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Thermal Response of Cold-Formed Structural Steel Elements Reinforced with FRP Material

Respuesta Térmica de Elementos de Acero Estructural Conformados en Frío y Reforzados con Material FRP

Khalid Abdel Naser Abdel Rahim[a]

[a] *Department of Civil Engineering, Faculty of Science and Technology, University of Coimbra, Rua Luis Reis dos Santos 290, 3030-790 Coimbra, Portugal*

**Corresponding author: khalid.ar@outlook.com*

Abstract—In general, several studies have been conducted to improve the load-bearing capacity of cold-formed structural steel elements using FRP strengthening materials. While other researches focus on the use of FRP materials to reinforce cold-formed structural steel elements without thermally testing these elements under fire. On the other hand, other investigations test the thermal capacity of un-strengthened cold-formed steel elements without using FRP materials. Accordingly, it has been found that it is necessary to investigate the thermal response of cold-formed structural steel elements reinforced with FRP materials. This short communication technical note aims at pointing the current and latest research on the topic and to propose a novel methodology to be used in the future. Besides, to draw and address a conclusion for advancing the thermal behavior of cold-formed structural steel elements when reinforced with FRP materials.

Keywords—Thermal response, cold-formed steel, structural elements, FRP material

Resumen— En general, se han realizado varios estudios para mejorar la capacidad de carga de elementos estructurales de acero conformados en frío utilizando materiales de refuerzo FRP. Mientras que otras investigaciones se centran en el uso de materiales FRP para reforzar elementos estructurales de acero conformados en frío sin probar térmicamente estos elementos bajo fuego. Por otro lado, otras investigaciones prueban la capacidad térmica de elementos de acero conformados en frío no reforzados sin utilizar materiales FRP. En consecuencia, se ha descubierto que es necesario investigar la respuesta térmica de elementos estructurales de acero conformados en frío y reforzados con materiales FRP. Esta breve nota técnica de comunicación tiene como objetivo señalar las investigaciones actuales y más recientes sobre el tema y proponer una metodología novedosa para utilizar en el futuro. Además, sacar y abordar una conclusión para mejorar el comportamiento térmico de elementos estructurales de acero conformados en frío cuando se refuerzan con materiales FRP.

Palabras Claves— Respuesta térmica, acero conformado en frío, elementos estructurales, material FRP

I. INTRODUCTION

THE investigation of the thermal response of cold-formed structural steel members has been always under development. Several studies were carried out to find the global thermal behavior of cold-formed steel members. This is also including the flexural behavior and buckling of steel member. Concerning Wald et al. (2006), the fire resistance design codes of steel structures do not reflect real case scenarios of a fire, nor can be validated on complete steel structural buildings. This is since these design codes are established on single steel members and analyzed under standard fire. Therefore, Wald et al. (2006) strongly believe that improvements should be carried out on fire resistance design codes by testing complete steel structures under real fire cases. Moreover, the investigation which was done by Wald et al. (2006) has presented a set of experimental results of a joint research project between several universities including the

University of Coimbra. Furthermore, the main objective of the research project was to determine the global structural behavior and to track the development of thermal distribution in different structural members within the eight-story building. The composite building consisted of steel-concrete frames and was located in the Cardington laboratory. Finally, the research project has observed that (1) during fire testing, local buckling occurred in the bottom flanges of the beams after 23 minutes, (2) the endplates started to fracture when the thermally pretentious areas were cooled and (3) A ductile behavior was recorded in the fin plate connections.

Moinuddin et al. (2011) have experimentally investigated the increase in temperature of structural steel. This was conducted on six columns and two beams made of steel. Moreover, the testing was carried out on un-protected and protected steel members. Furthermore, the protection layer consisted of plasterboard and analyzed thermally under real fire case scenarios following ISO 9705 room. Besides, the research has observed that the temperature of the structural steel members which were protected with plasterboard has decreased by a couple of hundred degrees Celsius when compared to unprotected steel members. Moreover, the experimental results were in good agreement with the numerical analyzed model which showed less temperature on the outer layer surface of the protected steel members. While the unprotected steel members showed higher surface temperature when induced to ISO 9705 room fire. Finally, Moinuddin et al. (2011) have recommended further future investigations to be carried out on other types of fire protect layer materials and to perform a 3D numerical simulation to calculate the heat transfer and mass escape from the fire room opening.

Gunalan and Mahendran (2013) performed fire performance tests on cold-formed steel wall panels to forecast the rate of fire resistances of the walls. Moreover, Laím et al. (2014) did a fire response evaluation experimental study on cold-formed steel beams.

