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A preliminary study of reactive powder concrete as a new repair material

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Abstract

This study aims to use reactive powder concrete (RPC) as a new repair material and evaluate its bond durability to existing concrete. One accelerated aging environment, namely a freeze–thaw cycle acceleration deterioration test, was selected for the evaluation of bond durability of the repair materials. Before and after aging, the samples were evaluated by the compressive strength, bond strength (slant shear test), steel pull out strength, and relative dynamic modulus NDT tests. The test results show that the RPC displays excellent repair and retrofit potentials on compressive and flexure strengthening and possesses high bond strength, dynamic modulus and bond durability as compared with other concretes. The adhesion between the RPC and the steel is also much greater than that for the other concretes. It would be interesting to verify the consequences of this improved adhesion and repair in reinforced concrete structures.

Keywords: Repair material; Retrofit; Bond strength; Freeze–thaw; Reactive powder concrete

1. Introduction

In the modern age, a highly developed infrastructure is essential for economic growth and prosperity. Many structures essential to this infrastructure, especially those made of reinforced concrete, have suffered severe degradation since their construction due to the combined effects of deicing salts, freeze–thaw cycles, aggressive environments, and drastically increased live loads. One of the major problems facing the civil engineers of today is to preserve, maintain, and retrofit these structures [1].

Repair, rehabilitation and strengthening of several structures are currently being undertaken in Taiwan. Some of these structures were damaged by the recent Chi–Chi earthquake. Enforcement of new seismic code provisions for structures in Taiwan also requires major retrofitting work. The repair and strengthening techniques includes enlargement of concrete cross-section, strengthening by bolted steel plates and fiber reinforced plastic (FRP) sheets [2,3].

The majority of concrete structures that require strengthening or rehabilitation are exposed to severe environmental conditions. Many of these severe circumstances are the result of cold climate conditions such as low temperature, freeze–thaw action, and exposure to deicing salts. Because of this, the environmental durability of both the repair materials and methods used in rehabilitation applications are of utmost importance, especially in aggressive climates such as those found in North Asia and North America [3].

Selecting repair materials for concrete structures requires an understanding of material behavior in the uncured and cured states in the anticipated service and

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exposure conditions. One of the greatest challenges facing the successful performance of repair materials is their dimensional behavior relative to the substrate. Relative dimensional changes cause internal stresses within the repair material and within the substrate. High internal stresses may result in tension cracks, loss of load-carrying capability, delamination or deterioration. Particular attention is required to minimize these stresses and to select materials that properly address relative dimensional behavior [4].

However, very little research has been performed in evaluating the environmental durability of different repair materials for concrete members. Very little work has been done on the effects of freeze–thaw cycling on bonding and repair materials. Green et al. [1] conducted durability tests on the bond between FRP and concrete, and found that the bond was not significantly damaged up to 300 freeze–thaw cycles. Lee and Wang [5] stated that the mechanical properties of reactive powder concrete showed high strength, toughness, and bonding strength. The characteristics of regular concrete (RC), high performance concrete (HPC) and RPC are shown in Table 1. The RPC displayed excellent repair and retrofit potentials. The improved properties of RPC are achieved by the following methods [5,6]:

(1) Improvement on the material homogeneity by removing all coarse aggregates.
(2) Increase of the compactness by granular optimization and compaction.
(3) Possible improvement of the microstructure by heat treatment.
(4) Achievement of material ductility by the addition of steel fibers.
(5) Reducing the amount of water in the concrete.
(6) Extensive use of highly refined silica fume.
(7) Optimum chemistry of all components [3,5].

The RPCs have a remarkable flexural strength and very high ductility; their ductility is greater than 250 times that of conventional concrete [7,8]. Their extremely low porosity gives them low permeability and high durability, and makes them potentially suitable for being used in a new technique for retrofitting reinforced concrete structures [9].

The main aim of the work presented here is to assess the performances of RPC, as a new repair material and to evaluate the strength and durability of its bond to existing reinforced concrete.

Table 1
Characteristics of RC, HPC and RPC [5,6]

Characteristics	RC	HPC	RPC
Compressive strength (MPa)	10–40	60–100	170–230
Flexural strength (MPa)	3–6	6–10	30–60
Elastic modulus (GPa)	30–35	35–45	50–60

2. Experiments

Freezing and thawing tests on concrete specimens are carried out in the laboratory to evaluate reactive powder concrete as a new repair material for concrete structures and the strength and durability of its bond on existing structures.

2.1. Materials

Two cement-based repair materials which were used as references in this study are representative of normal strength concrete and a high strength repair mortar. The regular concrete (RC) has a compressive strength of 30 MPa, contains no admixture and yields a slump of 150 mm. The non-shrinkage high strength mortar (HSM), is a prepacked repair mortar, contains 10% silica fume, its compressive strength and low water cement ratio assures good durability. The mix design of regular concrete (RC) and high strength mortar (HSM) is shown in Table 2.

The RPC to be used as a prospective repair material, contains a type II cement, silica fume, silica sand, quartz powder, steel fiber and a superplasticizer. The mix design of the RPC repair material is also shown in Table 2.

2.2. Accelerated experimental procedure

The bond strength and bond durability of three repair concrete and mortar RC, HSM and RPC was evaluated to old concrete. One accelerated aging environment, namely the freeze–thaw cycle acceleration deterioration test, was selected for the evaluation of bond durability of repair materials. Freeze–thaw cycling of all specimens was conducted using the cold climate testing facilities at Chaoyang University of Technology. Freeze–thaw cycles were applied to the blocks at a rate of one cycle per 185 min, in accordance with ASTM C666 (1997), with 90 min of freezing in cold air at −18 °C followed by 9 min of thawing in cool air at +4.4 °C. Specimens that were not subjected to freeze–thaw cycling were stored in the material testing laboratory by immersing in saturated lime water for 24-h prior to testing. The specimens were subjected to 0, 300, 600, or 1000 freeze–thaw cycles, with three specimens for each of these cycles.

Before and after freeze–thaw cycling, the samples were tested for their abrasion coefficient, compressive strength, bond strength (slant shear test), steel pull out strength, and relative dynamic modulus.

2.3. Test specimens

The strengthening specimens are flexural beam and compressive cylinder concretes, with two specimens for flexural or compressive strengthening tests. The