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FRP Reinforcement for Concrete Frame Buildings at Mexico City Around 1900 to 1960

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Abstract. *Mexico City is located at a seismic region with a complex soil. That condition had an impact on buildings and their conservation; it requires to know their structural state to control strain and cracks that could cause severe damages. To accomplish that objective this research contemplates the evaluation of concrete elements to propose an alternative to restraint antique concrete deformations using FRP system.*

Keywords: *Architecture, Reinforced Concrete, Plastic Flow, Textile Composites, Carbon Fiber.*

1 Introduction

Construction has always been complicated as the city is located on a seismic region (Servicio Geológico Mexicano, 2017), which also has a subsistence ground (Marsal J. and Mazari, 2016); specially during 1940, when technical information about the city complex soil was starting to be studied, and new constructive methods were developed for skyscrapers. Specialized research on the geotechnical and seismic engineering started in 1955 and 1962, respectively; twelve years after the Mexico City building code was used for the construction, about 1942- 1966. Thus, all RC structures built before 1960 have a probability of exhibiting some damage. The aging of RC structures could be accelerated due to soil and seismic stresses. Permanent axial load causes plastic flow on RC (Park and Paulay, 1988), creating disbalance between the load/stress distribution of the structural system and producing fissures, structural cracks, or increasing the one that exists (Muñoz and Mendoza, 2012). Another critical factor for RC frames built on seismic areas is ductility of columns, which is provided by reinforcing bars (rebars), but buildings constructed before 1970 are considered as non-ductile (Al-Mahaidi and Kalfat, 2018) while their columns have not enough rebars to accomplish with current regulation codes (Moehle, 1997).

Today most of these 1940-1960 buildings are still operative. The aim of this project is to improve the structural performance of historic buildings without affecting their patrimonial integrity. To accomplish the last objective, this study proposes the use of Fiber Reinforced Polymers (FRP) as a rehabilitation/reinforcement system. This method is selected because if its correctly applied, FRP could increase RC life-service by improving ductility and control plastic flow (Metha and Monteiro, 1998; Park and Paulay, 1988). The following variables will be analyzed to confirm the hypothesis:

a) The evaluation of FRP composites attached to a standard concrete mix will be made while analyzing the adherence between phases and the performance of FRP;

b) Analysis of the adherence between FRP composite and old concrete specimen;

c) Comparison between the previous data obtained with a weathering reinforced concrete specimen

2 Method and Materials

For this research FRP method refers to the use of a composite material made with carbon fiber impregnated with epoxy resin, applied to rehabilitate a structural member (American Concrete Institute, 2008). Carbon fiber CF) is the most commonly type of concrete reinforcement sections because its range of tensile properties allows an acceptable mechanical performance between phases (Hull, 2010; Park S.-J. , 2018), its semi crystalline microstructure exhibit an tensile strength over 1200-2250 MPa (Teng, Chen, Smith and Lam, 2002). Wet lay-up is the preferable method to applied CF because it has major advantages for *in situ* installation wherefor CF sheet can adapt to complex geometries (Teng, *et al*, 2002). Composites materials are based on mechanical adherence amid epoxy resin and concrete surface, so previous applied carbon FRP over the concrete section, it must be cleaned free of dust, oil or solvents. To increase phase adherence, it could be peel off the surface until it is removed, a thin layer with an average thickness from 0.5mm to 2mm. For the experimental campaign it selected 12K unidirectional carbon tow sheet thus one direction cloth has the strongest tensile resistance (Chanda, 2018). To attach the fiber, it is used an epoxy adhesive indicated by the manufacturer, Quintum ©. Their mechanical properties on Tables 1 and 2.

Table 1. Mechanical Properties of Carbon fiber.

Material	Ultimate Tensile Strength	Young Modulus	Weight
QuintumWrap-300©	875 MPa	34, 500 MPa	302 g/m^2

Mechanical properties of carbon fiber imbibed into epoxy resin. The cloth physical characteristics are: 0.5mm thickness, 500mm wide and 12K tow.

