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CFRP Strengthening of Structurally Deficient Mild Steel, Stainless Steel and Aluminum Tubular Short Columns under Axial Compressive Loads

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Abstract

Metal tubular columns are being used gradually increased due to aesthetic and numerous advantages such as being lightweight, high strength, structurally efficient and cost-effective. Aluminium, stainless steel and mild steel tubular member may often experience structurally deficiency leads to damages due to increased life loads, adverse environment corrosion, fatigue cracking by impact loading. Carbon Fiber Reinforced Polymer (CFRP) is one of the most important, effective, potential, and advanced composite materials for retrofitting and strengthening metal structures. The objective of this research is to investigate on CFRP strengthening of structurally deficient mild steel, stainless steel and aluminum tubular short columns under axial compressive loads. A series of tests have been conducted on deficient mild steel, stainless steel and aluminum tubular short columns. Eighteen tubular sections including reference section and CFRP strengthened sections were tested in this study. Hydraulic contorted universal testing machines were used for axial compressive loading. The collapse loads, collapse modes and the load-deformation behavior of reference sections and CFRP strengthen section are also presented in this paper. Based on test results, CFRP strengthening was increased ultimate load carrying capacity, and ductility as well as delay buckling control fracture and reduced stress, the damaged area. The load-carrying capacity increased significantly and it varied by 19.23%-76.47%, for aluminium, stainless steel and mild steel for CFRP strengthening sections. Therefore, it can be concluded that the tubular metal sections can be strengthened efficiently by CFRP.

Keywords: *CFRP, Steel tubular section, Strengthening, Short column, Structural behavior***.**

1 Introduction

Current modern construction industries are using steel tubular short columns more frequently because of their many benefits, including their lightweight, structural efficiency, low cost, high strength-to-weight ratios, and economic viability. This is also available in very different form of shapes and sizes, which can add aesthetic appeal. This metal short column may be found deficient due to corrosion, aging, and damage for overloading, seismic action, design and construction faults, and poor maintenance change, in application and implementation. Externally bonded carbon fiber reinforced polymer (CFRP) strengthening can be considered to solve this problem. Application of CFRP warp for strengthening tubular structural members is a comparatively new and smart strengthening technique over the conventional strengthening method and, also has a great potential to meet such challenges (Zhao and Zhang, 2007; Islam and young 2011, 2012). Since Fibre Reinforced Polymer (FRP) has huge tensile strength and stiffness compared to steel and concrete, it is recognized as a promising as well as an attractive solution to boost the strength of existing columns (Zhao and Zhang, 2007; Haedir and Zhao 2011). With relevance to un-strengthened steel columns, Shaat and Fam's (2006) investigated short steel column which was strengthened by CFRP. The enhancement of CFRP strengthen short steel column was found up to 18%. Comparing the impacts of several CFRP layer orientations, it had been revealed that using transverse CFRP layers was the foremost successful in preventing local buckling of columns. When the application of CFRP layers was combined in the transverse and longitudinal direction, Bambach et al. (2009) investigation was able to increase twice the axial compression capacity of short SHS columns in slender cross-sections. The membrane strains were reduced in local buckling by the longitudinal and transverse strengthening of short column

Bambach and Elchalakani , (2007), Sundarraja et. al (2014), Bambach and Elchalakani (2007), Silvestre et al (2014). It had been discovered that using CFRP leads to larger increases in capacity because slender section columns experience more buckling deformations. For compact section SHS columns, the use of CFRP similar results was obtained by Haedir and Zhao (2011). The strengthening was a mix of transverse and longitudinal CFRP layers and obtained 21% enhancement. For short steel tubular columns, this experimental research has produced design equations that forecast the axial compression strength enhanced with CFRP. The theoretical buckling stress and design approach of the CFRP-strengthened stub SHS column was developed by Bambach et al. (2009). However, this model has limitations due to base on assumption and identical effect of longitudinal and transverse CFRP layers for calculation of local buckling. The results of earlier investigations Imran et al. (2018) have demonstrated that the direction of the CFRP layer has significant effects on CFRP strengthening. CFRP strengthening was found effective to restore strength for structurally deficient steel tubular columns Karimian et al. (2017), Ghaemdoust et al. (2016), Ou et al. (2022). There is a clear gap among researchers on the effectiveness of retrofitting and strengthening deficient mild steel, stainless steel and aluminum short column failure by CFRP materials. However, little research has been conducted on the application of CFRP materials for strengthening and retrofitting pre-cracked steel stub column failure. Therefore, it is an innovative approach to study on strengthening and retrofitting of pre-cracked steel stub columns by CFRP.

