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EFFECT OF TROPICAL WEATHER CONDITIONS ON CFRP STRENGTHEN CORRODED TUBULAR STEEL JOINTS

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Abstract

Steel tubular T joints are most critical and the weakest part of a steel structure. Steel joint often experience corroded due to adverse weather conditions. Topical weather condition such as climate of Bangladesh may cause further damage and deficient of steel tubular T joint and leading to progressive collapse of the steel structure. CFRP (Carbon Fiber Reinforced Polymer) is an advance and attractive strengthening technique which can be consider overcoming this problem. The objective of this study is to evaluate the effect of tropical weather conditions on CFRP strengthen corroded tubular steel T joints. Influencing three different tropical weather condition such as cyclic rain water, cyclic 5% salt water and extreme humid are considered in this research. A series of test have been conducted on CFRP strengthen corroded steel tubular T joints under influencing tropical weather conditions. Twelve T-shaped tubular corroded steel joints specimen including 4 in cyclic rain water, 4 in cyclic 5% salt water and 4 in extreme humid condition were tested in this study. Hydraulic contorted MATEST test machines were used for compressive loading. LVDT and dial gauge were used to record for deformation of the specimen under compressive load. The failure loads, failure pattern and the load-deformation performance of reference joint and CFRP strengthen joint also provided in this paper. CFRP strengthening of corroded T joint enhance the load-carrying capacity significantly and it varied by 31.60% to 51.30% %. Enhancement for ductility in terms of displacement was found from 36.56-96.82%. Based on test results, it is found that cyclic saltwater exposure condition was most vulnerable for corroded steel joints than other conditions. Hence, it can be demonstrated that the improving structural performance can be achieved for corroded steel tubular T joints by CFRP composites strengthening.

Keywords: T-shaped tubular steel joints, Tropical weather, Strengthening.

1 Introduction

In modern world there is a frequent use of steel structures as an alternative of reinforced concrete structures because of their high strength to weight ratio, lightweight, structural stability and cost effectiveness. They can be constructed in desirable shapes also. But the biggest enemies of steel structure is corrosion which can occur under different weather condition. When corroded steel structures are kept under different weather condition it undergoes further corrosion and its material properties are severely affected. CFRP is retrofitting technique which can be a solution to this corrosion problem. Structures wrapped with CFRP at joints and at the places of corrosion have high strength and they can be corrosion resistant as well. The bond durability of steel structures under various exposed weather condition enhances when wrapped with CFRP [1-5]. Mehran et al. (2013) [5] conducted a review on steel/CFRP strengthening systems, emphasizing environmental performance. Their findings revealed that employing CFRP in aging structures enhances structural performance, durability, and load-carrying capacity. They observed that thicker CFRP plates and adhesives correlated with increased bond strength. Moreover, CFRP repairs substantially improved fatigue life, extending it by over three times. Researchers evaluated the axial compressive strength and failure modes of reinforced square hollow section (SHS) T-joints, crucial in structural engineering, with a focus on how member size, plate dimensions, and welding procedures affect junction strength, revealing insights into behavior and performance [6]. The study examines the impact of external stiffening rings on the axial compressive strength of circular hollow section (CHS) T-joints, revealing a significant enhancement in strength and stiffness in each reinforced joint. Through experimental analysis, the research highlights the effectiveness of external stiffening rings in increasing the compressive capacity and structural stability of CHS T-joints under axial loading [11]. The study investigated stress concentration factors (SCF) in FRP-reinforced tubular T-joints, analyzing the impact of axial loading and bending moments on joint performance. It also assessed the structural capacity factor (SCF) of T-joints reinforced with different FRP materials, offering valuable insights for offshore structure design and analysis

[15]. There is a clear gap among researchers on the effectiveness of wrapping and strengthening of steel joint by CFRP under weather condition in Bangladesh. As the climate of Bangladesh is tropical and experiences strong seasonal rainfall, elevated temperatures, and elevated humidity levels, all indicative of a tropical monsoon climate. As a result, it is an effective approach to investigate the strengthening and retrofitting of corroded steel joints using CFRP under tropical weather conditions.

The purpose of this research is to investigate the effectiveness of CFRP for strengthening of corroded tubular T-shaped joint under different tropical weather condition and to explore the most vulnerable condition for corroded steel joints against various weather condition. A series of test have been conducted on 12 T-shaped specimen. CTM machine is responsible for applying axial compression load and deformations were recorded by LVDT machine.

