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Effect of thermal exposure on the mechanical properties of polymer adhesives

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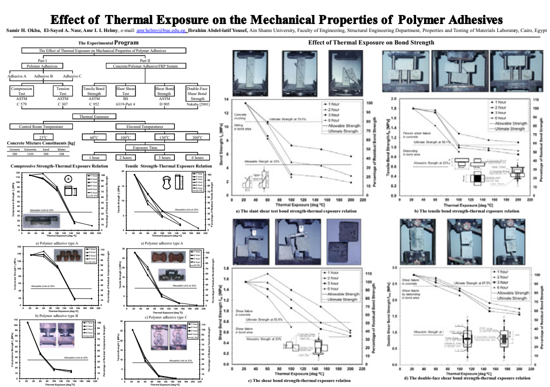
HIGHLIGHTS

- Effect of temperature and time on the mechanical properties of polymer adhesives was investigated.
- Decrease of strength depends on type of polymer, temperature, time and applied stress.
- Effect of temperature and time on the bond strength of concrete/adhesive/FRP specimens was investigated.
- Bond strength was reduced and the mode of failure changed due to temperature, time and increased bond area.

GRAPHICAL ABSTRACT



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ABSTRACT

An experimental research programme was carried out to study the effect of thermal exposure on mechanical properties of three different types of polymer adhesives widely used in the construction industry. All specimens were subjected to 4 different degrees of elevated temperature applied for 4 different exposure times. The compression and tensile strengths, carried out as per ASTM C579 and ASTM C307 respectively, were compared before and after thermal exposure. The majority of deteriorating strengths is due to higher temperature level while most of the deterioration took place after 1 h of exposure time. The decrease of residual compressive and tensile strengths, depends on the type of polymer adhesive, level of elevated temperature, type of applied stress and to a lesser effect on exposure time. The effect of elevated temperature on bond strength using concrete/polymer adhesive/FRP specimens was evaluated using four different test methods namely; slant shear test as per BS 6319 Part 4, tensile bond strength test as per ASTM C952, shear bond strength test as per ASTM D905 and double-face shear bond strength. The residual bond strength was reduced and the mode of failure changed due to the high temperature, prolonged exposure time, type of polymer adhesive and the increase in the surface area of bond.

1. Introduction

Polymer matrix materials differ from metals in several aspects such as their mechanical properties that depend strongly on ambient temperature and loading rate [1,2]. A thermoset resin is a polymer in a viscous state that through curing irreversibly changes into polymer network by crosslinking that yields molecules with a large molecular weight. Thermoset resin usually decomposes before melting and may not be re-shaped after curing. Thus it is one of the best adhesives used in the construction industry due to the three-dimensional network of bonds (cross-linking).

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The fib Bulletin 14 [3] recommends that for outdoor use of externally bonded fibre reinforced plastics EB FRP, if an elevated temperature occurs during service conditions, the glass transition temperature Tg of the adhesive used should not be less than 45 °C and should be 20 °C more than maximum ambient temperature at normal service conditions.

The success of retrofitting and rehabilitation of concrete structures by externally bonded FRP technology critically depends on the performance of the adhesive materials that bonds concrete to composite reinforcement. Bond strength of an adhesive depends on adhesion to the substrate materials, the strength of the adhesive, and the strength of the substrate materials. The bonded joint is only as strong as the weakest link of these three strengths. Concrete element strengthened using EB FRP usually uses thermoset polymers cured at room temperature with low Tg. EB FRP directly exposed [4] without proper protection to fluctuation of surface temperature conditions under the action of service loads are at great risk of deteriorating properties. Compressive strength, tensile strength, bond strength and shear strength of polymer adhesives would be significant measures for the damage effect of elevated temperature exposure on mechanical properties.

EB FRP was investigated as a solution to improve fire problems of concrete elements such as the behaviour of retrofitted RC elements after being subjected to fire [5,6], and the effect of fire and protection materials on structural behaviour of strengthened RC beams [7] and columns [8].

Research works were devoted to the effect of thermal loads such as; thermal effect on concrete cover [9], the effect of environmental conditions [10] and the presence of moisture [11] on adhesive properties, the deterioration effect of thermal exposure on mechanical properties of adhesives [12,13], and the bond strength between concrete and adhesives [12,14]. The effect of thermal degradation of EB FRP-concrete and the bond strength variation of CFRP strengthened concrete members with temperature were investigated [12,14–16]. The effect of cycles of salt fog, temperature and moisture [17], the effect of creep on the permissible shear stress of the interface [18], and the long term properties of FRP-concrete bond [12,14,19] were investigated. A 3D model was developed to predict the behaviour of CFRP–concrete composites under fire [20]. The bond between FRP bars and concrete under thermal cycles through a pull-out test [21] was investigated.

