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Review

Advances in concrete materials for sewer systems affected by microbial induced concrete corrosion: A review

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ABSTRACT

Microbial induced concrete corrosion (MICC) is recognized as one of the main degradation mechanisms of subsurface infrastructure worldwide, raising the demand for sustainable construction materials in corrosive environments. This review aims to summarize the key research progress acquired during the last decade regarding the understanding of MICC reaction mechanisms and the development of durable materials from an interdisciplinary perspective. Special focus was laid on aspects governing concrete - micoorganisms interaction since being the central process steering biogenic acid corrosion. The insufficient knowledge regarding the latter is proposed as a central reason for insufficient progress in tailored material development for aggressive wastewater systems. To date no cement-based material exists, suitable to withstand the aggressive conditions related to MICC over its entire service life. Research is in particular needed on the impact of physiochemical material parameters on microbial community structure, growth characteristics and limitations within individual concrete speciation. Herein an interdisciplinary approach is presented by combining results from material sciences, microbiology, mineralogy and hydrochemistry to stimulate the development of novel and sustainable materials and mitigation strategies for MICC. For instance, the application of antibacteriostatic agents is introduced as an effective instrument to limit microbial growth on concrete surfaces in aggressive sewer environments. Additionally, geopolymer concretes are introduced as highly resistent in acid environments, thus representing a possible green alternative to conventional cement-based construction materials.

Contents

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1. Introduction

The efficient, safe and cost-effective collection and transport of wastewater is a key criterion maintaining expected sanitary standards of modern society (Hvitved-Jacobsen et al., 2013). Especially in developing countries insufficient operating or lacking wastewater networks can lead to the spread of infectious diseases and the contamination of drinking water (Hvitved-Jacobsen et al., 2002). Microbial induced concrete corrosion (MICC) has been recognized as one of the main processes for degradation of concrete based wastewater networks worldwide, increasingly triggering high economic expenses, as well as severe health and environmental concerns (Herisson et al., 2017; Islander et al., 1991; Jiang et al., 2016; Li et al., 2017; O'Connell et al., 2010; Peyre Lavigne et al., 2016). Typical damages of concrete elements from different sewer systems caused by MICC are shown in Fig. 1. Annual rehabilitation costs were estimated to reach over €450 million in Germany (Berger et al., 2016) and £85 million in the UK, while the USA needs to spend around $390 billion within the next 20 years, in order to keep the existing wastewater infrastructure operational (Gutiérrez-Padilla et al., 2010). Additionally, hazardous gas production of mainly hydrogen sulfide (H_2S) and carbon dioxide (CO_2), but also methane (CH_4), ammonia (NH_3) and other volatile organic compounds (VOCs) associated with MICC, represent a severe health risk for community workers and wastewater system operators (Gutierrez et al., 2014, 2008; World Health Organisation, 2000). MICC is a complex process. To efficiently study MICC, an interdisciplinary approach that brings together the fields of civil and chemical engineering (material scientists), microbiology, mineralogy, hydro(geo)chemistry as well as environmental sciences is desired. Intensive research within segregate research areas has produced a wide spectrum of data and hypothesis. To further promote the emergance of innovations for sustainable building material design in wastewater infrastructure efficient cooperation between scientist from the before mentioned areas is required. While the fundamental corrosion processes have been intensly investigated (Islander et al., 1991; Jiang et al., 2014a; Ling et al., 2015), to date no sustainable product is available, which meets the long term requirements in such extremely aggressive and corrosive sewer environments. Extensive laboratory research and in-situ testing have shown that significant durability variations exist between different types of concrete subjected to MICC. Nevertheless, none of the so far tested materials can entirely resist this biogenic acid attack. All materials failed to reach their projected operating life time (Alexander et al., 2013; De Belie et al., 2004; Girardi et al., 2010; Goyns and Alexander, 2014; Herisson et al., 2013). Reasons for this failure may originate from insufficient knowledge on the initial processes leading to microbial colonization of construction materials in heterogenous wastewater environments. While Li et al. (2017) have recently summarized the existing knowledge on microbial community structures of acidophilic bacteria associated with MICC, little is known about initial microbial colonization of concrete structures in sewer systems. Moreover, it is lagerly unknown how biofilms develop, which organisms typically compose these communities, how dynamic they are over time, and how they interact with the applied concretes. Vise versa, the role of specific physical and chemical concrete properties on microbial growth, subsequent corrosion initiation, and propagation still needs further research. A general description of biofilm characteristics together with the central physiochemical aspects of concrete are described in Fig. 2.