2 Material Properties

In this study we have used corroded tubular mild steel that have collected from local market and later they were cut and welded to make T-shaped specimens. When mild steel corrodes, it produces iron oxide, often known as rust. Corroded mild steel is mostly composed of iron oxides, namely iron(III) oxide (Fe_2O_3) and some iron(II) oxide (FeO). The typical chemical reaction for the corrosion of mild steel is as follows:

$Fe + O_2 + H_2O = Fe(OH)_2 + Fe(OH)_3 \rightarrow Fe_2O_3.xH_2O$ (rust)

The general composition of rust on mild steel that has corroded are iron(III) oxide (Fe_2O_3) which roughly consists of 70-95%, iron oxide (FeO) which consists a portion of about 5-30% and water. Young's modulus is insensitive to the degree of corrosion or the rate of strain. So the Young's modulus of corroded mild steel is approximately 200 GPa (29,000 ksi) and the density is of approximately 7.85 g/cm^3 (7,850 kg/m^3 or 0.284 lb/in^3).

Figure 1: Total 12 specimens of corroded tubular T-joints for experiment

Carbon Fiber Reinforced Polymer (CFRP) is a composite material made up of carbon fibers inserted in a polymer matrix. Its mechanical qualities, including as high strength-to-weight ratio, stiffness, corrosion resistance, and fatigue resistance, make it ideal for a wide range of applications. In this study we have used SikaWrap-230C as CFRP which has high tensile strength and long term durability.

Table 1: Properties of SikaWrap-230C

SikaWrap-230C	
Areal Weight (g/m^2)	230 g/m^2
Fabric Thickness (mm)	0.131
Tensile Strength	4900Mpa
Fiber Stiffness (GPa)	230
Fiber Density	1.76 g/cm^3
Elongation at Break	1.8% (nominal)

The primer used before wrapping CFRP (Carbon Fiber Reinforced Polymer) acts as an important intermediate layer, improving adhesion between the substrate and the CFRP composite. This primer, which is made up of resins, solvents, and additives, promotes chemical bonding by making the two materials more compatible. In our experiment we used epoxy primer F1-3540. The adhesive used to wrap CFRP is Lapox Metalam Sytem B. Their characteristics are given below:

Table 2: Lapox Metalam System B characteristics
https://pdf.indiamart.com/impdf/2849204952597/MY-47849774/lapox-metalam-system-b-resin-hardener.pdf

Test	Unit	Reference	Value	
			Resin	Hardener
Description	-	Visual	Clear, transparent liquid	Clear, transparent liquid
Viscosity at 25°C	M Pas	ASTM D2196	800 - 1200	300 - 600
Color	APHA	ASTM D1209	Max 60	-
Color	GS	ASTM D1544	-	Max 1
Density	g/cc	ASTM D792	1.00 – 1.20	0.95 – 1.00

Figure 2: CFRP, Primer and Adhesive

3 Experimental Program

A series of test program has been conducted on CFRP-strengthened corroded tubular steel joints. A series of test have been conducted on CFRP strengthen corroded steel tubular T joints under influencing tropical weather conditions. Twelve tubular T-shaped have been prepared for test in this study including 4 specimens in extreme humid condition, 4 in cyclic rain water condition and 4 in cyclic 5% salt water condition. For portraying the effect of extreme humid condition we have kept the specimens in university washroom for 2.5 months. For rain water condition specimens were immersed into a container filled with distilled water and for 5% salt water condition a container is filled with a mixture of 20 litres of water and 1 kg of salt. For developing a cyclic condition specimens were kept into water for 12 hours and put outside for 12 hours for a period of 2.5 months. For each weathering condition we have prepared specimens on the basis of following arrangement :

- T F_0 C_0
- T F_0 C_1
- T F_1 C_1
- T F_1 C_0

Here,
T = T-joint.
F_0 = Specimen without CFRP.
F_1 = Specimen with CFRP.
C_0 = Specimen without cut or uncracked.
C_1 = Specimen with cut or pre-cracked for making it deficient.
The dimensions of specimens are same for all three conditions are same. The dimensions are given below:

Table 3: Specimen dimensions for compressive load test for all three conditions

Specimen Type	Specimen material	Thickness (mm)	Dimension (mm)	
			Brace (mm)	Chord (mm)
T F_0 C_0	Corroded Mild Steel	2.5	254	305
T F_0 C_1		2.5		
T F_1 C_1		2.5		
T F_1 C_0		2.5		

After that the specimens were brushed and cleaned thoroughly by using hand brush and sand paper. Later primer was applied to prepare a smooth surface where CFRP can be wrapped properly. Before applying CFRP adhesive was brushed uniformly over the joint. We have used epoxy primer F1-3540 and Lapox Metalam System B as adhesive. The CFRP used for this test was SikeWrap-230C. Specimens were tested in CTM machine where axial load was applied vertically and deflections were recorded using LVDT machine.