The significance of the research work herein is that it demonstrates factors influencing the damage effect of elevated temperature and exposure time on 3 different polymer adhesives widely used in the construction industry namely; general purpose unsaturated Polyester [1], structural epoxy adhesive [22] and modified epoxy mortar [23], after thermal exposure at 60, 100, 150 and 200 °C and for 4 different exposure times namely 1, 2, 3 and 6 h by measuring the compressive and the tensile strengths, carried out as per ASTM C579 [24] and ASTM C307 [25] respectively, of And measuring the residual strength after exposure at and beyond the glass transition temperature of the bond strength of polymer adhesive used for concrete/polymer adhesive/CFRP wraps system for the same previously mentioned thermal exposure regimes using 4 different test methods namely; slant shear test as per BS 6319 Part 4 [26], tensile bond strength test as per ASTM C952 [27], shear bond strength test as per ASTM D905 [28] and double-face shear bond strength test proposed by Nakaba et al. [29].

2. Experimental

Fig. 1 illustrates a diagram for the experimental programme that consists of two parts as follows.

2.1. Effect of thermal exposure on mechanical properties of polymer adhesives

Three polymer adhesives, commercially available and widely used in the construction industry, were tested in the experimental study namely; general purpose unsaturated polyester [1], structural epoxy adhesive [22] and modified epoxy mortar [23] noted as type A, B and C respectively. The compressive and tensile strengths of the polymer adhesive specimens were measured according to ASTM C579 [24] and ASTM C307 [25] respectively. All standard specimens were cast and cured at ambient temperature at 23 °C for 7 days at a relative humidity of 30%. Then, specimens were subjected to 4 different degrees of elevated temperature namely 60, 100, 150 and 200 °C for 4 different exposure times namely 1, 2, 3 and 6 h. Three specimens were tested for each combination of elevated temperature and exposure time in each test. The specimens were tested outside the oven, immediately after subjected to thermal exposure without being subjected to any cooling regime.

2.2. Effect of thermal exposure on bond strength

It is designed to study the effect of elevated temperature on bond strength of polymer adhesive using concrete/polymer adhesive/CFRP wraps specimens. The polymer adhesive type B was used, that is the compatible polymer adhesive with CFRP wraps [22]. Standard tests were slant shear test according to BS 6319 Part 4 [26], tensile bond strength test according to ASTM C952 [27], shear bond strength test according to ASTM D905 [28], and double-face shear bond strength proposed by Nakaba et al. [29]. All specimens were assembled at 28 days of age of concrete and cured at ambient temperature at 23 °C for 7 days at a relative humidity of 30%. Then, specimens were subjected to 4 different degrees of elevated temperature namely 60, 100, 150 and 200 °C for 4 different exposure times namely 1, 2, 3 and 6 h. Three specimens were tested for each combination of elevated temperature and exposure time in each bond test. The specimens were tested outside the oven, immediately after subjected to thermal exposure without being subjected to any cooling regime.

3. Materials

3.1. Aggregate, cement and concrete

Natural sand, composed mainly of siliceous materials, and crushed Dolomite were used as fine and coarse aggregate respectively in the experimental work. Both constituents were free of impurities and clean from organic compounds confirmed to the Egyptian Standard ES specifications [30,31]. Ordinary Portland cement OPC confirmed to the ES specifications [30,31]. The concrete mix was designed [30] to achieve a target compressive strength of 30 MPa after 28 days with 120 mm slump. The mix proportions for the normal-strength concrete used for the tested specimens are shown in Table 1.

3.2. Polymer adhesives

Table 2 shows the physical properties of three different types of polymer adhesives widely used in the construction industry as stated in the manufacturer's product data sheet. Polymer adhesive type A is general purpose unsaturated Polyester [1] that belongs to a large group of synthetic resin [1]. Polymer adhesive type B [22] is a two-component 100% solid, high modulus, moisture-tolerant, structural epoxy adhesive. Polymer adhesive C [23] is an adhesive mortar, pre-filled medium viscosity and solvent free