To gain a better overview on the multifacetted phenomenona of MICC, this review aims to compile the key research findings in the field of MICC during the last decade from an interdisciplinary perspective, intertwining advances in concrete materials with microbiological and hydro(geo)chemical related aspects. This contribution emphasizes the central role of specific physical and chemical concrete properties on MICC initiation and propagation, allowing adhesion of microbial cells, microbial growth and subsequent biofilm development. These properties are likely key factors for MICC and are central for further research advances and the development of durable materials. Moreover, we summarize potential additives, such as antimicrobial agents applicable in MICC environments. In addition, possible advantages of geopolymer concretes, being cement free alternatives, compared to conventional cement based building materials, such as Portland cement (OPC) and calcium aluminate cement (CAC) based concretes, are discussed. Due to their acid resistance (Pacheco-Torgal et al., 2014), innovative geopolymer technology could represent a significant step towards the development of sustainable materials for MICC

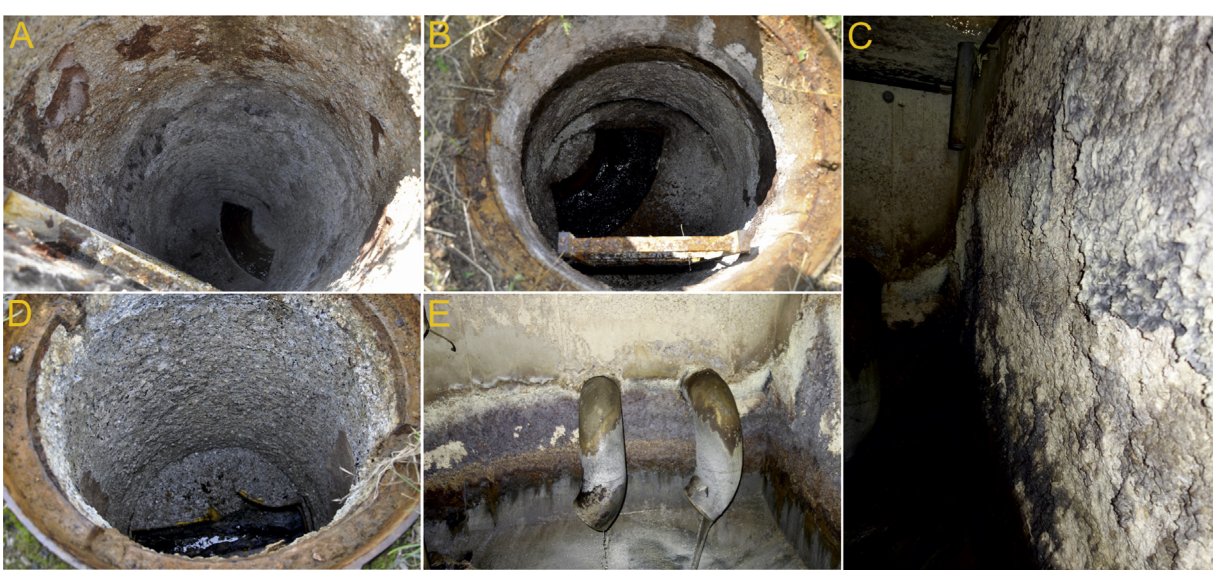

Fig. 1. Examples of typical deterioration symptoms within systems affected by microbial induced concrete corrosion. Pictures A, B and D were taken in concrete manholes following power mains, while pictures C and E display damages within wastewater catchment basins.