Construction and Building Materials 170 (2018) 418–423

Contents lists available at ScienceDirect

Construction and Building Materials

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

A preliminary study on capsule-based self-healing grouting materials for grouted splice sleeve connection

Yun-Lin Liu [a], Yan-Shuai Wang [b,*], Guohao Fang [c], Yazan Alrefaei [b], Biqin Dong [d], Feng Xing [d]

[a] School of Civil Engineering, Anhui Jianzhu University, Hefei, China
[b] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[c] University College London, Department of Civil, Environmental and Geomatic Engineering, London, United Kingdom
[d] School of Civil Engineering, Guangdong Province Key Laboratory of Durability for Marine Civil Engineering, Shenzhen University, Shenzhen, China

HIGHLIGHTS

- A capsule-based grouting material is conceived for crack self-healing.
- Less than 3% capsules imposed a marginal influence on engineering requirements.
- Free water is absorbed by the capsules to lower flowing property.
- Capsules may form weak zones in grouting materials.
- A pull-out test was performed to assess the healing effect.

ARTICLE INFO

Article history:
Received 9 January 2018
Received in revised form 5 March 2018
Accepted 10 March 2018

Keywords:
Splice sleeve connection
Grouting material
Self-healing capsule
Flowing property
Ductility

ABSTRACT

Grouted splice sleeve connection is a crucial component in modular/prefabricated building structures. However, the reliability (e.g., crack-induced durability issues) of the grouting materials in the splice sleeve connection during their service life is hardly assessed. The external maintenance strategy is usually unimplemented. A capsule-based grouting material was considered in this paper to prolong the service life of the connection through self-healing micro-cracks induced by mechanical force (e.g., seismic and wind load). The influences of capsules on the grouting material in terms of flowing property, compressive strength and porosity were investigated in this paper. The morphological features of the capsule, as well as its status in uncracked and cracked (i.e., failed and triggered) grout matrix, were characterized by scanning electron microscope (SEM). The experimental results revealed that adding no more than 3% capsules into the grouting material can meet the engineering requirements of flowing property (i.e., more than 300 mm in the initial time and more than 260 mm at 30 min) and compressive strength (i.e., over 35, 60 and 85 MPa at 1-day, 3-day and 28-day, respectively). Excessive dosage of capsules added to the grouting materials increased the porosity of the matrix. The pores ranging from 100 nm to 500 nm were significantly influenced due to poor hydration (free water absorbed by the capsule), whereas the relatively large pores (>200 μm) formed weak zones in the matrix. The self-healing effect of the capsule on the splice sleeve connection was assessed by a preliminary pull-out test. It was found that the overall ductility of the connection system could be improved after self-healing for the crack-induced damage of the grouting materials.

1. Introduction

Precast concrete structures have gained worldwide popularity. The prefabricated concrete components can be assembled on site rapidly compared to the conventional concrete structures [1–4], which reduces the labor cost and the construction time. Thus, the prefabricated concrete structure delivers the need of a high-efficient, energy-conserving and eco-friendly construction industry. Currently, some relatively new materials (e.g., geopolymer with low carbon footprint [5–8]), which are difficult to be implemented in-situ due to the complex raw materials and mix proportion, might be used in prefabricated precast concrete structures. Because the properties of the concrete members made from these materials could be optimized in prefabricated factory before use.

* Corresponding author.
E-mail address: yanshuai.wang@connect.polyu.hk (Y.-S. Wang).

https://doi.org/10.1016/j.conbuildmat.2018.03.088
0950-0618/

To facilitate the installation of precast segments, rebar connections, such as the grouted rebar splicing sleeve connection system, is widely implemented. This splicing technique usually employs a non-shrinking high early strength cementitious grouting material as a load-transfer medium. Such a connection system is securely required to join the loose precast components together to ensure the structural integrity and reliability, as well as to anchor the rebar embedded in the sleeve to inhibit its pull-out failure. However, the concentrated damage (e.g., crack and slip) always accumulates in this connection area [9–11]. According to a typical bond stress-slip relationship shown in Fig. 1, the failure mode of a grouted connection can be empirically described as three stages. Generally, no obvious cracking occurs at the first stage, where the adhesive and frictional resistance between the grouting materials and the internal wall of the sleeve are dominant in the connection system. Cracks initiation in the grouting materials, due to wedging action of the ribs in the connection, will cause more slippage, which will activate the second stage consequently. These cracks may downgrade the reliability of the precast structures connected using such a system, then followed by an irretrievable structural failure in the third stage if no adequate confinement is provided.