Figure 3: Specimens under humid, cyclic rain water and cyclic 5% salt water condition

Figure 4: Specimens smoothing, cutting, brushing and applying primer

Figure 5: Specimens drying, application of adhesive and CFRP wrapping

Figure 6: Specimens testing under CTM and LVDT

4. Results and Discussions

Under compressive stress, a comprehensive testing program was carried out on a CFRP strengthened mild steel tubular hollow T-joint. The Compression Testing Machine (CTM) was responsible for applying the load, and the specimens were deformed as a result. Under compressive loading, the behavior of corroded tubular T-joints under a variety of different types of weather conditions, including pre-cracked, uncracked types were investigated with and without the use of CFRP.

During loading deflection was measured by the use of LVDT. With the help of deflection value, load deflection curve can be achieved and the most vulnerable condition can be determined.

Table 4: Data table for specimens under extreme humid condition

Specimen Name	**Specimen Type**	**Ultimate Load (kN)**	**Increase**
TF_0C_0 (Uncracked; No CFRP)	Reference specimen	26.42	
TF_0C_1 (Pre-cracked; CFRP used)	Reference specimen	18.14	
TF_1C_0 (Uncracked; No CFRP)	Retrofitted specimen	35.02	32.55%
TF_1C_1 (Pre-cracked; CFRP used)	Retrofitted Specimen	27.45	51.30%

Table 5: Data table for specimens under cyclic rain water condition

Specimen Name	**Specimen Type**	**Ultimate Load (kN)**	**Increase**
TF_0C_0 (Uncracked; No CFRP)	Reference specimen	24.37	
TF_0C_1 (Pre-cracked; CFRP used)	Reference specimen	15.89	
TF_1C_0 (Uncracked; No CFRP)	Retrofitted specimen	32.17	32%
TF_1C_1 (Pre-cracked; CFRP used)	Retrofitted Specimen	24.924	51%

Table 6: Data table for specimens under cyclic 5% salt water condition

Specimen Name	**Specimen Type**	**Ultimate Load (kN)**	**Increase**
TF_0C_0 (Uncracked; No CFRP)	Reference specimen	22.139	
TF_0C_1 (Pre-cracked; CFRP used)	Reference specimen	15.54	
TF_1C_0 (Uncracked; No CFRP)	Retrofitted specimen	29.13	31.60%
TF_1C_1 (Pre-cracked; CFRP used)	Retrofitted Specimen	23.374	50.40%

