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Behavior of EBR FRP strengthened beams exposed to elevated temperature

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Abstract

Externally bonded laminates based on high strength fibers nowadays are often used to strengthen the structures. It is possible, that some of those strengthenings are subjected to direct insolation. The paper presents the dangers appearing with the rise of temperature caused by the infrared solar radiation. Heating conditions were planned on the basis of exposition of concrete samples during the summer months in the southern Poland. The maximum recorded temperatures in the adhesive layer reached 65°C and it was therefore 20°C higher than the glass transition temperature of commercially available adhesives based on epoxy resin. Laboratory tests included a group of fifteen reinforced concrete beams in the real scale, seven of them were strengthened with externally bonded CFRP strip, seven with SRP tape. They were tested in various temperature conditions, from 20°C to 80°C. Beams were heated from the strengthened side with the use of linear infra-red radiators and when the temperature of the adhesive layer reached the predetermined value, beams were loaded to failure. Noticeable impact of temperature appeared from about 50°C. In all cases failure was followed by delamination. Differences in behavior of CFRP and SRP strengthened beams were observed. Delamination of CFRP strip appeared in unexpected way, without any specific symptoms, while SRP failed with grater deflection and lower mid-span strains compared to the beam tested at room temperature. At temperatures above 65°C appears significant bearing capacity degradation. It means that CFRP strengthening, which could be subjected to direct sun exposition, should always be protected by thermal insulation.

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Keywords: FRP composites; bond performance; sun exposition, glass transition

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1. Introduction

Majority of externally bonded fiber reinforced strengthening solutions are based on the polymer systems. Because of the price the most widely used are epoxides. Epoxy polymers are not only adhesives bonding external strengthening with the structure. Usually they are playing a role of matrix of FRP laminate, sometimes also they are applied as a primer for the substrate. One of the drawbacks of epoxides is generally low temperature of glass transition. For commercially available epoxy resins used in structural engineering it could occur around 40÷50°C [1]. Near that temperature epoxy polymer changes its rigid characteristic into a soft and viscous one and therefore the adhesion between the FRP laminate and the strengthened element decreases. For that reason most of EBR FRP solutions are not resistant to elevated temperatures. What is not always obvious, is that the problem concerns not only the fire conditions but may occur after warming by the sun rays. The danger of such situation is associated not only with the loss of bearing capacity, but primarily with the deterioration of strengthening effectiveness resulting from the phenomenon of stress relaxation in the composite after slip in the adhesive layer.

Transition from a solid, glasslike state to a rubberlike or viscous one is a continuous process passing gradually in the range of 10÷20°C [2]. The glass transition temperature of an adhesive depends upon the degree of chemical cure understood as the proportion of potential cross-links formed between polymer chains [3] and the physical configuration of the polymer chains within the adhesive [4].

In practice, the glass transition conditions are dependent upon the age of the adhesive, the temperature and humidity to which it has been exposed. Curing can be accelerated at high temperature, which enables stronger chain cross-linking [3]. Thanks to that phenomenon, the heating can be effective post-curing method, enhancing the glass transition temperature. Optimum cure temperature varies around 60°C [5]. Also dry conditions during curing are important for final glass transition temperature [3] because the moisture content affects the Van der Waals bonds between polymer chains.

Despite the popularization of external reinforcements, knowledge about the decrease of the properties of the FRP–concrete interface at elevated temperatures still is very limited. The rigid glass into liquid transition in practice means the reduction of mechanical properties of the polymer and consequently reduction of adhesion forces between concrete and FRP laminate. Rapid loss of the adhesive bond strength appears in the temperature range of 60°C and 70°C [6]. Double face shear tests provided by Tadeu demonstrated the 55.3% decrease in bond capacity at a temperature of 60°C and 72.2 at 90°C [7]. Bending tests of strengthened concrete beams performed by Aguiar [8] have shown 50% decrease in strengthening efficiency, while at 80°C total achieved capacity was similar to not strengthened beam. Interestingly, at temperatures of about 50°C bond capacity may slightly grow [9, 10]. It may be the effect of secondary curing during heating of the sample.

The decrease of adhesion is also dependent on the type of strengthening overlay. Leone [11] indicated that CFRP laminate behaves a little better than CFRP sheet. Weakening in the adhesive can cause increased deflection of beams. That phenomenon was observed by Ulaga [12] already about 45°C. Another interesting effect is different image of failure. At normal temperatures failure is initiated in the concrete - adhesive interface, leaving small layer of concrete attached to the debonded plate, while at temperatures of 50°C and higher specimen fails without any concrete remained attached to the adhesive [9].

Concluding described researches it can be stated that changes related to glass transition may occur at relatively low temperatures, just above 45°C. As will be shown in the paper such a temperature may occur after several minutes of sun exposition.

Nomenclature

T_g glass transition temperature