Construction and Building Materials 167 (2018) 115–142

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Experimental characterization of the self-healing capacity of cement based materials and its effects on the material performance: A state of the art report by COST Action SARCOS WG2

Liberato Ferrara [a,*], Tim Van Mullem [b], Maria Cruz Alonso [c], Paola Antonaci [d], Ruben Paul Borg [e], Estefania Cuenca [a], Anthony Jefferson [f], Pui-Lam Ng [g], Alva Peled [h], Marta Roig-Flores [i,1], Mercedes Sanchez [c,2], Christof Schroefl [j], Pedro Serna [i], Didier Snoeck [b], Jean Marc Tulliani [k], Nele De Belie [b]

[a] Department of Civil and Environmental Engineering, Politecnico di Milano, Italy
[b] Magnel Laboratory for Concrete Research, Faculty of Engineering and Architecture, Ghent University, Ghent, Belgium
[c] Instituto de Ciencias de la Construcción Eduardo Torroja, Consejo Superior de Investigaciones Científicas, Madrid, Spain
[d] Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Italy
[e] Faculty for the Built Environment, University of Malta, Malta
[f] School of Engineering, University of Cardiff, UK
[g] Faculty of Civil Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
[h] Department of Structural Engineering, Ben Gurion University of the Negev, Beer Sheva, Israel
[i] Instituto de Ciencia y Tecnologia del Hormigon, Universitat Politecnica de Valencia, Spain
[j] Institute of Construction Materials, Technische Universitaet Dresden, Dresden, Germany
[k] Department of Applied Science and Technology, Politecnico di Torino, Italy

HIGHLIGHTS

- Review of test methods for assessing healing efficiency.
- Novel perspective in correlating healing to durability and mechanical recovery.
- Correlation between different test methods.
- Characterization methods of healing products.
- Pioneer monitored case studies are presented.

ARTICLE INFO

Article history:
Received 18 December 2017
Received in revised form 23 January 2018
Accepted 24 January 2018
Available online 9 February 2018

Keywords:
Self-healing
Cementitious materials
Test-methods
Durability Properties
Mechanical properties
Self-healing products
Field evaluation

ABSTRACT

Heuristically known at least since the first half of XIX century, the self-healing capacity of cement-based materials has been receiving keen attention from the civil engineering community worldwide in the last decade. As a matter of fact, stimulating and/or engineering the aforementioned functionality via tailored addition and technologies, in order to make it more reliable in an engineering perspective, has been regarded as a viable pathway to enhance the durability of reinforced concrete structures and contribute to increase their service life.

Research activities have provided enlightening contributions to understanding the mechanisms of crack self-sealing and healing and have led to the blooming of a number of self-healing stimulating and engineering technologies, whose effectiveness has been soundly proved in the laboratory and, in a few cases, also scaled up to field applications, with ongoing performance monitoring. Nonetheless, the large variety of methodologies employed to assess the effectiveness of the developed self-healing technologies makes it necessary to provide a unified, if not standardized, framework for the validation and comparative evaluation of the same self-healing technologies as above. This is also instrumental to pave the way towards a consistent incorporation of self-healing concepts into structural design and life cycles analysis codified approaches, which can only promote the diffusion of feasible and reliable self-healing technologies into the construction market.

* Corresponding author.
E-mail address: liberato.ferrara@polimi.it (L. Ferrara).
[1] Now at Instituto Eduardo Torroja de Ciencia de la Construccion, Centro Superior de Investigaciones Scientificas, Madrid, Spain.
[2] Now at University of Cordoba, Spain.

https://doi.org/10.1016/j.conbuildmat.2018.01.143

In this framework the Working Group 2 of the COST Action CA 15202 "Self-healing as preventive repair of concrete structures – SARCOS" has undertaken the ambitious task reported in this paper. As a matter of fact this state of the art provides a comprehensive and critical review of the experimental methods and techniques, which have been employed to characterize and quantify the self-sealing and/or self-healing capacity of cement-based materials, as well as the effectiveness of the different self-sealing and/or self-healing engineering techniques, together with the methods for the analysis of the chemical composition and intrinsic nature of the self-healing products. The review will also address the correlation, which can be established between crack closure and the recovery of physical/mechanical properties, as measured by means of the different reviewed tests.

Contents

1. Introduction

The susceptibility of concrete to cracking because of load- or deformation-induced stresses all along its service life is well known and represents one of the major hindrances to the durability of concrete structures. Cracks stand as a straightforward path for the ingress of harmful agents into concrete, whose bulk matrix, with modern high performance technologies, can be made as low porous as desirable.

Worldwide increasing consciousness for sustainable use of natural resources has made overcoming the apparent contradictory requirements of low cost and high performance a challenging task. *fib* Model Code 2010 has also recently highlighted the importance of sustainability as a requisite which has to inform structural design since from its concept. In this context, the availability of self-healing technologies, by controlling and repairing early-stage cracks in concrete structures where possible, could on the one hand prevent permeation of driving factors for deterioration, thus extending the structure service life, and on the other hand even provide partial recovery of engineering properties relevant for the application.

The ability of concrete and cement based materials, as well as of other hydraulic binders such as limes, to self-seal cracks has been "heuristically" observed for about two centuries, as exemplified by the research findings on autogenous healing by Loving [102] and Lauer and Slate [92].

The aforementioned capacity, depending on the age of cracking, crack width, as well as on a significant presence of water, was regarded as a sort of bonus: self-healing was able to counteract the drawbacks of early-age shrinkage cracking in certain types of structures, such as tanks and reservoirs, which, thanks to the presence of water, experience favourable conditions of exposure.

Though more systematic studies were carried out all along the second half of the last century (see, e.g., [66], the topic has been gaining continuously increasing interest in this last decade. On the one hand this is due to the increased durability problems which have been observed in existing concrete structures, which require repair. The available repair solutions are expensive and can cause a lot of inconvenience when infrastructure has to be closed down. Therefore, there has been a growing interest in alternative, preventive measures. On the other hand, the interest in self-healing cement based construction materials is steered by