Figure 7: Deformed specimens after applying load

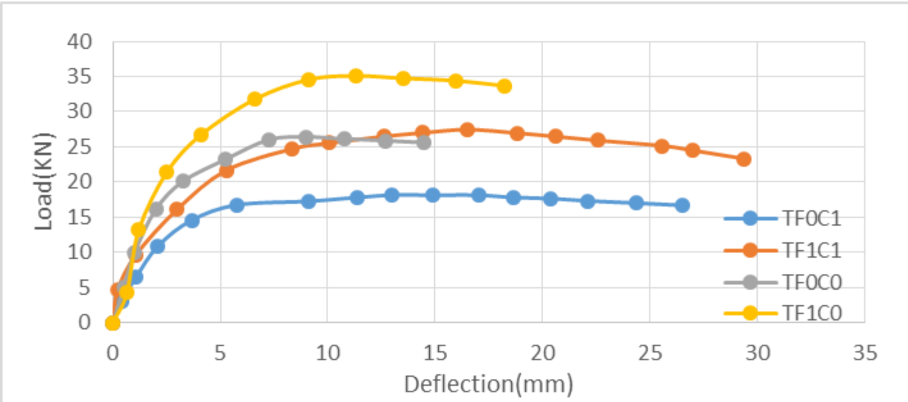

Figure 8: Load-deflection graph for four specimens under extreme humid condition

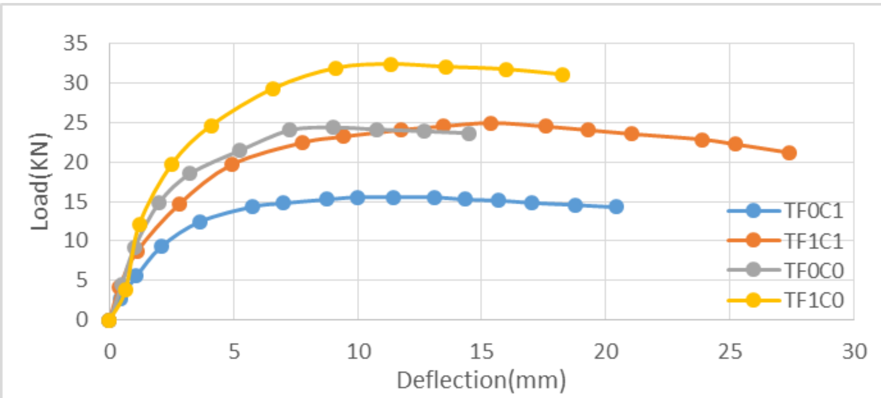

Figure 9: Load-deflection graph for four specimens under cyclic rain water condition

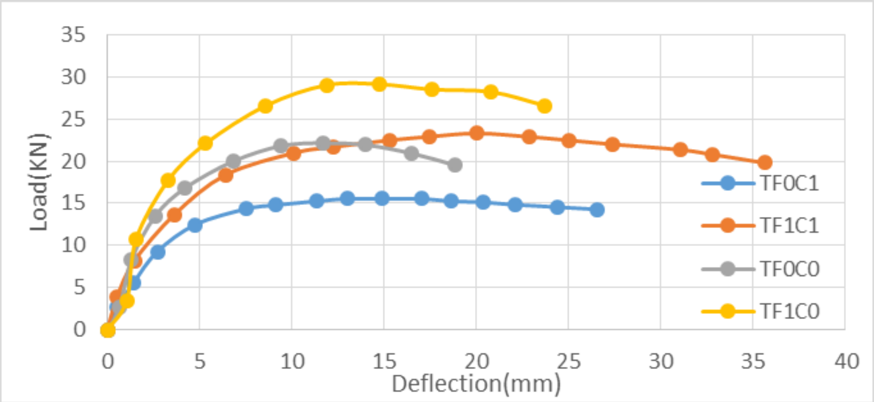

Figure 10: Load-deflection graph for four specimens under cyclic 5% salt water condition

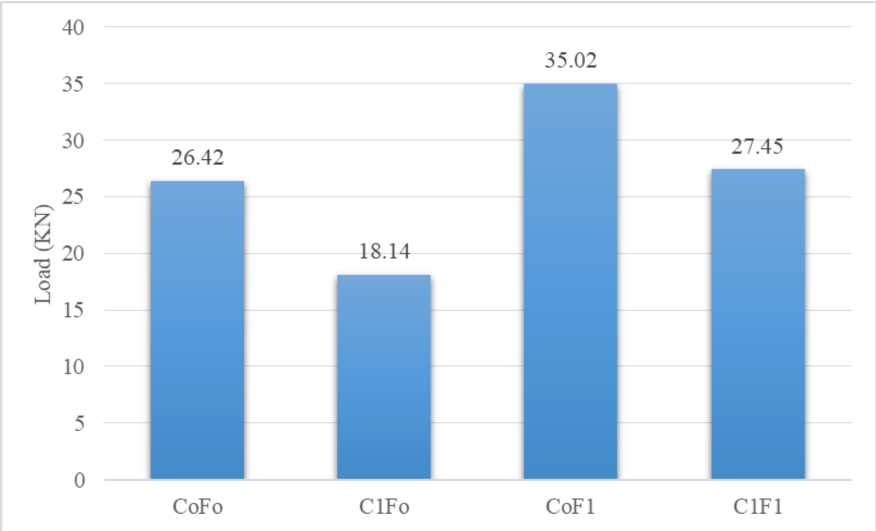

Figure 11: Bar diagram of ultimate load for four specimens under extreme humid condition

