International Journal of Sustainable Built Environment (2016) 5, 176–182

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International Journal of Sustainable Built Environment

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Original Article/Research

Thermal properties of sand modified resins used for bonding CFRP to concrete substrates

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Received 27 January 2016; accepted 7 March 2016

Abstract

This study is an experimental investigation about the thermal properties of adhesive before and after mixing with fine sand. The results show that such an addition significantly improves the thermal characteristics, such as reducing the initial and the final shrinkage, reducing the heat of the reaction, coefficient of linear expansion, and the coefficient of the thermal conductivity. Also, such an addition leads to a reduction in the adhesive cost and a small increase in the compressive strength and the modulus of rupture. The ratio of the fine sand to the adhesive equal to 1 is considered the best in terms of the cost reduction, maintaining workability, as well as maintaining the mechanical properties.

Keywords: Concrete; Epoxy; FRP; Sand; Thermal

1. Introduction

The high strength-to-weight ratio, electro-chemical corrosion resistance, and orthotropic properties of fiber-reinforced polymer (FRP) have made them attractive to civil engineers, faced with deteriorating infrastructure. Fiber wrapping is perhaps one of the most successful applications of FRP, simply because the strength enhancement is accompanied by a considerable cost savings over the traditional retrofitting alternatives (Mirmiran et al., 1999).

Epoxy adhesive is used to paste the fibers on the concrete or steel, and is available in several types according to the manufactures. It usually consists of two parts, the first is called "Resin" and the second is called "Hardener". Strengthening the concrete structure with the Epoxy bonded carbon fiber reinforced the polymers "CFRP" has been proven to be a good strengthening technique. However, there are some disadvantages with such a technique, such as diffusion closeness, thermal incompatibility to the base concrete, working environment and the minimum application temperature (Täljsten and Blanksvärd, 2007).

Sen et al. (2001) have studied the effect of the climate in Florida, throughout the year, on the concrete strengthening by the "CFRP". Their work includes the effects of air temperature and the cycles of moisturizing and drying. They have proved that the carbon fiber and the epoxy adhesive are highly resistant to weather conditions.

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2016.03.001
2212-6090/

Gao et al. (2004) have studied the effects of the adhesive properties on the structural performance of the reinforced concrete beams, strengthened with carbon fiber reinforced polymer (CFRP) strips. The Epoxy adhesive which is modified by liquid rubber of different content was used to bond the CFRP strips. Four point bending experiment was carried out on RC beams. The results have shown that the different CFRP strips, 0.22 and 0.44 mm thick, have resulted in a transition of failure mechanism from interfacial debonding, along the CFRP-concrete interface, to concrete cover separation, starting from the end of the CFRP strips in the concrete. Moreover, it is suggested that no matter how the interfacial debonding or concrete cover separation will be, the rubber modifier enhances the structural performance by increasing the maximum-load carrying capacity and the corresponding ductility, compared with the beams, bonded with a net Epoxy resin.

Camata et al. (2007) have studied the effect of exposing concrete models, strengthened by plates of carbon fiber, to heating cycles with temperatures up to 1000 °C. The study has proved that all kinds of used Epoxy have significantly affected the heating cycles.

Klamer et al. (2008) have, also, studied the effect of temperature on the reinforced concrete beams, strengthened by CFRP. Test results have shown that, compared to room temperature, the type of failure and failure load of the beams tested at 50 °C were not significantly affected. At 70 °C, the type of failure changed for one of the beams from failure in the concrete adjacent to the concrete adhesive interface to failure exactly in the concrete-adhesive interface. The failure loads of the beams tested at 70 °C were not significantly affected compared to room temperature, except for the beam with a relatively short laminate length. For this beam, the load capacity is expected to be mainly related to the capacity of the end anchorage zone, which was negatively affected by the effects of the elevated temperature.

Blanksvärd (Blanksvärd, 2009) has used adhesive material consisting of reinforced polymer mortar (Polymer, mortar, superplasticizer, and fibers) instead of epoxy. His experiments have proved that this new adhesive is efficient for the CFRP. But, this material is expensive and difficult to use because of the difficulty to control mixing ratios for many components. Therefore, this adhesive can be used as crack reinforcement in prefabricated concrete elements.

Cabral-Fonseca et al. (2011) have studied the effect of environmental conditions on three different types of epoxy used in strengthening or rehabilitating concrete structures. The models have been immersed in seawater and in alkaline solutions for 18 months at a temperature of 40–60 °C. The mechanical properties and the weight loss of the samples have been measured. The study has proved that the epoxy is greatly influenced by the environmental conditions, being immersed in seawater and alkaline solutions. Büyüköztürk et al. (2012), in turn, have studied the effect of moisture on the cohesion between epoxy and concrete, and the tests have shown that humidity reduces cohesion between the epoxy and the concrete.

Al-Safy et al. (2012) have studied the thermal and mechanical properties of nanoclay-modified adhesives for use in civil engineering applications. Differential Scanning Calorimetry (DSC), X-ray diffraction (XRD) and Transmission Electron Microscopy (TEM) were used to characterize the adhesive structure. The glass transition temperature (Tg), measured by DSC, was found to decrease with nanoclay addition. Measurements from XRD and TEM have identified an intercalated/exfoliated structure of the nanoclay, nanomer I.30E in the epoxy matrix. The adhesive tensile strength showed a reduction with the addition of nanoclay at elevated temperatures. However, improvement in the tensile modulus was found for all nanoclay addition. The bond-loss temperature of CFRP/concrete systems with a modified adhesive was observed to be lower than that for the control (0% NC), using adhesion (pull-off) tests at elevated temperatures. Also these materials were very expensive.

Nguyen et al. (2012) have studied the effects of UV on the bond between steel and CFRP. Specimens (epoxy adhesive, CFRP laminates, and steel/CFRP adhesively bonded joints) were exposed to UV for various time periods while identical reference specimens were exposed to only thermal environments without UV. They have found that the exposure to UV does not influence the tensile strength of CFRP composites. The tensile strength of the adhesive is reduced by 13.9% while modulus has shown a significant increase by 105% after 744 h of exposure. The tensile modulus of adhesive, exposed to only thermal environment, has also increased by 38%, considerably less than that induced by UV exposure. The UV exposure has also led to a decrease in the joint strength. An increase in stiffness is caused by the temperature effect rather than the UV rays.

The present study aims at enhancing the properties of adhesives, used for bonding FRP or others by mixing a well-known adhesive with a cheap material (fine sand). The sand is cheap compared to the price of epoxy which represents almost 2000–3000 times the price of sand. So, the proposed method leads to a large reduction in the cost of the adhesive (sand price consider negligible) in addition to improving their properties. Some mechanical properties and thermal properties for adhesive, with or without fine sand, were mainly investigated to prove the efficiency of this addition which is, in fact, intended to improve the adhesive properties and saving the cost.

2. Experimental works

2.1. Materials

– *Adhesive:* Sikadur®-330 from 330 is used. The properties of the adhesive are shown in Table 1.