2 Material Properties

Tubular metallic structures are extensively used due to their lightweight efficiency and excellent load-carrying capacity. Five materials have been used to prepare the tested specimens. These are mild steel (MS), stainless steel (SS), Aluminim (Al), CFRP wrap, and adhesive as shown in Figure 1. Externally bonded strengthening highly depends on the properties of metal surface, adhesive and CFRP materials. The effective bond strength, elastic modulus, and elongations are the key mechanical properties of adhesive for strengthening structures. CFRP material is a composite material that typically consists of fibers embedded in a resin matrix. Epoxy resin is the most widely used resin for CFRP. In this research, carbon CFRP fabrics Kor-CFW450 are used having fiber strength of 4900 MPa, fiber stiffness of 230 GPa, an areal weight of 450 g/m^2, and fabric thickness of 0.255 mm. Primer and saturant were used having density 1.14 gm/cm3 1.8 gm/cm^3; pot life 30 min,1hr 30 min, tensile strength 1350 MPa, 4875 Mpa, Modulus of elasticity 99.37 GPa, 238.00 GPa, respectively. Adhesive Kor-CPA 10 Base Resin and hardener used in this research have the tensile strength of 49.8 MPa, shear strength of adhesive of 29 MPa, and pot life of 70 min. Aluminium, stainless steel, and mild steel coupon specimen thickness are 0.80 mm, 0.80mm, and 1.1 mm respectively. The Coupon specimens are prepared from a web of tubular sections according to American and Australian standards AISI (2007) and AS/NZS (2005). Tensile yield stress is 245 MPa, 434 MPa, and 390 MPa, ultimate stress 268 MPa, 464 MPa, and 450 MPa, initial Young's modulus 68.3, 201.1, and 198.6 GPa for aluminum, stainless steel and mild steel tubular sections, respectively.

Figure 1. Primer, Saturant, CFRP and adhesive Fabric.

3 Experimental Program

A series of test program has been conducted for restoring strength by CFRP-strengthened deficient mild steel, stainless-steel and aluminium, hollow shot column under compressive loading. A series of tests have been conducted on the metal tubular sections which are strengthened by CFRP. Eighteen tubular sections including reference section and CFRP strengthened sections were tested in this study. In this study, six specimens for each material were prepared for testing. Six specimens for aluminium, six specimens for mild steel and other six others for stainless steel were considered for this research. Mild steel (MS), stainless steel (SS) and aluminim (Al), tubular sections specimen is shown in Figure 2. Dimensions, deficient and CFRP strengthen test aluminum, stainless steel and mild steel specimen is shown in Figure 3-5, respectively. Figure. 6 shows the mixing of primer and base resin & hardener adhesive. The specimens were labelled as AlC_0F_o, AlC_1F_o,AlC_HF_1, AlC_VF_1, SSC_0F_o, SSC_1F_o, SSC_HF_1,SSC_VF_1 , MSC_0F_o,MSC_1F_o, MSC_HF_1, $MSC_VF_1$where A indicates aluminium tubular section, SS indicates stainless steel tubular sections, MS indicate mild steel tubular sections, C_o indicates zero cracks, C_1 one layer crack; C_H indicate horizontal crack, C_V indicate vertical crack, C_o indicates reference column no pre-crack and F_o indicate no CFRP.

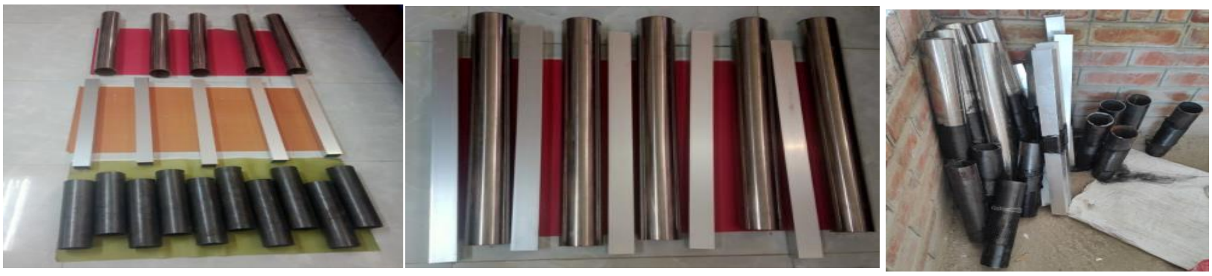

Figure 2. Details dimension of without and with FRP of aluminum specimen

Figure 3. Dimensions, deficient and CFRP strengthen test aluminum specimen

Figure 4. Dimensions, deficient and CFRP strengthen test stainless steel specimen