Recently, a capsule-based self-healing technology was proposed to create a built-in capability to repair structural damage autonomically or with minimal help of external stimuluses [12]. Current researches focus on the triggering mechanism (including mechanical triggering system, chemical triggering system, and microbial triggering system [12]) of the self-healing materials. A representative mechanical mechanism was proposed by White [13] and later developed and modified by Rule [14]. The microencapsulated monomers (liquid dicyclopentadiene) and wax microspheres containing Grubbs' catalyst were dispersed in advance in a fiber-reinforced polymer composite [13,14]. An autonomic self-healing may be activated when the matrix damage (e.g., cracks) ruptures the capsules to release monomer into the crack zone, in which the liquid dicyclopentadiene polymerizes in the presence of catalyst and provides structural continuity across the crack plane. Recently, this concept was implemented in concrete materials to evaluate the damage repair capability of such capsule-based self-healing technique [15,16]. The chemical triggering system, demonstrated by Dong and his co-workers [17–21], has been proven to be feasible in corrosion protection. Microbial triggering system mainly depends on bacteria which generate calcium carbonate precipitation to seal micro-cracks in the concrete materials [22,23]. However, such bacteria usually need some survival requirements for metabolism (e.g., carbon source, pH environment) in order to function properly.

This manuscript proposes a built-in crack sealing concept in the grouted splice sleeve connection to prolong its service life through a capsule-based mechanical triggering system. It is expected that the capsule-based self-healing system can be activated during the crack propagation at the failure stage. As shown in Fig. 1 (healing process), a crack-pierced capsule releases its healing agent into cracking area to mitigate (even stop) crack development. The released healing agent reacts with the embedded hardener via polymerization to form a hardened polymer matrix that seals the cracked zones to maintain structural continuity. Thus, the slippage in the third stage (Fig. 1) (e.g., ductility) may be improved. Dong et al. [21] suggested that the recovery of the concrete performance (e.g., permeability and mechanical properties) could be obtained using self-healing capsules, but the high cost of the capsules discouraged their large-scale application. However, the dosage of the grouting materials injected in splice sleeve connection for prefabricated concrete structures is relatively marginal. Additionally, the cracked grouting material inner sleeve connection cannot be externally repaired and detected. Therefore, these limitations create a suitable condition where the capsule-based self-healing is possible in the grouted sleeve connection. Considering the engineering requirements and standards of the grouting materials (e.g., excellent workability and injectability, high strength and density), this paper mainly revealed the influences of the capsules on the cementitious grouting material in terms of flowing property, compressive strength and porosity before use in connection, and characterized the uncracked and cracked features capsule-based grouting materials. A preliminary pull-out test was performed on coupling sleeves grouted by the capsule-based grouting materials to assess their mechanical responses and self-healing effects. The healing efficiency (e.g., strength and density recovery or upgrade) will be elaborated in the next project.

2. Experimental details

The capsules used in this research were synthesized using urea-formaldehyde (molar ratio of urea/formaldehyde = 1:1.5) as a shell material and epoxy resin (type E-51) as a core material by means of in-situ polymerization procedure. A hardening agent (MC-120D) was premixed with the cementitious grouting materials. As shown in Refs. [21,24], the microcapsules were fabricated with a mean diameter of 173 μm. The commercially available grouting materials used in this study were provided by Sievert Quick-mix (Hefei) Co. Ltd. The nominal performance of the grouting materials was in compliance with Chinese Industry Standard (JG/T 408-2013) [25]. The capsules contents used in this research were 0, 1%, 3%, 5% and 8% by the mass of grout with a water-to-grout ratio of 0.13 [26]. The capsules and water were uniformly mixed together by an ultrasonic dispersion technique, and the grouting material was added gradually during mixing to form a well homogenous

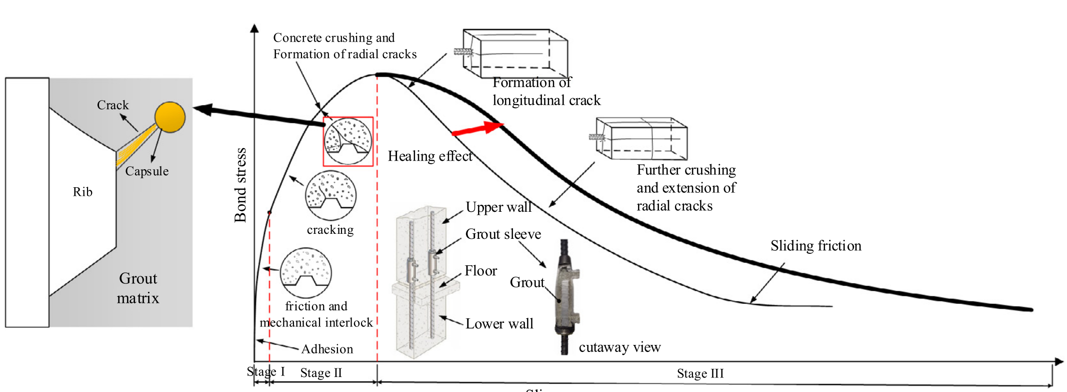

Fig. 1. Self-healing mechanism of grouted connection during a typical bond stress-slip process.