

CFRP Materials for Reinforced Concrete Structures

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INTRODUCTION

The use of carbon fiber reinforced polymers (CFRP) as internal reinforcements, prestressed reinforcements and as external strengthening for reinforced and prestressed concrete structures and bridges has become common practice during the last two decades. The widespread acceptance of CFRP in the concrete industry has led to questions and concerns regarding the use of CFRP in conjunction with conventional mild steel reinforcements. Specifically, some engineers have raised concerns regarding the possible occurrence of galvanic corrosion between the CFRP materials and the conventional mild steel reinforcements. While direct electrical connection of carbon and steel in the presence of an electrolyte, such as saltwater, can possibly lead to galvanic corrosion, this type of direct contact rarely occurs in typical reinforced and prestressed concrete applications. Proper detailing of the reinforcements to ensure electrical isolation of the two materials can minimize or eliminate the

possibility of galvanic corrosion. Further, CFRP has been extensively used in conjunction with metals such as steel and aluminum, which are typically highly susceptible to galvanic corrosion, in marine, aerospace and civil engineering applications. In these applications the materials were subjected to harsh environmental conditions for several years without exhibiting any signs of degradation or deterioration. This short note briefly discusses the conditions necessary for galvanic corrosion to occur between two materials. Several applications are presented which demonstrate the successful use of carbon fibers in conjunction with metals under harsh environmental conditions. Finally, detailing recommendations are discussed to help minimize or prevent the occurrence of galvanic corrosion of members reinforced with CFRP and mild steel materials.

FUNDAMENTAL FACTS

The galvanic corrosion process is presented schematically in Figure 1. Four conditions are necessary in order for galvanic corrosion to occur between CFRP and steel materials¹. First, the two materials must be in electrical contact. That is, they must be in direct contact or somehow directly or indirectly connected by a conductive material such as a steel tie wire. The two materials must be bridged by an electrolyte such as saltwater or deicing solution. The electrolyte can be in the form of a bulk liquid, a thin film of condensation on the surface of the materials or a damp solid such as soil or concrete. The two materials must have a sufficient difference of electric potential so as to be able to provide significant

galvanic current. This is typically the case between steel and carbon. Finally, there must be a sustained cathodic reaction on the more noble material, in this case the carbon. In most applications, this typically means that dissolved oxygen must be present in the electrolyte to take part in the galvanic reactions. Under these conditions the anode, in this case the steel, can experience an accelerated rate of corrosion while the cathode, or the carbon, can exhibit a reduced rate of corrosion. Elimination of any one of these factors will successfully prevent the occurrence of galvanic corrosion of the materials. Therefore, although carbon and steel have sufficiently different electrical potentials to drive a galvanic current, elimination of one or a combination of the other factors could prevent accelerated galvanic corrosion of the steel material.