Figure 5. Dimensions, deficient and CFRP strengthen test mild steel specimen

The aluminum, steel and stainless-steel tubular short column test were done by MATEST compressive testing machine. The short specimens were placed into the machine with the help of plates. Two dial gauges were used for determining the deflection of the loading surface and deformation of the strut column. One dial gauge was touched at the strut surface and another at the base of the loading surface. The loadings were obtained from the test machine as it is built with the help of a computerized function. Figure 7 shows the setup arrangement of the compressive testing machine. Figure 7 shows schematic test rig and test setup for CFRP strengthening short column. Test setup and failure mode of deficient CFRP strengthening short column is shown in Figure 8.

Figure 6. Mixing primer and base resin & hardener adhesive

Figure 7. Schematic test rig and test setup for CFRP strengthening short column

Figure 8. Test Setup and failure mode of deficient CFRP strengthening short column

4 Results and Discussions

A series of tests have been conducted to investigate the structural strength and behavior of CFRP-strengthened deficient aluminium, stainless steel and mild steel tubular short column subjected to axial compressive loading. Eighteen tubular sections including reference section and CFRP strengthened deficient sections were tested in this study. The mode of failure, ultimate loads and the load-deformation behavior of the reference beam and CFRP strengthen short column are observed in this research. The failure modes of unstrengthen and CFRP strengthen deficient short column are shown in Figure 9. Local bucking failure is observed in unstrengthen tubular short column specimen. Column end failure is found due to high-stress concentration at the column end for the middle portion of the transverse CFRP strengthening specimen. Deboning and CFRP failure were observed for single-layer strengthening of the specimen. Yielding failure is found for double-layer CFRP strengthening which restrains inward and outward buckling of the tubular specimen. The pre-cracked specimens failed at the middle of the portion of the short column. The percentage of increase in load carrying capacity was found 76.47%, 36.26%, and 20.23% for deficient aluminum, stainless steel and mild steel tubular sections strut column strengthening, respectively as shown in Figure10. The load-displacement curve of CFRP strengthening deficient short column is shown in Figure 11.