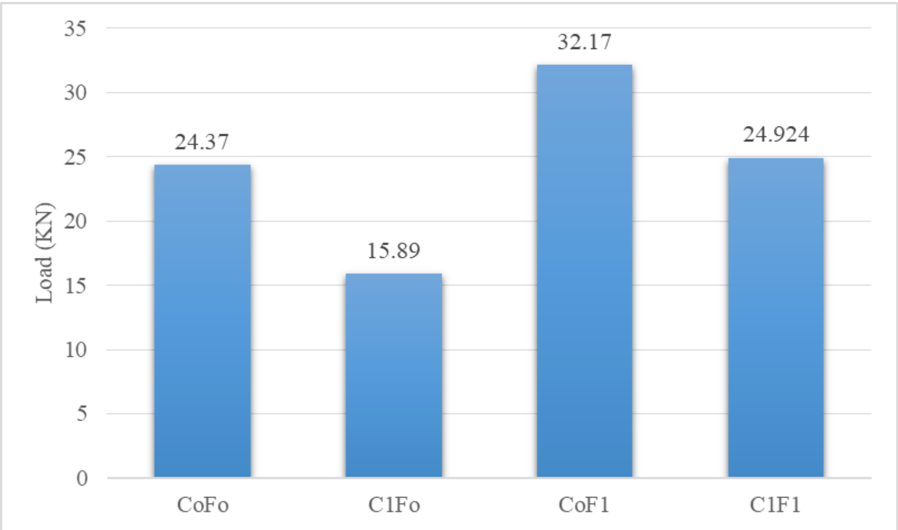

Figure 11: Bar diagram of ultimate load for four specimens under cyclic rain water condition

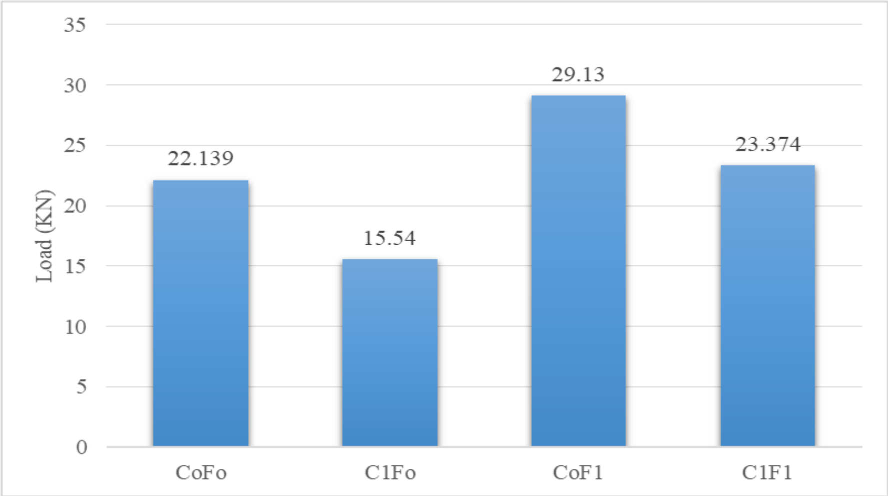

Figure 11: Bar diagram of ultimate load for four specimens under cyclic 5% salt water condition

The study conducted tests to evaluate the effectiveness of CFRP on corroded steel joints and identify the most vulnerable corrosion condition under tropical weather. Results showed significant improvements in load carrying capacity with CFRP retrofitting across different weather conditions: approximately 32% increase for cyclic rainwater conditions, 31.60% for 5% saltwater conditions, and 32.55% for extreme humid conditions, compared to pre-cracked specimens. Similarly, CFRP retrofitted specimens exhibited about 51% increase in load carrying capacity compared to cracked specimens. Overall, load bearing capacity for pre-cracked specimens increased by 5% in extreme humid conditions and 3.2% in cyclic rainwater conditions compared to cyclic saltwater conditions, with similar trends observed for cracked specimens. These findings underscore the effectiveness of CFRP in enhancing the structural integrity of corroded steel joints, especially in diverse tropical weather conditions.

5. Conclusion

The study investigated the behavior of corroded mild steel tubular T-shaped junctions under compressive loads, comparing pre-cut and non-precut specimens, with and without CFRP reinforcement. Testing involved twelve tubular members across three tropical weather conditions, revealing that CFRP-strengthened joints exhibited less deformation under pressure, outperforming all other conditions. Corrosion from saltwater was identified as the most vulnerable condition, bearing the least load. The study enhanced understanding of the structural response of corroded mild steel tubular T-joints to compression. Extreme humid conditions exhibited the highest load-bearing capacity, indicating the least corrosion concern. Deformation percentage decreased in mild steel tubular T-joints under compressive loading, correlating with increased final strength. The results supported the effectiveness of CFRP for strengthening and retrofitting, with a straightforward and successful application process. Consequently, applying CFRP composite laminates to reinforce and repair damaged RC slabs is deemed highly effective and desirable.

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