According to Danilov (2016), there has been a lot of research carried out on strengthening RC members with CFRP material, which is not the case for structural steel members. This was explained by Danilov (2016) due to the high elastic modulus and structural properties of the steel material. Moreover, the investigation which was carried out by Danilov (2016) focused on the CFRP/steel bond behavior. As a conclusion to his studies, Danilov (2016) demonstrated that the use of CFRP as a strengthening material to structural steel members can increase the safety level factor.

Chen et al. (2016) mentioned that strengthening structural steel members with CFRP has a great benefit. Besides, the research conducted by Chen et al. (2016) has majorly focused on tracing web crippling in a square hollow section type made of galvanized steel and strengthened with CFRP. Furthermore, the analysis considered the variation in web crippling under various boundary, load conditions, and CFRP strengthening sheet layers. It was concluded that strengthening galvanized steel tubular sections with CFRP has raised the ultimate capacity of web crippling when tested under concentrated loads. Also, Craveiro et al. (2016) conducted experimental research on the fire behavior of cold-formed steel columns. Moreover, IU (2016) has researched the geometrical change in steel structures under fire by analyzing the fire nonlinearly. To achieve this IU (2016) has suggested a corresponding thermal load before nonlinear fire analysis. Furthermore, it has been observed that the majority of work that has been carried out in the field of Fire behavior of cold-formed steel beam was done by Laím and Rodrigues (2018).

Abu-Sena et al. (2019) have performed both experimental and numerical analysis of twenty steel columns specimens. Moreover, two different types of section types were tested. The first section type was a short square, while the second section type was rectangular hollow. Moreover, three different sections with different dimensions were tested for a short square, while two different sections with different dimensions were tested for rectangular hollow. Furthermore, all tested specimens were strengthened with CFRP material with four different strengthening techniques. These are (1) Un-strengthened, (2) fully rapped, (3) one-layer strips, and (4) two layers strips. Additionally, the CFRP steel columns specimens were tested under pure compression until failure. Abu-Sena et al. (2019) have concluded from the results obtained, that the CFRP fully rapped technique has provided the steel columns with immunity against deformation. Besides, the CFRP fully rapped technique reduced the early occurrence of elastic buckling and achieved higher stiffness and more axial load capacity in the steel column. Moreover, the research has found that the layer strips strengthening technique has prevented the early occurrence of elastic buckling between the un-strengthened zones in the steel columns. It has also been found that there isn't any advantage between strengthening the steel columns with one layer or two layers strips. This was reasoned by Abu-Sena et al. (2019) due to the direct relationship between the rate of elastic buckling and CFRP reinforcement spacing and width. Finally, the numerical analysis results have shown good agreement with experimental results.

Furthermore, Yang et al. (2020) studied experimentally the fire performance of assembled box columns made from cold-formed steel. On the contrary, Abdel Rahim (2020) has presented the latest literature review on the fire resistance of RC members strengthened with CFRP Laminates. However, Abdel Rahim (2020) has focused majorly on RC structural members.

II. SUMMARY OF THE SHORT COMMUNICATION NOTE

It has been noted that no research was performed on Fire resistance of cold-formed steel beam reinforced with/using CFRP laminates. Moreover, it is strongly believed that the application of carbon fiber reinforced polymer on cold-formed steel beams will improve the global response and flexural behavior of the structural member in the event of a fire. Additionally, the use of CFRP laminates as an external reinforcement on cold-formed steel beam could reduce the buckling during the fire. Furthermore, Abdel Rahim (2020) has proposed to glue an L-shaped steel-plated (thickness 6mm) to the extruded side soffit CFRP laminates with a metallic adhesive. Accordingly, and concerning the proposed method by Abdel Rahim (2020), the main technique which could be applied to reinforce the cold-formed steel with FRP structural material is via external gluing using a special metallic adhesive. It is to propose a further investigation and continuation of the study which has been carried out by Laím et al. (2018) by using the same sectional parameters of cold-formed steel beams and analysis with an extension of reinforcing the structural member with CFRP laminates. Moreover, different types of CFRP application techniques could be used on the specimens to investigate the best technical method of CFRP application to improve the thermal response of cold-formed steel beam reinforced with CFRP material. Moreover, the cold-formed steel beam reinforced with CFRP should be tested under ambient and ISO 834 fire. Furthermore, the results will be compared with the previous results achieved by Laím et al. (2018) to prove that externally reinforcing the cold-formed steel beams will provide higher fire resistance to the structural member. Finally, the experimental test results should be evaluated numerically using an appropriate numerical analysis application; which could include a parametric geometrical study to validate the experimental results and to draw the conclusion and future work recommendations.

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