EVALUATION OF CFRP/STEEL BOND PERFORMANCE UNDER TROPICAL ENVIRONMENTAL CONDITION IN SRI LANKA

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ABSTRACT
Steel bridges play a key role of the road and railway network and most of them were build under British colonial period. After 100 – 150 years of time some of bridges are playing a major role in current road and railway network system. But the present condition of these are been affected by environmental effect which has reduced the strength of the bridges to achieve the current traffic demand. However, it is difficult for most of these bridges to perform their service to the existing traffic conditions of country. Therefore new bridges are needed to replace them. But the cost of construction of new bridges is a heavy burden to the economy and on the other hand construction consumes more time and makes inconveniences to users. CFRP is the most popular technology to strengthen steel structures such as bridges, towers and offshore marine platforms etc. This technology can significantly enhance the characteristics of existing structures. This research review the bond performance of CFRP /steel strengthens technology under tropical climate environment in Sri Lanka.
Keywords: Steel bridges, Retrofit, CFRP, Relative humidity,

1. INTRODUCTION

The need to repair and retrofit deteriorating steel structures such as bridges in a rapid fashion, the potential market for using CFRP composites for repair has been realized to a greater extent in past decades. Vast numbers of successful research outcomes and field applications using FRP materials have been reported in the civil engineering field. Due to the specific properties such as strength to weight ratio and resistant to corrosion carbon fiber reinforced (CFRP) materials are popular for structural strengthening. In addition economic and environmental factors also affect to this popularity and mainly considered reduction in labour costs and less harmful effect on environment. However, one of restrain factor is the lack of quality control for installation under environmental condition such as level of humidity and temperature. Hence, understanding the effect of such factors for bond performance under installation process of CFRP materials is most important in the development of quality control of composites, because CFRP laminates adds additional flexural or shear strength. The

reliability for this technology depends on how well they are bonded and can effectively transfer stress from the CFRP laminate to steel. Therefore the bond strength between an FRP sheet and steel influences the health of the structure. A lack of research information availability on the effects of environmental conditions in Sri Lanka is one of the problems to understand the bond performance during installation. The effect of moisture and temperature of the steel surface on the bond strength between steel and CFRP reinforcement is not well understood or documented and is examined in this study. The behavior of FRP bonded steel may also vary with the variation of moisture level, presence of saline conditions, relative humidity, etc

2 METHODOLOGY

Review of existing literature regarding CFRP application of strengthening steel structures under different environment condition.

3. LITERATURE REVIEW

Environmental durability covers the effects of moisture, temperature, thermal cycles, alkaline environment, and UV radiation. Durability of FRP materials has been deeply investigated during past two decades Rege and Lakkad .1983;[1] and Tavakolizadeh et al .2010[2]; . Most of research outcomes have shown CFRP materials exhibit excellent performance under varies environmental condition.

3.1MOISTURE LEVEL (RELATIVE HUMIDITY)

Ingress of moisture to the CFRP/steel bonding joint is one of the main problem. In generally both epoxy adhesive and CFRP matrix resin may be affected by penetration of water molecule into the bonded joint. But, carbon fiber is resistive to moisture and is less affected by it. Because, CFRP shows non transitive characteristic and as a result water absorption controlled. However FRP matrix resin is quite permeable and has high possibility to absorb water and weakens the attraction between these two components. Moisture absorption of FRP matrix shows physical changes and it may cause to reduce the glass transition temperature. According to study of Collings et al.1993[3]; and Hollaway . 2010[4] are shown affected to failure of the matrix. In addition, the absorption of moisture may cause unexpected structural distortions during the service life of structures. Kumar et al .2008;[5] has found that water absorption reduce the shear strength of the polymer as swelling leads to plasticization, a softening effect. Therefore a remarkable swellings in thickness of the laminates cause a significant decrease in tensile strength. Zhang et al.2012; investigations have shown that moisture absorption of CFRP laminates around 1% will cause to decrease bending strength approximately by 17% after 14 days water exposure. However, Nguyen et al (2012)[7] , have demonstrated CFRP materials exhibit excellent durability against severe environmental conditions and degradation of strength or stiffness is negligible. Experiment done by Nguyen et al .2012;[8] identified the moisture absorption increased very fast at the beginning of the immersion and then reached a constant level. However, the temperature of moisture influenced the amount of water uptake as well.

3.2THERMAL EFFECTS (TEMPERATURE EFFECT)

Thermal effects explain of reaction due to high temperatures, thermal cycles constitute heating and freezing both conditions. In general, high temperature causes to baneful effects on CFRP/steel bonding system. Although, carbon fiber material shows resistivity against elevated temperatures, however matrix resin usually has a flexible behavior for temperature. Practically, the strength and stiffness of polymer matrix will decrease rapidly due to the temperature exceeding the glass transition temperature (Tg) leading to reduction of CFRP mechanical properties (Hollaway .2010)[9] . Similarly, the adhesive layer between CFRP and steel is sensitive to high temperature. According to Nguyen.2011[10] consequently, the mechanical performance of CFRP/steel bonding system subjected to elevated temperature prevailed greatly by the adhesive. In fact, subjecting to temperatures around the glass transition temperature of the adhesive causes the viscosity to increase rapidly and as a result the strength and stiffness of joint reduce substantially.

