THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
國家鋼結構工程技術研究中心香港分中心
Chinese National Engineering Research Centre For Steel Construction (Hong Kong Branch)

Address: Hong Kong Polytechnic University, Phase 8, Hung Hom, Kowloon, Hong Kong.
Telephone: (852) 3400 8451 Email: cnerc.steel@polyu.edu.hk Website: https://www.polyu.edu.hk/cnerc-steel/

Project Title:

Corrosion mechanism of steel bars in nano-modified cement-based materials

Principal Investigator: **Prof. C.S. Poon (CEE)**

Project Team Members: **Dr. H.B. Zheng**

Project Outline:

Recently, nano-scale cement based materials was reported as the next ground-breaking development for concrete structures. Many kinds of nano materials, nano-silica (NS), nano-alumina (NA), carbon nanotube (CNT), carbon nanofiber (CNF) etc., have been studied for possible application in concrete. These nano-materials with ultra-high specific area might exhibit a) nucleation effect, b) filling effect and c) bridging effect (for CNT and CNF) in concrete. Therefore, these nano materials might serve as effective admixtures in concrete for corrosion inhibition, and the application of nano-materials would also be a potential novel corrosion-prevention method to extend the service life of concrete structures in aggressive environments. However, studies about the influence of nano materials on the corrosion of steel bars in concrete are rather rare.

Four aspects of studies will be conducted, which would offer a systematic knowledge of the corrosion of steel bars in nano-modified cement based materials. a) corrosion resistance (durability) of nano-modified cement-based materials. b) passivation of steel bars in nano-modified materials. c) determination of chloride threshold value (CTV) of steel bars. d) monitoring of corrosion propagation of steel bars in nano-modified concrete.

Objectives:

The aim of this project is to understand the influence of the nano-materials on the corrosion of steel bars in concrete, revealing the corrosion mechanism of steel bars in nano-modified cement based materials. There will be great significance for understanding the application of nano materials in reinforced concrete and the behavior of steel reinforcement in high performance reinforced concrete.

Expected deliverables:

By the end of the project period, at least 2 journal papers will be submitted for publication/published.

(a) Progress made during the reporting period

Progresses on the 1st and 2nd parts of the work have been made:

- the durability of the nano-silica modified concrete has been studied by electrochemical experiments in cement pastes and cement mortars.
- The passivation of the galvanized steel bars in cement mortars has been studied by conducting related experiments.

The detailed contents are as following:

The present study aims to investigate the influence of nano-silica on the dynamic passivation process of the galvanized steel bars in concrete. The focus was placed on the synergistic effects of using nano-silica and galvanized steel bars simultaneously on the prevention of deterioration of reinforced concrete structures in aggressive environments. Our previous work had proven that the passivation process of galvanized steel bars in solutions simulating different concrete environments with supplementary cementitious materials (SCMs) varied significantly. Hence, the experimental work conducted in this work also provided further insights into the dynamic passivation processes of the galvanized steel bars in a real concrete environment from the perspective of cement hydration.

To achieve the objective, two parts of work were conducted: (a) the dynamic variation of the internal environment of the mortar: the variation of the hydration products $Ca(OH)_2$ concentration was determined by thermogravimetric analysis, the calcium ion concentration of the pore solution in mortar was obtained by using inductively coupled plasma atomic emission spectroscopy and the pH value of the pore solution was also tested. (b) the passivation process of galvanized steel bars in cement mortar: the electrochemical tests, such as open circuit potential (OCP), linear polarization resistance (LPR), electrochemical impedance spectroscopy (EIS) and the potentiodynamic polarization (PP), were conducted. In addition, scanning electron microscopy (SEM) and dispersive X-ray energy spectroscopy (EDS) were also used to characterize the surface

morphology and chemical composition of the passive film formed on the surface of the galvanized steel bars.

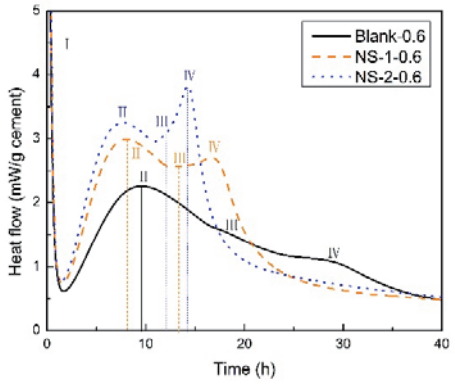

Fig. 1. Heat flow of the cement paste with and without nano-silica as a function of time.