Table 2. Mechanical Properties of Epoxy Resin.

Material	Compressive Strength	Lap shear Adhesion Strength	Tensile Strength
Q102R ©	121 MPa	12 MPa	42 MPa

Epoxy adhesive is formed by two components: part A, bisphenol resin type and part B, ammonium adduct as hardener. Both shall mix in a 100g :10gr relation.

2.1 Manufacturing Specimens

Concrete specimens were designed considering a structural resistance of 25Mpa (CEMEX) using the standards C192/C192M (ASTM, 2002). For the experimental campaign they were made six concrete cylinders of 150mm radius and 300mm height, using Portland Composite Cement (IMCyC, s.f.). Three of them were selected for control of the mix and three more for FRP reinforcement.

2.2 Confined Concrete with Carbon Fiber

After 20 days of demolding concrete cylinders, three specimens were prepared to attach CF by scabbling a 2mm layer from the surface using an angle grinder. FRP method consisted of five steps that were made considering the combined action principle (Callister, 2009). The first step was applying a uniform layer of epoxy resin over the concrete surface. The second step was immersing the CF sheet ultimately into epoxy resin to reduce the air content and dry zones. The third step was wrapping to confining specimens with an impregnated fiber sheet with overlapping of 10 centimeters. The fourth step was removed the air trapped into the tows dragging a palette knife over the wrap. The fifth step was applied another uniform epoxy layer.

3 Compression Test

The compression test consists of applied a uniaxial increasing load on the material to deformed it until it's ultimate strain. If carbon fiber is correctly attached to concrete, it shall restring the lateral pressure and radial expansion, assuming that epoxy layer has the same thickness on both sides of fiber; tensile stress shall be equal in the hoop direction. Specimens were tested 28 days after manufacturing. Tests were made in an INTRON universal testing machine, screw-type UTM model MII 400WHVL with capacity for 200 tons.

4 Results

Control specimens showed average compression strength of 22MPa and for the FRP it was an average strength over 38 MPa. CF almost doubled the compressive strength of concrete. In Table 3 shown test results.

Table 3. Results of compression test for Control and FRP specimens.

Specimen	Maximal Load	Ultimate Compression Strength	Strain
Control 1	38,514 kgf	21 MPa	2.1 mm
Control 2	43,154 kgf	23.5 MPa	3.6 mm
Control 3	39,791 kgf	21.7 MPa	2.9 mm
FRP 1	65,914 kgf	36.5 MPa	5.1 mm
FRP 2	66,235 kgf	36.7 MPa	5.2 mm
FRP 3	73,090 kgf	40.5 MPa	5.5 mm

Table 3 shows the maximal values obtained from data bases of test machine.

Mechanical behavior of FRP specimens is shown in Figure 1. The three curves have a similar development with a semi-ductile trend, and all of them showed a small dropping when concrete reached its maximal compressive strength, as it is shown on figure 1 (left). All curves had the same geometrical composition, also, according with data in table 3: FRP 1-2 had a very similar mechanical behavior. On the other hand, FRP 3 continues growing asymmetric. The average FRP ratio was calculated using a sixth-grade polynomial trend line to correct each curve. After that, corrected data were put on the same base to define another trend line and made one more correction. The final result was the edited stress-strain curve, which had the average behavior of FRP specimens, it is shown in Figure 1 (right). Physical analysis shown in Figure 2-4.

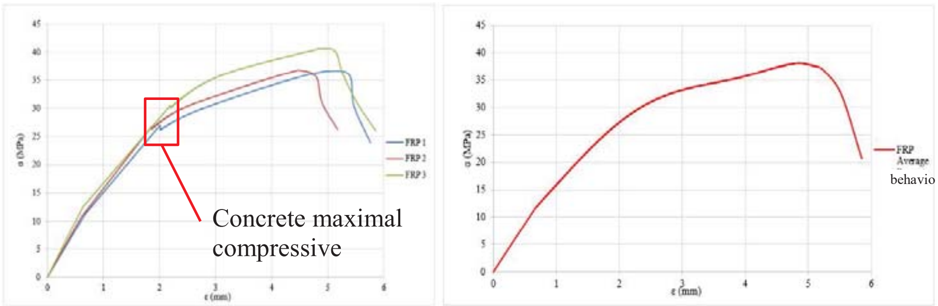

Figure 1. Stress-strain curves of FRP specimens and edited curve after statistical analysis.