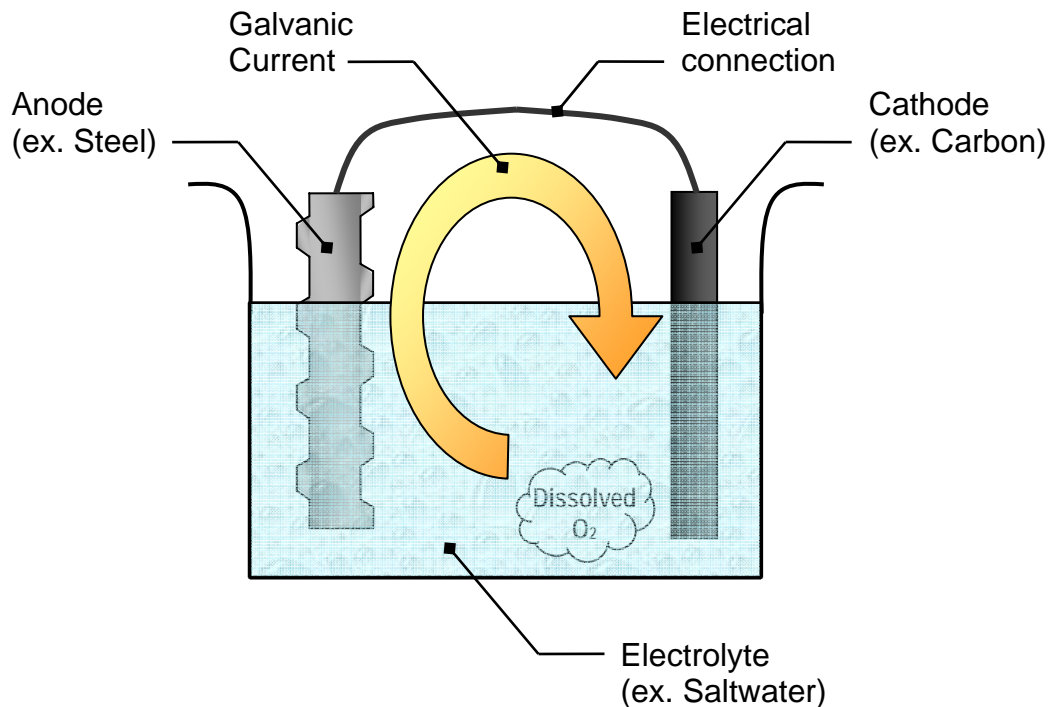


Figure 1: Schematic representation of the galvanic corrosion process

FIELD APPLICATIONS

The use of carbon in close proximity with metals which are susceptible to corrosion has a proven track record in a number of industries, including marine, aerospace and civil engineering infrastructure. These represent cases of severe environmental exposure in which corrosion could be catastrophic. Specifically in civil engineering infrastructure applications, CFRP has been used together with mild steel reinforcement for new construction and for repair of existing structures throughout the last two decades. In these cases no deterioration or accelerated corrosion was observed after several years in service.

In 1993 a bridge in Alberta, Canada was among the first bridges in Canada to implement CFRP prestressing strands². This represents an environment in which the use of deicing chemicals, which are a harsh electrolyte, is prevalent. A total of six precast bulb-tee girders were prestressed using CFRP tendons. The girders were subsequently post-tensioned together using conventional steel prestressing strand to provide continuity across two spans of the bridge. Additional steel spiral reinforcement was provided at the ends of the CFRP tendons, as shown in Figure 2, to prevent possible failure of the highly stressed anchorage zone. The girders were reinforced for shear using epoxy coated steel transverse reinforcement. This project represents an early civil engineering application of CFRP in conjunction with conventional steel reinforcements with minimal additional precautions to prevent contact between the materials and to prevent galvanic corrosion. Despite this, the structure was subsequently load

tested and inspected by ISIS Canada in 2006, 13 years after its construction, and no indications of deterioration or corrosion were observed.