Stratford and Bisby .2012; review the reduction of adhesive stiffness in high temperatures above Tg. Usually the glass transition temperature (Tg) of epoxy adhesives is vary between 40_C and 70 _C. According to Stratford and Bisby (2012) it showed that considerable joint slip appeared before Tg of the adhesive and reduced the strength of the bond and joint slip began at around 40 _C and reached the maximum amount at Tg (65 _C).

Effective bond length is depended on temperature and the ultimate load capacity is reduced by a considerable amount when temperature reached to Tg. Nguyen (2011) experimentally prove the reduction of ultimate load capacity was about 15%, 50%, and 80% when temperature reached Tg, 10 _C above Tg, and 20 _C above Tg, respectively. Furthermore, structural adhesives or FRP composites identified a time-dependent degradation when exposed to a constant temperature in an elevated range. Nguyen et al .2012; Has explained the specimens subjected to 20% of ultimate load capacity and 50 _C temperature, failed just after 25 min of exposure while the joints subjected to 80% of ultimate load and 35 _C temperature (Tg = 40 _C) did not fail after 150 min. Another recent study has shown the degradation depended on stress level and made it to fail at a lower temperature if the exposure time was sufficiently long Nguyen et al .2012; Mazzotti and Savoia .2009; has found that long term exposure to lower temperatures than Tg may cause creeping in epoxy adhesive . Meanwhile, various expansions between CFRP and steel causes to build shear stresses across the adhesive joint and they may affect the bond performance. Nguyen et al.2012; explained thermal cycles near to Tg and estimated decreased load carrying capacity around 30%. However, it had less influence comparing to specimens subjected to constant high temperature. Research done by Al-Shawaf et al .2006; were study, effect of freezing condition to degrade CFRP material due to matrix hardening which cause micro-cracks parallel to fibers and at the fiber–matrix interface. However, same study demonstrated that short term subzero temperature had negligible effect on the joints strength. In practice, for typical temperature levels in civil structures, undesired performance can be overcome by choosing a system where the glass transition temperature is always higher than the maximum temperature of the structure. Aiello et al .2002; is suggested that the expected service temperature should be 5–10 _C lower than the Tg of the adhesive. However, Stratford and Bisby .2012 ; design guidelines recommend that Tg must be higher than 15 _C from operating temperature . Deng .2004;, Smith & Teng.2001;, Stratford and Cadei.2006; which were analytical models of temperature degradation have been developed in linear elastic behavior . The effect of applied load and differential thermal expansion of materials articulate to these models by Stratford and Bisby.2012;However, modeling the joints subjected to thermal cycles has not been expressed yet. In fact, the process of strength improvement during temperature reduction is still unknown (Mehran Gholami. et al .2013).In the field work, bond must have good temperature tolerability at both elevated and freezing conditions. Case study of bridges located in North America selected adhesive that has shown good durability under such kind of environmental conditions (Mertz and Gillespie. 1996).

4. CONCLUSION

Environmental durability covers the effects of moisture, temperature, thermal cycles, alkaline environment, and UV radiation. Ingress of moisture to the CFRP/steel bonding joint is one of the main problem. In generally both epoxy adhesive and CFRP matrix resin may get affected by penetration of water molecule into the bonded joint. But, carbon fiber is resistive to moisture and is less affected by it. However, a study conducted by Wu et al.2004; showed that exposure to small amount of moisture (<2%) improved the curing rate and enhanced bonding strength. Moisture absorption of FRP matrix causes physical changes and it may affect to reduce the glass transition temperature. But CFRP shows excellent resistivity for water molecule. Thermal effects explain of reaction due to high temperatures, thermal cycles constitute heating and freezing both conditions. According to Nguyen .2011 consequently, the mechanical performance of CFRP/steel bonding system subjected to elevated temperature prevailed greatly by the adhesive. In fact, subjecting to temperatures around the glass transition temperature of the adhesive causes the viscosity to increase rapidly and as a result the strength and stiffness of joint reduce substantially. Meanwhile, various expansions between CFRP and steel causes to build shear stresses across the adhesive joint and may affect the bond performance. The effect of applied load and differential thermal expansion of materials articulate to these models by Stratford and Bisby.2012; In the field work bond must have good temperature tolerability at both elevated and freezing conditions. Ultimate load capacity is reduced when operating temperature reached to Tg. However, Stratford & Bisby .2012 design guidelines recommend that Tg must be higher than 15 C from operating temperature. A study conducted by Wu et al.2004 showed that exposure to small amount of moisture (<2%) improved the curing rate and enhanced bonding strength. Therefore CFRP technology can be recommended for Sri Lankan climate.

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