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Textile-Reinforced Mortar (TRM) System as a Strengthening Technique on Reinforced Concrete Beams

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There is considerable investment in construction industry in Qatar for civil infrastructures and taking into account the severe environmental conditions, they would entail for proper maintenance, repair and strengthening for safe, continuous, uninterrupted, and efficient functionality. Reinforced concrete (RC) structural members, which constitute majority of construction works in Qatar, can be easily deteriorated by the deleterious effect of seawater exposure in the form of humidity or direct splashing for sea-level and offshore structures. Such deterioration can also be due to the exposure to extreme high temperatures, severe humidity and high chloride. All such environmental effect can significantly reduce the life-span of RC structures by up to 10–15 years.

The cost of rehabilitation and strengthening is usually estimated in millions of dollars. Traditional methods of strengthening corrosion-damaged structures involve the replacement of the corroded bars and the substitution of deteriorated concrete layers with new concrete. Our study proposes an “optimum strengthening technique” for RC structures to mitigate the prevailing conditions of Qatar. This relatively new technique utilizes “textile-reinforced mortar (TRM)” to strengthen concrete beams. TRM systems consist of one or more layers of textiles made of carbon, glass, or Polyparaphenylene benzobisoxazole (PBO) grids that are sandwiched between layers of associated cementitious mortars. The cement-based mortar used in TRM acts as a barrier against chloride ions penetration thus protecting the main reinforcing bars from corrosion attack. Textiles’ lightweight, high tensile strength, corrosion resistance, and ease of application make the strengthening system appealing. The potential of TRM for the repair and strengthening of concrete structures is not just the result of its physio-mechanical performance but also the ease and simplicity of installation that does not require any sophisticated equipment or retraining of the construction work. In addition, the compatibility between the mortar used and the concrete substrate is inherited since both materials

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have the cement as a common “base”. TRM systems, with their innovative features, ensure the endurance of the rehabilitation process and consequently the sustainability of the strengthened structure.

Recently in the last few years, several research works in the USA and Europe in the field of TRM strengthening technique have been reported for masonry and concrete structural members. Majority of these works is limited to single type of textile (either carbon, PBO or glass) and on limited types of reinforcement levels. The work presented here compares two different types of TRM systems in the same domain, performed on three different levels of reinforcement ratios representing flexural deficient, lightly reinforced and typical under-reinforced beams.

Experimental works were done to state the efficiency and effectiveness of textile reinforced mortar (TRM) in increasing the ductility and the flexural capacity of reinforced concrete (RC) beams. The aim of the experimental work was to investigate the parameters that contribute to the increase in the load carrying capacity of beams strengthened with TRM system. Eighteen medium-scale rectangular RC beam specimens, 2500 mm long, 150 mm wide and 260 mm deep, were prepared at three different reinforcement ratios of “ $\rho_{s1}=0.5\%$,” “ $\rho_{s2}=0.72\%$,” “ $\rho_{s3}=1.27\%$.” The strengthened beams utilized two TRM types namely carbon and Polyparaphenylene benzobisoxazole (PBO) TRM systems respectively. The RC beam specimens were tested in flexure under four point loading until failure with a clear span of 2.2 m. The strengthening technique was applied to the soffit of the beam (flat type) altering the number of layers of textile. Three beams (of three different reinforcement ratios) without TRM strengthening were used as control specimens. Nine beams were externally reinforced by one (“ $\rho_{T-c1}=0.014\%$ ”), two (“ $\rho_{T-c2}=0.028\%$ ”) and three (“ $\rho_{T-c3}=0.041\%$ ”) layers of carbon TRM system. Six beams were strengthened with one (“ $\rho_{T-PBO1}=0.009\%$ ”) and two (“ $\rho_{T-PBO2}=0.018\%$ ”) layers of PBO TRM system.

From Based on the experimental observations, a reasonable gain in flexural strength and energy absorption was achieved for both the TRM systems. An increase of the initial stiffness was achieved for strengthened specimens; however, an apparent decrease in the overall ductility was observed with TRM strengthening. Results showed that the flexural capacity of strengthened beams increased to an average of 38% for carbon TRM system and an average of 26.7% for PBO TRM system over that of their control (un-strengthened) specimens. The highest increase in the load carrying capacity was 77.51% for a specimen having with the main reinforcement ratio of D12 (“ $\rho_{s2}=0.72\%$ ”) and was strengthened with main carbon TRM system using three layers of carbon textile.

Ductility index (ΔI) and energy absorption (Ψ) values were also calculated in order to know the behavior of ductility and flexural capacity in each of the beam specimen. The term ductility index (ΔI) is defined as the ratio between the deflection at the ultimate load and that at yield load, representing its ability to stretch/deform under sustained load before fracture. During experimentation, it was observed that the average values of ductility indices of using carbon as strengthening material were 1.1 \times , 1.2 \times and 0.5 \times for “ $\rho_{s1}=0.5\%$,” “ $\rho_{s2}=0.72\%$ ” and “ $\rho_{s3}=1.27\%$ ” beam specimens respectively to that of their control specimen. Similarly the average values of ductility indices of using PBO as strengthening material were 2.42 \times , 0.75 \times and 0.56 \times for “ $\rho_{s1}=0.5\%$,” “ $\rho_{s2}=0.72\%$ ” and “ $\rho_{s3}=1.27\%$ ” specimens respectively to that of the control specimen. Also the term energy absorption (Ψ) is defined as the area under the load- deflection curve up to the ultimate load, representing the amount of energy absorbed by the specimen before complete failure. The average values of energy absorption for using carbon as strengthening material were 1.8 \times , 1.2 \times and 1.6 \times for “ $\rho_{s1}=0.5\%$,” “ $\rho_{s2}=0.72\%$ ” and “ $\rho_{s3}=1.27\%$ ” beam specimens respectively to that of the control specimen. Similarly the average values of energy absorption for using PBO as strengthening material were 2.0 \times , 1.0 \times and 1.5 \times for “ $\rho_{s1}=0.5\%$,” “ $\rho_{s2}=0.72\%$ ” and “ $\rho_{s3}=1.27\%$ ” specimens respectively to that of the control specimen.

Therefore, both the adopted TRM systems performed exceptionally well within the scope of the work, with carbon TRM system showing a relatively higher increase in the capacity of strengthened specimens and PBO TRM systems exhibiting relatively more ductile failure with higher bond strength between the TRM surface and concrete substrate. Moreover,

crack patterns for the strengthened beam showed effective distribution of cracks/damage over the length of beam as compared to severe and concentrated damage in the associated control un-strengthened beams. Further, during the experimentation, it was seen that the technique of applying the TRM system also considers the contractor's ease where the construction workers (although not very skilled) can easily implement the technique after being given simple demonstrations.

The study puts forth proper procedures and standards to the construction industry on the rehabilitation and strengthening of the existing concrete structures using innovative TRM strengthening technique. Successful implementation of the project will result in "state-of-the-art recommendations for design and construction specifications", which will place Qatar and research at Qatar University in a leadership position not only limited to the Gulf region. Furthermore, this can potentially act as an "important initiation for the development of new industrial opportunities" in the country.

Keywords

Reinforced concrete beams, textile reinforced mortar, flexural strengthening, ductility index, energy absorption.