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Experimental study of geopolymer used as adhesive in anchorage of steel bars

Jiang-Xia Quan[a], Hai-Yan Zhang[a, b*], Le-Yuan Zhou[a], Yue Zhou[a], Jia-Wen Su[a]

[a] *Department of Civil Engineering, South China University of Technology, Guangzhou, P.R. China*

[b] *State Key laboratory of Subtropical Architecture Science, South China University of Technology, Guangzhou, P.R. China*

Abstract

Pull-out tests were performed on 42 post-installed steel bars embedded in two large concrete substrates. Three types of adhesive agent, including commercial available organic adhesive (Hilti HiT-Re), inorganic geopolymer paste and geopolymer mortar were used to bond the post-installed reinforce bars, with different embedment length (5d, 8d, 10d, 12d and 15d, where d is the diameter). Data from the pull-out tests is utilized to compare the bond performance of the three types of adhesive agent and determine the optimum embedment depth of rebars when using geopolymer paste and geopolymer mortar as adhesive. The test results showed that the failure modes of the post-installed rebar system changed from concrete cone failure to combined failure or even rebar fracture failure, with an increase in the rebar embedment depth. When the embedment length of post-installed rebars was less than 10d, the specimens bonded with organic adhesive exhibited the best bond performance, and which were followed by those bonded with geopolymer mortar. And the specimens bonded by geopolymer paste exhibited the lowest bond strength. However, for specimens with rebar embedment depth higher than 10d, the anchoring behavior of three types of adhesive was similar.

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Keywords: Pull-out test; Geopolymer; Organic adhesive; Post-installed rebar;

* Corresponding author Tel.: +86-20-8711 1030;
E-mail address: zhy116107@163.com

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1. Introduction

Post-installed reinforcing bars are found increasing application in the addition or connection of new structural elements to other already existing structures, for structural strengthening and retrofitting. The anchor behavior of post-installed reinforcing bars is dependent on the bond capacity of structural adhesive. Organic adhesive, usually synthetized with polyester, vinylester and epoxy, is popularly used for bonding post-installed reinforcing bars [1], but its weak high temperature performance and higher cost limit its application. Cement-based inorganic adhesive exhibits better high temperature performance than organic adhesive, but a great amount of carbon dioxide (CO_2) is released during cement clinker production, which leads to the aggravation of global greenhouse effect. It is reported that the CO_2 emissions of cement production worldwide accounts for roughly 8% of global CO_2 emission [2].Therefore, there is a necessity for developing a kind of green structural adhesive, with high mechanical property and good high temperature behavior, but with lower cost.

Geopolymer, named by Davidovits [3, 4], is usually synthesized by alkaline solution (such as NaOH and KOH) activating aluminosilicate source material. Metakaolin (MK) with lower calcinations temperature or industrial waste materials like fly ash (FA), slag and rise husk ash, are commonly chosen as aluminosilicate source material. Therefore, the production of geopolymer exhibits lower carbon dioxide emission and lower energy consumption. In addition, geopolymer is regarded as a promising alternative of cement due to its excellent properties, such as low shrinkage, quick concretion, high early compressive strength, and good fire resistance [5-7]. Recently, the bond property of geopolymer has attracted researchers' attention. Hu et al. [8]found that geopolymeric or geopolymeric containing steel slag binder used as repair material exhibits better bond strength than cement-based repair materials. Smith et al. [9] showed that the geopolymer paste, which used rice husk and bark ash incorporating lignite fly ash as starting material, possess higher bond strength than commercial bonding agent by 1.24-1.81times. In authors' work [10, 11], metakaolin-fly ash based geopolymer exhibited good bond strength and comparable compressive strength with ordinary cement both at ambient temperature and after exposure to elevated temperature.

In the current study, three types of adhesive agent including commercial available organic adhesive (Hilti HiT-Re), inorganic geopolymer paste , geopolymer mortar, were used for anchorage of post-installed reinforcing bars in concrete substrates, with different embedment length. The main objective is to compare the bond performance of the three types of adhesive agent and determine the optimum embedment depth of rebars using geopolymer paste and geopolymer mortar as adhesive.

2. Test program

2.1 Raw materials

2.1.1Binder materials

Geopolymer paste used in this study is derived by MK, FA, alkaline solution (KOH). Commercially produced MK with an average particle size of 0.017 mm was supplied by Shan xi Jinkunhengye Ltd, China, through calcified kaolin under 900C. Low calcium FA, with an average particle size of 0.032 mm, was supplied by Guangzhou Huangpu Power Plant. The chemical composition of MK and FA can be referred to reference [10]. Potassium silicate solution with SiO_2/K_2O molar ratios of 1.0 was used as alkaline activator. Geopolymer mortar is manufactured through mixing geopolymer paste and fine aggregates. The fine aggregate is local river sand with a maximum size of 1 mm. The mix proportions of geopolymer paste (GP) geopolymer mortar(GM) are tabulated in Table 1.

Table1. Mix proportion of GP and GM

Group	MK	FA	Potassium Silicate Solution	Sand
GP	350	350	636.3	—
GM	350	350	636.3	2290.8

Hilti HiT-Re500, a kind of high strength organic adhesive, was used as a reference for evaluating bond strength of GP and GM. The main component of Hilti HiT-Re500 is: epoxy resin and hardener amine base.