The concept of a novel approach to control MIC corrosion in civil structures

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ABSTRACT

Impressed current cathodic protection (CP) based on pulse technology has been proven to be a more efficient and effective alternative of traditional CP for reinforced concrete applications. Essentially, the superiority of pulse CP is in achieving the required steel polarization with otherwise reduced side effects (e.g. influence on bond strength or cement-based bulk matrix properties are minimized); further utilization of lower anodic surface is possible with pulse CP as a result of a better “current throw” at certain frequency and duty cycle of the pulse. The technique has not been tested so far with respect to microbiologically induced corrosion (MIC) and marine applications of steel structures.

This paper will present the concept of recently initiated research for MIC corrosion control through the synergetic action of pulse CP and bio-based coatings. The emphasis is on steel structures for marine applications. An essential part of the expected corrosion control is based on the action of hybrid bio-based coatings, involving competitive microorganisms. The application targets self-healing with respect to MIC and hydrogen-induced damage. Control of anaerobic MIC will be one of the main goals of this research. Extending the application to reinforced concrete and underground pipe-network is also foreseen.

The fundamental mechanisms with respect to MIC corrosion will be defined in parallel to the mechanisms of cathodic polarization when MIC is involved. Clarifying the reasons for steel ennoblement in anaerobic conditions under CP will be achieved and an optimum polarization level will be derived. The first step in this research will be studying the electrochemical behavior of steel in simulated environment as within aerobic, anaerobic and mixed MIC conditions (at open circuit and under cathodic polarization) and the results coupled to steel surface analysis and bacterial viability under conventional and pulse CP.

1. INTRODUCTION

Microbiologically Induced Corrosion (MIC) is a phenomenon where microorganisms initiate or accelerate a corrosion process. It provokes serious damages in various industries and systems which involve the use of natural waters (e.g. oil/gas, shipping, electrical industry) [1]. Conventional cathodic protection (CP) in combination with coatings, has been used to control steel corrosion, but in most cases, it is necessary to increase the cathodic current density in order to reach protection levels. This is a common problem when MIC is involved due to the “barrier effect” of the bio-film, generated by microorganisms causing MIC. Often, among other phenomena, the bio-film composition i.e. polymeric substances, acts as electrical “insulation” for the cathodic protection. A consequence of increasing the cathodic current density is hydrogen evolution and possibility for hydrogen embrittlement. Pulse cathodic protection has been proven to be more effective than conventional CP in reinforced concrete applications [2-4]. It achieves the required level of polarization by using lower current density, exerts reduced side effects (e.g. bond strength) and enhances positive effects (e.g. Ca-substituted and protective steel product layers). Although known to be applied for underground pipe-networks, the application of pulse CP is to our best knowledge not applied for offshore structures in combination with bio-based coatings, where MIC is involved. A novel approach to solve MIC and hydrogen embrittlement is the synergetic action of pulse CP and hybrid coatings, involving competitive microorganisms that will control the cathodic hydrogen evolution reaction. With this respect it is important to understand the local electrochemical mechanism of microbiologically induced corrosion and the consecutive alterations within cathodic polarization in order to develop more efficient protective alternatives. Therefore this project targets MIC corrosion control through employing self healing hybrid bio-based coatings and pulse CP.

2. MOTIVATION

MIC is a phenomenon affecting properties and service life of civil structures such as carbon steel pipelines (offshore and onshore), bridges, reinforced concrete structures and sewage pipes. Specific environmental conditions can cause different types of MIC, depending on the various microorganisms, as present in the environment. With respect to anaerobic MIC, the most commonly related microorganisms are sulfate reducing bacteria (SRB).

Coatings are the primary protection for corrosion problems in steel structures due to the barrier effect they create by insulating the metal surface from the aggressive environment. A novel solution to control MIC would be a bio based coating that could be used as primer or top coat and act as a barrier on one hand. On the other hand, competitive microorganisms can be involved in the coating and their metabolism will result in self-healing of the interface steel/primer by consuming cathodic and MIC produced hydrogen; additionally the viability of un-wanted microorganisms will be reduced. Sol-gel coatings, containing living cells and oppositely charged poly-electrolytes would be a suitable choice for the above application.

Conventional impressed current CP has been proven of not being able to efficiently deal with MIC due to the above discussed phenomena and those particularly related to steel ennoblement within cathodic polarization. The complexity of the bio-based processes in the presence and absence of cathodic polarization needs in depth investigation, since these determine the electrochemical phenomena, related to the corrosion process itself and/or to CP efficiency respectively.

3. EXPECTED RESULTS

Results to be expected in this work are: to define the fundamental mechanisms with respect to MIC corrosion; to identify the mechanisms of cathodic polarization when MIC is involved; to clarify the reasons for steel ennoblement in anaerobic, aerobic and mixed conditions under CP and to determinate the optimum regime of pulse CP application.

The project targets the formulation of bio-based coatings with the capability to consume cathodic and bio-produced hydrogen and therefore provide the possibility to control the risk of hydrogen embrittlement at a more efficient regime of cathodic polarization. Cost-efficiency is also considered in order to encourage industrial applications

4. SUMMARY AND CONCLUSION

The primary goal of this project is to ensure corrosion control and safe operation within offshore and underground applications (both steel and reinforced concrete) by an integrated approach, combining a novel CP technique based on pulse technology and bio-based, sol-gel coatings for self-healing of hydrogen induced degradation and corrosion damage. The project targets:

- development of a suitable bio-based coating that will control hydrogen formation, absorption/desorption and hydrogen evolution via self-healing mechanisms;
- application of a tailored CP providing larger (or modified) cathodic polarization, so that the cathodic reaction is still effective and not suppressed; using current controlled (instead of the generally applied voltage controlled) regime;
- integration and ensured compatibility of bio-based sol-gel coatings and DC pulse techniques (instead of conventional DC technique), aiming simultaneous corrosion protection, minimised possibility for hydrogen embrittlement and reduced viability of corrosion-inducing microorganisms.

The main outcome(s) of this research will be as follows:

- Formulation of a hybrid, bio-based coating suitable as a primer or top coat for offshore structures (steel), reinforced concrete (underground water mains, sewers) and pipelines (reinforced concrete or steel).

- Bio-based, sol-gel coating for self-healing of MIC induced damage, simultaneously active to resolve hydrogen-induced damage (as within CP applications). The coating will serve as a matrix (living medium) for competitive microorganisms which consume the cathodic hydrogen (e.g. methanogenes). Alternatively, a sol-gel matrix containing also Gramicidin S producing bacteria can be designed, in order to oppose the SRBs.

- A hybrid, sol-gel coating containing layer-by-layer deposited bio-polymers on living cells: an approach utilizing bacterial cells and a pair of oppositely charged polyelectrolytes. The low cost of the suggested bio-polymers, compared to others, suggests wider industrial application.

- Bio-based cementitious materials (or mortar/concrete mixtures), containing living organisms of the above defined variety, encapsulated in bio-based polymers. These cement-based materials can be directly applied for new reinforced concrete or as repair materials for existing infrastructure (e.g. underground water mains), where MIC corrosion and/or CP are involved.

- Establishing the optimum regime of pulse CP application in combination with self-healing hybrid coatings: The advantage here with respect to MIC will be reduced viability of the microorganisms (block shaped currents decrease bacterial viability and growth) and reduced hydrogen evolution, while providing the possibility for enhanced cathodic polarization.

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