Influence of moisture and thermal cycles in bonding of FRP laminates on timber elements

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Abstract Durability of composite systems used as strengthening material in timber elements, is a topical issue, especially in the field of preservation and restoration of historical structures. The influence of moisture on the adhesion of composites, before and after application, as well as the effect of thermal exposure, are not clarified yet. Moreover, in the specific field of composites application, standards are still lacking.

In the paper, several experimental procedures, both micro-structural and mechanical, are considered, to measure the effect of moisture and temperature, also combined. Carbon, glass and aramid textiles are applied with epoxy resins on timber samples. Pull-off tests were performed to preliminarily compare the ultimate loads and to check the failure modes. Then, optical microscopy allowed investigating the behavior at wood-FRP interface. Finally, IR spectrometry was used to identify possible modification in the matrix of the strengthening material due to the alteration of the two environmental factors.

Keywords durability, moisture, temperature, FRP, strengthening

Durability of composite systems, as FRP (Fiber Reinforced Polymer) laminates, is a topical issue, especially in the field of conservation and restoration of historical structures. These materials, widely applied for rehabilitation of reinforced concrete and masonry, have recently found application in the reinforcement of timber elements, as floor beams or roof truss. Despite the actuality of the topic, many studies have been carried out, but in this specific field, standards are still lacking.

It is necessary to clarify what are the effects of temperature and humidity (acting either alone or in combination) on the durability of these composite systems. Moreover, it is also important to define the influence of the moisture content of wood on the successful bonding of FRP to the substrate, in order to understand which materials are most appropriate for the reinforcement in different environmental conditions.

To this aim an extensive experimental campaign was planned at the University of Padova (Italy). Carbon (CFRP), glass (GFRP) and aramid (AFRP) textiles applied with epoxy resin (wet-lay-up system) on prismatic specimens made by spruce wood. A total of 225 samples fiber-reinforced and 75 samples un-strengthened were prepared.

After a preliminary evaluation of the state of art, the condition to reproduce in laboratory on the fiber-reinforced specimens were identified.

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In order to understand the behavior of the different materials, both mechanical tests and micro-structural analysis were used. Following ASTM C 1583-04, 600 pull-off tests were carried out. Both ultimate strength and failure modes were compared among the various fibers.
The interface wood-FRP was then analyzed with light microscopy. Finally, IR spectroscopy was used to determine the possible changes in the chemical structure of the resin produced by the treatments. The results show that the different fibers are slightly sensitive to specific environmental conditions of temperature and humidity, although in general the potential expected for these products have been confirmed. It emerged that the moisture content in wood doesn't influence significantly the success of the reinforcement for all fibers. In the samples with GRRP, there are many air bubbles, because of which the reinforcement tends to detach easily from the support. Despite the presence of these voids, that affect the failure mode during pull-off test, the pull-off strengths are comparable to those of the other two fibers. The sections of material obtained from samples in which the fiber have been applied on very wet wood (MC = 40%), are characterized by a reaction layer in which the epoxy resin has a different color.
CFRP and AFRP are very sensitive to cyclical variations in temperature and humidity. High temperatures have an effect on all fibers, in particular it was noted that temperature higher than 80° C provokes substantial drop in performance, particularly in carbon and glass fibers, which show a reduction of more than 30% in strength, operating at 120° C. AFRP doesn't show evident drop at high temperatures, but generally shows a global less resistance (up to 25%) than the other two fibers.
The prolonged stay under conditions of high humidity provokes the decrease of the resistance; in particular, AFRP shows tensile strength lower than 35%, operating at MC = 40 %. The data obtained in this study shows that the more aggressive condition is the permanence at high humidity and that there is a gradual deterioration in relation to elapsed time. Even continuous variations of temperature and moisture are due to deficient performance of all the fibers considered in the study. Instead, the temperature is not a particularly affecting parameter; it was observed that only temperatures higher than 80° C are detrimental, which are hardly reached in environmental conditions.
The resin used is very stable chemically. The IR spectrometry analysis showed that only the heating to 120 ° C can induce mutations in the chemical structure of the polymer. The changes induced by high temperatures is not in the "skeleton", but probably in additional substances that are included as additives to increase the performance of the matrix. Samples in which anomalies were observed in the spectra are characterized by the appearance of small yellow spots on the resin. This observation suggests that the heat-sensitive substance is a chromophore, although this hypothesis has yet to be confirmed.