On Figure 1, it is presented, from left to right, stress-strain curves of all FRP cylinders; stress-strain curve performed with edited compression data base.

Figure 2. FRP specimens after compression test.

On Figure 2 it is shown, from left to right, FRP 1 with total detachment of CF; FRP 2, total detachment of CF; FRP 3, partial detachment of CF.

Specimens FRP 1 -2 failed because a delamination from overlap section, it shown on Figure 3A. The revision of the pulled off carbon layer showed the presence of a considerable quantity of voids at overlapping area, Figure 3B. While the rest had concrete residuum, Figure 3C. For those two cases, the matrix layers were detached because the distribution of stress was discontinuous due to voids. Internal stress at borders generated micro tangential tensions which broken the matrix, then shear produced by pressure delaminates the overlap. Concrete aggregate exposed refers to such good phase adhesion. According to the partial uniform state of the concrete section, specimens FRP 1-2 can not reached their ultimate compression strength; otherwise, residual concrete would be abundant cracks on the cylinder section; checking numerical data at Table 3, load stress was transmitted by both phases only before delamination of FRP, after that each phase was working by itself: CF jacket was just restrung cylinder bulge until epoxy matrix was completely broken.

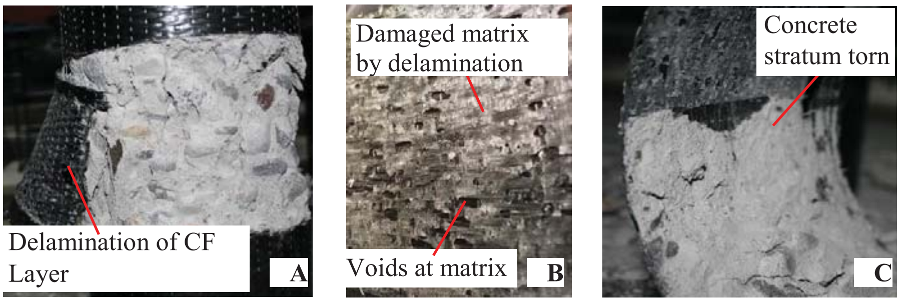

Figure 3. Detail of delamination in FRP at compression test.

On Figure 3 showed: (A) delamination of FRP matrix; (B) detail of voids at overlapping; (C) detail of adherence between phases.

FRP 3 reached its ultimate compressive strength. In this case, tangential tension was uniformly distributed over the cylinder's section until pressure shear the carbon layer causing an explosion. The tested specimen had small delamination on overlap area, Figure 4D. Then, it assumes less void contain at matrix and a uniformly epoxy coat on each side of layer. The explosion also produced the tearing of CF cloth, shown in Figure 4E; it observes parts from the concrete section who were torn by the adhesive and remained attached to the epoxy matrix, Figure 4F. In FRP 3, serious cracks were caused by stress distribution, which means that when the concrete reached its maximal compressive strength, it still transmitting load. That indicates the simultaneous transmission of stress from both phases; this specimen already worked as a composite material.

