reinforced concrete repair strategies [6,16–18].

Strategies	Comments
Patch Repair: Removal of all cracked and delaminated concrete, cleaning of all corroded reinforcement, application of protective coatings on the embedded steel bars and repairing with mortar or micro-concrete.	• Popular due to low cost and temporary aesthetic improvement. • Limited success against chloride-induced corrosion.
Barrier Coating: These systems attempt to seal the surface of the concrete, restricting the flow of oxygen to the cathode, thus stifling the corrosion process.	• Not suitable for large concrete structures, because substantial amounts of oxygen are already present in the system. • Generally ineffective due to the presence of defects underneath the new coating. • Likely to promote the formation of differential aeration cells, further accelerating the corrosion potential.
Hydrophobic Coatings (penetrating pore liner, e.g. silanes and siloxanes): Surface capillary channels are lined with a hydrophobic coating, which repels water during wetting, but allows water vapor movement during drying.	• Reduces the moisture content, thereby electrolytically stifling the corrosion reaction. • Suitability for marine structures is questionable due to the high ambient humidity, effect of capillary suction and presence of high salt concentrations, all of which interfere with its drying. • Application to a new construction is effective for about 10–15 years.
Electrochemical Techniques: They restore the passivated condition of the steel rebar by temporary application of a strong electric field to the concrete cover region.	• Re-alkalization: Nondestructively restoring the alkalinity of the carbonated concrete; treatment can be completed in less than two weeks. • Electrochemical Chloride Removal (ECR): A more time-consuming and complex technique; its suitability must be carefully assessed.
Cathodic Protection: The electrical potential of the embedded reinforcement is artificially increased either by an impressed external current or by a sacrificial anode system, thus decreasing the corrosion rate.	• Sacrificial Anode System: Most effective in submerged structures (saturated concrete with low resistivity) and temperature above 20 °C. • Impressed Current (The anode system is normally designed for a long service life of 20–50 years). Cathodic systems require electrically continuous reinforcement and uniformly conductive, delamination-free concrete cover.

inability to accurately predict the performance of a protective repair system and the remaining service life of a repaired structure.

Corrosion is a natural destructive process which transforms the metal from its unstable state to a stable ore state, mostly oxides, chlorides, or sulphates. Thermodynamically, the metal tends to revert to its natural form, an oxide, by releasing energy [9,10]. Electrochemically, it is a progressive removal of the metal-atoms from its surface to the electrolyte environment [11]. Steel corrosion products can have a volume up to ten times that of the iron in the steel rebar due to the formation of iron oxides and hydroxides [9,12]. This expansion of rebar due to corrosion results in rapid damage to the encasing concrete which requires significantly expensive repairs [5,13,14].

Any choice of repair for a deteriorated reinforced concrete structure demands cost-effectiveness, technical feasibility, and reliability. Engineers must understand all relevant materials, and the structural and environmental issues associated with any concrete repairs to make intelligent choices [7,15]. There are a few crucial factors, which should be considered in selecting a suitable cost-effective and durable repair, such as the level of deterioration, specific conditions of the structure and the environmental conditions [6,16,17]. High-quality repairs require a thorough investigation of the causes of deterioration, appropriate repair specifications and high-quality execution of the repair work. The various repair options are summarily compared in Table 1.

The repair methodology of damaged concrete structures depends on whether the rebar corrosion is carbonation-induced or chloride-induced. The important aspects of a traditional patch repair procedure are divided into various steps, such as exposing the corroded reinforcement by removing all cracked and delaminated concrete, thoroughly cleaning of the corroded reinforcement and applying a protective coating (anti-corrosion epoxy coating or zinc-rich primer coating) to the steel surface and sealing of the entire concrete surface to reduce the ingress of moisture in the concrete [19–21].

Patch repair has limited success against chloride-induced corrosion because of the surrounding chloride-contaminated concrete; as a result, the reinforcement continues to remain susceptible to corrosion [6,7]. The patched area of new repair material often causes the formation of incipient anodes adjacent to the repairs as shown in Figs. 1 and 2.

2. Research scope and objectives

Dickson Bridge in Montreal, Canada was constructed in 1959 and abandoned after a service life of only 35 years because of the influence of severe environmental conditions, poor construction

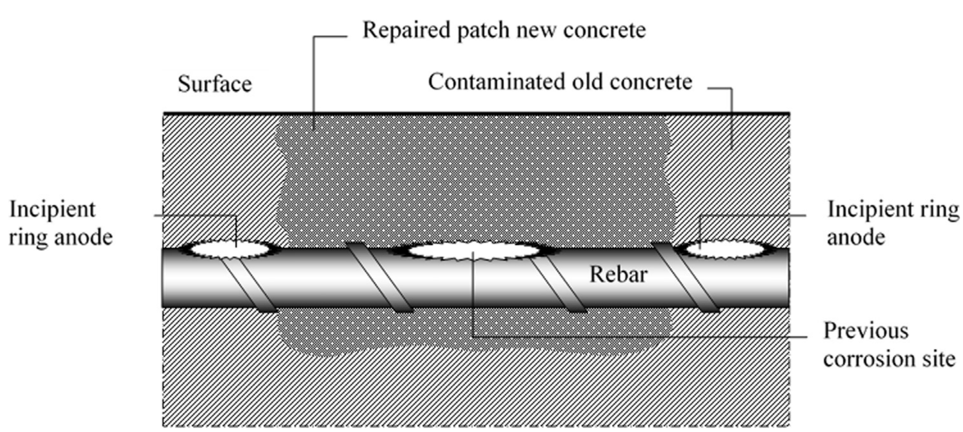

Fig. 1. Schematic of formation of incipient ring anode after patch repairs.