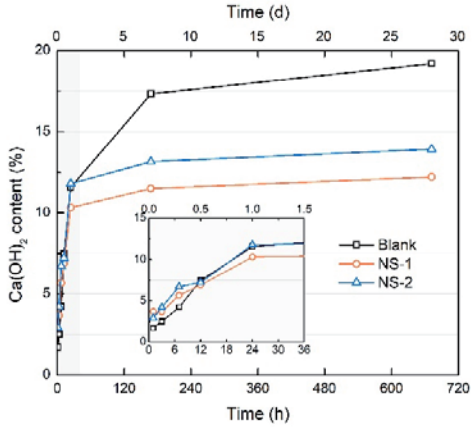

Fig. 2. $Ca(OH)_2$ concentrations calculated from thermogravimetric analysis as a function of time.

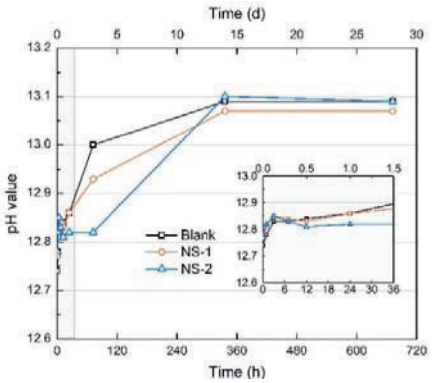

Fig. 3. pH values of the cement pore solution as a function of time.

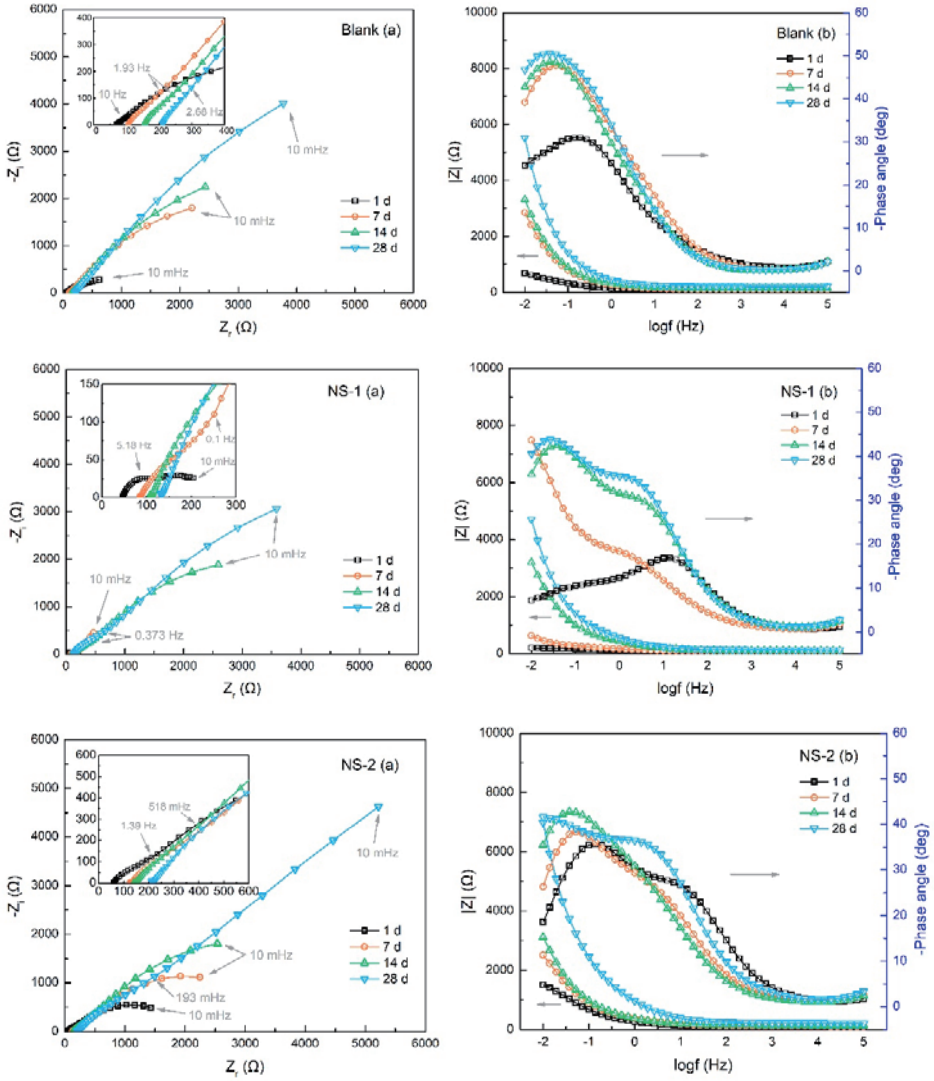

Fig. 4. Nyquist plots (a) and Bode plots (b) of galvanized steel bars in mortar with and without nanosilica at different times.