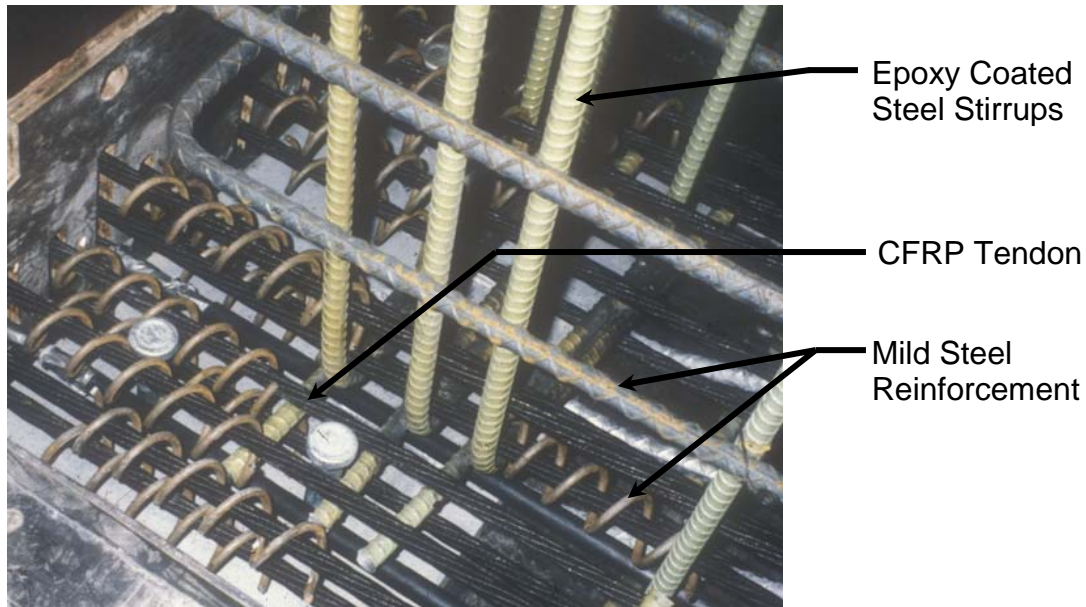


Figure 2: Reinforcing details of a bridge girder reinforced with CFRP and steel in Alberta, Canada

In similar applications externally bonded CFRP materials have been used for repair and strengthening of concrete bridge girders which are reinforced with conventional and prestressed steel reinforcements. In these applications, the steel reinforcement and carbon materials are typically separated by the concrete cover layer which is typically 50 mm (2 in.) thick. This separation prevents direct electrical contact between the two materials and prevents the formation of a harmful galvanic current. This technique was implemented for shear strengthening of two prestressed concrete bridges in 1999 as shown in Figure 3³. Both of these bridges were located over large bodies of water and exposed to

frequent use of deicing chemicals. Structural health monitoring and inspection of the bridges did not show any indication of corrosion or deterioration during the service life of the repairs.



Figure 3: Shear strengthening of prestressed concrete bridge girders using externally bonded CFRP

Use of carbon fiber materials together with conventional steel for new construction and also for repair and strengthening of existing bridges is commonly accepted by the bridge engineering community, the construction industry, ACI and by highway departments throughout the US. The proven track record of these techniques in several civil engineering infrastructure applications

provides a high level of confidence for the use of CFRP together with conventional mild steel reinforcements.

RECOMMENDATIONS

Based on the current knowledge of the mechanisms of galvanic corrosion the following detailing recommendations are made to provide protection against possible galvanic corrosion.

1. Electrically isolate the carbon materials from the steel

Direct contact between carbon fibers and mild steel should be avoided. Previous research has indicated that a thin, 0.25 mm (0.01 in), layer of epoxy on the surface of the carbon fibers can reduce the galvanic corrosion rate of steel in seawater by up to 21 times as compared to the case of unprotected fibers⁴. Conventional CFRP products are typically manufactured with a thin layer of adhesive which coats the fibers that is left behind by the manufacturing process or intentionally added to enhance bond.

Providing adequate spacing between carbon and steel materials provides an additional barrier of concrete which serves to electrically isolate the two materials. Previous research has indicated that galvanic currents between CFRP rods and uncoated steel reinforcing bars embedded in concrete are typically small⁵. This was found to be the case even when the epoxy

coating on the surface of the CFRP was damaged and the concrete was moist and contaminated with chlorides. Carbon fiber reinforcement should not be tied to mild steel reinforcement as the tie wire can act as a direct electrical connection between the two materials.

2. Prevent ingress of moisture and oxygen into the concrete

Providing adequate concrete cover to the reinforcement can prevent or minimize ingress of moisture to the level of the reinforcing materials. Since moisture can travel directly along cracks, it is preferable to eliminate or minimize cracking of the concrete, which is typically the case for prestressed structures. Use of concrete with significant interconnected voids should be avoided as these voids provide locations for electrolytes to collect within the concrete and could possibly bridge the steel and carbon materials.

CONCLUSIONS

While galvanic corrosion between steel and carbon can occur under certain environmental conditions, proper detailing based on an understanding of the mechanisms of galvanic corrosion can be implemented to prevent this phenomenon. CFRP materials have been successfully used together with mild steel reinforcements in many civil engineering applications since the early 1990's without exhibiting any signs of deterioration or corrosion even when exposed to

severe environmental conditions. As in any application, the key to durability is detailing.

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