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Externally Bonded FRP Strengthening: Effects of Elevated Temperatures and Sustained Loads

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Abstract

Fiber reinforced polymer (FRP) composites are gaining widespread acceptance as an economical way to repair or strengthen existing concrete, masonry, steel, and timber structures. Design guides for the application of FRP composites for strengthening (and repair) have been published by several organizations around the world. Typically, high strength synthetic fibers such as carbon or glass are impregnated with an ambient-curing epoxy resin and attached to the structure on-site. Alternatively, pre-cured composite plates manufactured off-site by the pultrusion process are bonded to the structure using an ambient-curing epoxy. Both of these techniques are rapid by virtue of the light weight and easy handleability of the FRP material, which reduce labor costs and minimize the out-of-service time of the structure. Also, by extending the service life of a functionally obsolete or deficient structure, replacement costs are avoided, including environmental costs related to demolition and replacement. One outstanding issue with FRP strengthening is the long-term durability of the material that connects the stiff, strong fibers to the substrate: i.e., the ambient-cured epoxy. In fact, the organizations that develop guidelines have been wrestling with this issue for the past several years. It is widely known that the degree of cure (chemical cross-linking) and mechanical performance of ambient cured epoxies depends significantly on time along with the ambient temperature and perhaps moisture over the service history. It is also known that the environmental conditions along with applied stress level dictate the time-dependent deformation (creep and relaxation) of the epoxy, which in turn can affect the stress state in the all-important adhesive layer between the FRP and substrate. If debonding of the FRP from the substrate (the typical failure mode) is to be avoided, a better understanding of the implications of sustained loads and environmental conditions on the long-term performance of the strengthening systems is needed. An investigation of the combined effects of elevated temperatures and sustained loads is underway at Penn State, with a focus on a wet-laid carbon/epoxy FRP system bonded to concrete. It has been determined that exposure of the FRP material to moderately elevated temperatures increases the mechanical properties of the epoxy resin not by advancement of cure but, rather, by advancement of physical aging. In turn, it has been observed that the bond strength between the FRP and concrete can increase as well. Thus, it is clear that performance of the strengthening system over extended periods of time is a complicated process governed by physical changes in the epoxy resin and changes in the local stress distributions at the interface between the FRP material and substrate. The full paper will present specific experimental and numerical modeling results behind these observations, and will also suggest avenues for further advancement of our understanding of this important problem.