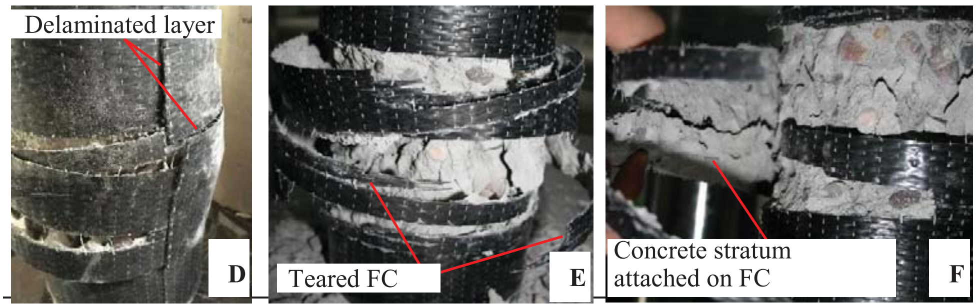

Figure 4. Detail of failure in FRP at compression test.

On Figure 4 it can be seen: (D) Partial delamination of FRP matrix; (E) detail of CF teared by shear strength; (F) detail of adherence between phases.

Below its presented, on Figure 5, the results of concrete and FRP cylinders to contrast the influence of CF cloth. On this figure observes that carbon fiber actually extend the plastic zone of concrete allowing it major load resistance.

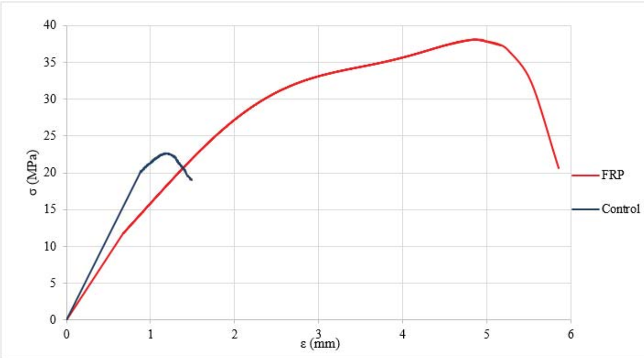

Figure 5. Comparation between FRP and pure concrete specimens.

Based on the current normative of the ACI (American Concrete Institute, 2008), the FRP manual of SIKA (SIKA, 2015) and current investigations about carbon fiber (Hernández Pérez, 2019), the theorical compressive strength results for FRP cylinders are compared with the practical test results. On Table 4 shown the results.

Table 4. Results of compression test for Control and FRP specimens.

Specimen	Theorical Confined Compressive Strength	Practical Confined Compressive Strength
FRP 1	30.92 MPa	36.5 MPa
FRP 2	30.92 MPa	36.7 MPa
FRP 3	30.92 MPa	40.5 MPa

Theorical confined compressive strength at table 4 only consider the design target compressive strength of 25 MPa for the three specimens.

Comparison of numerical results at table 4 expressed an increment of 40% in practical tests compared with the theorical calculation, even with the cylinders whose FRP was detached.

5 Conclusions

- Based on the numerical data provided by the mechanical test, the method of manufacture, and the physic analysis of the FRP concrete specimens it concludes that the fiber reinforcement polymer method increases the compressive strength of concrete even if FRP is not well attached. This condition means that quality control at FRP application must be hardly supervised.

- The surface treatment had successful results on adherence between epoxy-concrete interphase. Mechanical adhesion between phases was strong to keep them together after radial pressure pull off the epoxy matrix. Considering that, significant attention must be put on overlapping while FRP method is applied. Delamination at this zone is the common cause of failure at confining, the matrix is easy to fracture by shear strength if there is a high void percent.
- The adherence range of service is such enough to control longitudinal and transversal deformation and consequently adding partial ductile properties. So then, carbon fiber is capable of retarding plastic deformation on concrete by full confining. The compression test is an accelerate process to deforming concrete until it is destroyed, then considering that plastic flow is a slow process it can conclude CF could stop deformation by aging.
- At service, FRP could produce some elasticity to concrete because its tensile resistance parallels to the axis. However, the characteristic of its materials still having a fragile trend. Under that premise, the porous matrix at the overlapping area is vulnerable to shear, torsion, impact, etc. As an optional experimental purpose to improve adherence in epoxy-epoxy interphase, it could use a compatible polymeric adherence bridge.

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