

Durability and bond performance of CFRP tendons in high strength concrete

Eleni Toumpanaki

Abstract

Steel corrosion can be critical in prestressed structures, where the tendons are loaded up to 70% of their ultimate tensile strength, allowing for a limited steel stress increase as a result of the reduction in the effective cross-sectional area. Carbon Fibre Reinforced Polymer (CFRP) tendons are an alternative measure against steel corrosion problems that are most commonly found in bridges resulting in an enhanced durability performance for prestressed concrete structures. CFRP tendons with an additional sand coating layer are used in industry to increase the bond. The bond failure interface between CFRP sand coated tendons and concrete typically lies in the epoxy, at the interface between the sand coating layer and the core tendon. Exposure of CFRP tendons to moisture (e.g. at a crack location) can be detrimental to the mechanical performance of the epoxy material due to the porous matrix structure. The manufacturing process also affects the strength retention of CFRP tendons under wet environments by controlling the stability of the epoxy network structure and the void percentage in the matrix material. An investigation of CFRP tendons subjected to wet environments provides insight into the structural bond performance of pretensioned concrete structures under similar exposure environments.

To assess the mechanical degradation of the epoxy in CFRP tendons due to exposure in water, torsion tests were conducted on CFRP samples that had been immersed. The matrix dominated property of shear modulus was then measured as a function of exposure time. The diffusion properties of the CFRP tendons were studied using mass uptake readings of fully immersed samples in distilled water. A connection between moisture absorption and shear modulus degradation was made. Accelerated ageing at elevated temperatures (60°C) was used to extrapolate the long-term behaviour from relatively short-term periods. For tendons with minimal voids a maximum loss in stiffness of 17% was observed after 141 days of exposure at 23°C plus 71 days at 60°C. CFRP tendons with a greater void percentage exhibited a greater shear modulus degradation up to 29% near the saturation point.

Pull out tests were carried out to assess the bond strength performance of sand coated tendons embedded in high strength concrete and immersed in water at either 23°C or 40°C. Sand coated CFRP tendons with two different core diameters, $D=4.2$ and 5.4 mm, were studied. Losses of the sand coating due to handling, storage and transportation have been reported in industry. To assess the effect of the sand coating coverage on the bond, half sand coated and uncoated tendons were also tested. An image processing technique was developed to help correlate bond strength variations with variations in the sand coating. An average difference of 24% between the bond strengths of the half sand coated and fully sand coated tendons was recorded and correlated well with the image processing method. A greater variability in bond strength was observed between sand coated tendons with different diameters. This was attributed to Poisson's ratio effects and differences in the quality of the external sand coating layer. There was a large scatter in the pull out results for the sand coated tendons of $D=5.4$ mm and this was attributed to the manufacturing process. There was no clear trend of bond strength degradation in the sand coated tendons even after roughly 1.5 years of full immersion in water irrespective of the exposure temperature. However, an increase in the bond strength of the uncoated tendons and in the bond stiffness of all CFRP tendons was observed. This was felt to be the result of concrete autogenous shrinkage in high strength concrete and the potential swelling effects of the tendons in a concrete humid environment.

A tension stiffening analysis was undertaken to study the effect of bond strength variations and bond durability scenarios on the cracking behaviour, deformability and structural performance of CFRP prestressed beams. Specimens with a low bond performance that could be indicative of a reduction of bond properties due to long-term exposure exhibited a smaller number of cracks and higher deflections at failure compared with high bond tendons. The flexural bond length in low bond tendons and debonding did not extend to the transfer length of the prestressing force. If deformability is a criterion for the warning before the collapse of CFRP prestressed structures then low bond strength tendons are preferable. However, high bond strength tendons can give an indication of impending failure with the higher number of cracks developed before failure.