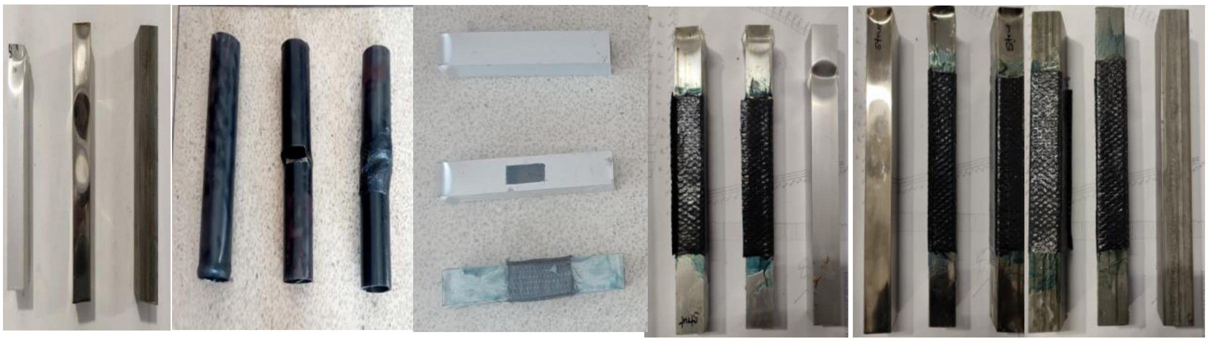

Figure 9. Failure mode of CFRP strengthening stub column specimens

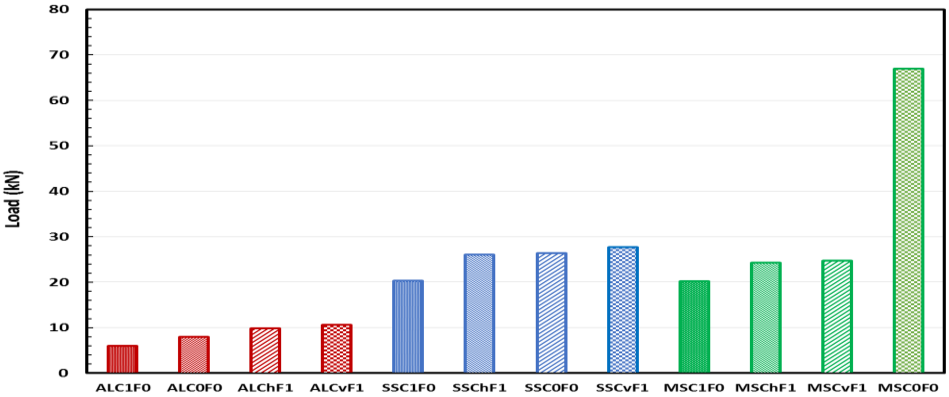

Figure 10. Enhanced load carrying capacity of deficient column strengthening by CFRP

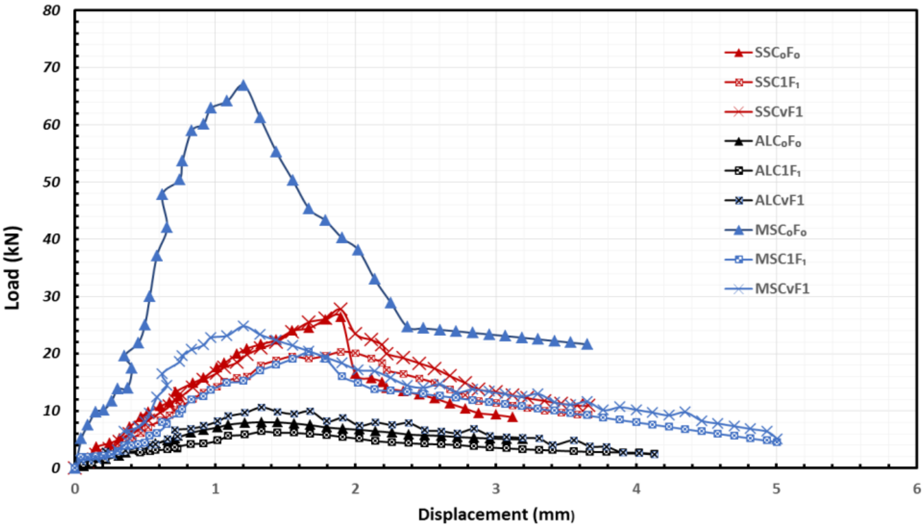

Figure 11. Comparison of load-displacement curve for reference and CFRP strengthening deficient short column

Based on experimental observation, it can be revealed that by increasing CFRP length and number of layers, load carrying capacity enhancement also is increased. Deformation is also increased due to CFRP strengthening. The strength enhancement in terms of load carrying capacity significantly varied from 63.18-76.47%, 28.35-36.26%, and 19.23-20.23% for different orientation CFRP of deficient aluminium, stainless steel and mild steel tubular short column subjected to axial compressive loading, respectively. Failure load have increased due to CFRP strengthening and local buckling shifted to yield failure. Therefore, better performance can be attained by CFRP strengthening of deficient metaltubular short columns with appropriate technique.

5 Conclusion

In this paper, a series of tests on mild steel, stainless steel and aluminium deficient tubular short column subjected to axial compressive loading by CFRP strengthening have been presented. Failure mode, maximum load, and load-deformation behavior improvement of load-carrying capacity are also presented in this research. CFRP-wrapped sheet strengthening provided better results with an effective length of strength, confinement effect and local buckling shifted to yielding failure. Unstrengthen short column failed by local buckling either inward or outward directions. Based on experimental results, it was found that CFRP strengthening short column provides significant performance compared to reference metal column. The membrane strains were reduced in local buckling by the transverse strengthening of the short column. Based on experimental observation, it can be revealed that by increasing CFRP length, load-carrying capacity enhancement also is increased. The value of load-carrying capacity improved and it varied from 63.18-76.47%, 28.35-36.26%, and 19.23-20.23% for different technique CFRP of aluminium, stainless steel and mild steel tubular short column subjected to axial compressive loading, respectively. It is shown that aluminium load enhancement was higher than that of mild steel and stainless steel. The percentage increase in load-carrying capacity significantly. Deformation is also increased due to CFRP strengthening of steel short column. The test results revealed that externally bonded uni-directional CFRP strengthening restrains local buckling failure. Therefore, it can be concluded that the aluminium, stainless steel and mild steel tubular short column can be strengthened efficiently by CFRP with the appropriate method.

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