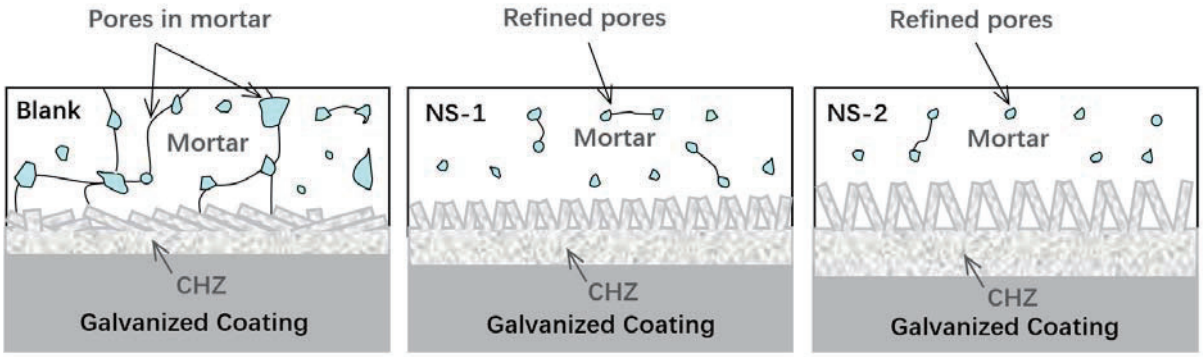

Fig. 5. Models of rebar/mortar interface in mortar with and without nano-silica.

(b) Scope of investigation undertaken

The investigation undertaken included the studies on the durability of nano-modified cementitious materials and the passivation of the steel bar in nano-modified cementitious materials.

(c) Significant results achieved

- nano-silica accelerated the hydration rate of the cement paste at early age and thus the Ca^{2+} concentration and the pH value of the pore solution varied significantly, which are the two main influential factors affecting the dynamic passivation process of the galvanized steel bars in concrete.
- the initial corrosion process of the galvanized steel bars was influenced by the nano-silica during the very early age and the passive film formed in the mortar prepared with nano-silica was much thicker and more compact than that formed in the mortar without the nano-silica. The stability and the protective properties were enhanced by adding nano-silica. The galvanized steel bars showed good compatibility with the nano-silica with respect to the corrosion resistance for the concrete structure.
- the passive film formed in the mortar without nano-silica was attached firmly to the galvanized coating surface and mainly formed after the setting of the cement paste. The morphologies of the passive films formed in the mortars with nano-silica were different and the passive film was mainly formed prior to the setting of the cement paste.

(d) Summary of objectives addressed/ achieved

- Have the objectives of the project been changed/ revised since the last report? If so, why?

The objectives of the project have not been changed.

- How many objectives have been pursued, and to what extent has each objective been achieved? (Express as a percentage.)

Two of the four objectives have been pursued and 80% of them have been achieved.

(e) Difficulties encountered and variations from the original plan of the project proposal, with reasons

Not all the nano materials could be successfully used in the concrete to improve the corrosion resistance of the whole reinforced concrete, due to the detrimental effects on the concrete matrix caused by the additives (e.g. dispersant) in the commercial nano materials.

(f) Work expected to be performed in the remaining period of the project

According to the results of our recent wok, the passivation of the galvanized steel bar in concrete with the addition of nano-silica was enhanced, which is beneficial to the overall corrosion resistance of the galvanized reinforced concrete members. However, the corrosion behavior of the traditional carbon steel in nano-modified cementitious materials was not studied, which is more critical for the knowledge of the corrosion mechanism of the reinforced concrete structures. Therefore, the passivation of the traditional carbon steel bars in nano modified cementitious materials will be conducted.

(g) Outcomes

H. Zheng, J. G. Dai, C. S. Poon. Dynamic Passivation Process of Galvanized Steel bars in Cement Mortars Prepared with Nano-silica [J], Cement & Concrete Composites. **(Under review)**