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Durability, Service Life, and Long-Term Integrity of Concrete Materials, Bridges, and Structures

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Editors:
Yail J. Kim, Chris P. Pantelides, and Xianming Shi

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Durability, Service Life, and Long-Term Integrity of Concrete Materials, Bridges, and Structures

Durability is one of the most important requirements for built-environments. Federal, state, and local agencies expend significant effort to maintain the quality and condition of aging civil infrastructure, especially in aggressive service environments. Among many factors, durability influences the service life, integrity, and reliability of concrete materials and structures. Extensive research has been conducted to understand the deterioration mechanisms of concrete in an effort to extend the longevity of concrete members. This Special Publication (SP) contains nine papers selected from three technical sessions held during the virtual ACI Fall Convention in October 2021. Emphasis is placed on durable reinforcing schemes, service life prediction, structural integrity, repair and retrofit, corrosion mitigation, inspection techniques, and the application of state-of-the-art construction materials. All manuscripts were reviewed by at least two experts in accordance with the ACI publication policy. The Editors wish to thank all contributing authors and anonymous reviewers for their rigorous efforts. The Editors also gratefully acknowledge Ms. Barbara Coleman at ACI for her knowledgeable guidance.

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Axial Compression Capacity of Concrete Columns Reinforced with GFRP and Stainless Reinforcement

J.W. Wright and C.P. Pantelides

Synopsis: Axial compression performance of concrete columns reinforced with GFRP bars and spiral, 2304 duplex stainless bars and spiral, and 316L stainless clad bars, in varying combinations is examined after exposure to accelerated corrosion. The hybrid columns were reinforced with a combination of metallic and GFRP reinforcement. After corrosion exposure the columns were tested under axial compression to failure. Columns with GFRP vertical bars and stainless steel spiral were less corrosion resistant and had smaller axial load capacity than hybrid columns with stainless clad or stainless steel vertical bars and GFRP spiral. Columns reinforced with stainless steel spiral achieving two to three times the maximum axial displacement of columns with GFRP spiral. Axial compression capacity of hybrid columns in both corroded and uncorroded conditions was modeled using concrete confinement models for metallic and GFRP reinforcement with good agreement.

Keywords: carbon steel, columns, concrete, corrosion, glass fiber reinforced polymer, stainless clad, stainless steel.

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INTRODUCTION

Reinforced concrete structures are susceptible to corrosion-induced damage; exposure to de-icing salts or saltwater causes chlorides to penetrate concrete and accelerate corrosion of the reinforcing steel. Corrosion-resistant reinforcement includes stainless steel, stainless clad reinforcement with a carbon steel core and stainless cladding, and glass fiber reinforced polymer composite (GFRP) bars. The upfront material cost of corrosion-resistant reinforcement is greater than carbon steel, but increase in service life and decrease in maintenance and repair costs could offset the initial investment. Duplex stainless steel with a dual-phase austenitic and ferritic microstructure, and reinforcement with a carbon steel core and outer austenitic stainless steel cladding have the potential to resist corrosion much longer than carbon steel or epoxy coated bars [1]. An economical option for reinforcement is 2304 stainless steel (alloy including 23% chromium and 4% nickel); this material has higher corrosion resistance than carbon steel and lower cost than alternative stainless and stainless clad options [2]. Stainless clad reinforcement performs similarly to solid stainless, with 0.25 mm to 0.80 mm thick 316L austenitic stainless cladding providing the best performance [3].

GFRP composites do not experience electrochemical corrosion although other environmental factors such as moisture, temperature, pressure and acidity can affect bar tensile strength or degrade the resin matrix. GFRP bars encased in concrete are projected to retain over 70% of their tensile capacity, even after continual submersion in tap and salt water for a 100-year service life [4]. Chloride-driven degradation in GFRP bars has been explored and found to be insignificant [5]. GFRP reinforced concrete columns immersed in distilled water and chloride saturated water had superior retention of long term capacity compared to carbon steel [6]. Hybrid columns with carbon steel vertical bars and GFRP spiral had favorable corrosion behavior compared to all-carbon steel columns [7]. GFRP spiral in confinement exhibits different behavior than steel due to its comparatively low modulus of elasticity; analytical models can predict its performance when used for concrete confinement [8].

This research compares the performance of corrosion-resistant materials in an accelerated corrosion test and mechanically, using medium scale column specimens containing various combinations of GFRP and 2304 stainless-steel bars and spiral, and 316L stainless clad vertical bars. A set of columns using GFRP vertical bars and GFRP spiral was also tested for comparison. The columns were subjected to 60 days of accelerated corrosion. Qualitative effects of corrosion such as spalling and cracking were compared. Theoretical mass loss was calculated using Faraday's law based on recorded current. The columns were tested under axial compression to failure, and their axial compressive strength and displacement capacity were compared; in addition, these tests allowed examination of the degree of corrosion of the reinforcement. The axial compressive capacity of corroded and uncorroded columns was determined using theoretical models developed by Mander et al. [9] and Hales et al. [8]; the axial capacity obtained in the experiments was compared to the theoretical axial capacity.

The primary objective of this study was to investigate how 2304 stainless steel, 316L stainless clad bars and GFRP bars and spiral are affected by corrosion. The effect of corrosion on the axial compression capacity of medium-scale columns in axial compression when reinforced with 2304 stainless steel and GFRP bars and spiral, and 316L stainless clad bars in varying combinations was a second objective. Axial compression capacity of the columns in both the corroded and uncorroded conditions was also modeled using concrete confinement models for metallic and GFRP reinforcement.

RESEARCH SIGNIFICANCE

Research on concrete columns reinforced with a combination of metallic and non-metallic corrosion-resistant reinforcement is rare. In this research, corrosion performance and axial compression capacity of medium-scale concrete columns reinforced with combinations of corrosion-resistant reinforcement was investigated. The materials studied include 316L stainless clad bars, 2304 duplex stainless steel bars and GFRP bars and spirals. The effect of corrosion on the axial compression capacity of medium-scale columns in axial compression when reinforced with 2304 stainless steel and GFRP bars and spiral, and 316L stainless clad bars in varying combinations is examined. Axial compression capacity of the columns in both the corroded and uncorroded conditions is predicted using concrete confinement models for metallic and GFRP reinforcement.