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A Comparative Study on Carbon Fiber Bar and Steel Bar in Axially Loaded Reinforced Concrete Column

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ABSTRACT

This paper is a review of study carbon fiber reinforcement bar with the substitute of steel bar and their properties in axially loaded column. Corrosion and handling is the long concern for civil engineers so we have some alternative like carbon fiber reinforcement polymer (CFRP) and glass fiber reinforcement polymer (GFRP) and sometimes aramid fiber reinforced polymer (AFRP). From all of these we concerned about carbon fiber reinforced polymer bar which is not only light weight than steel or GFRP bar, but also corrosion resistive, Fatigue resistance, good tensile strength, electric and magnetic resistance which is favorable in structures where interference is undesirable. CFRP bar also stiff than any other polymer so the ultimate capacity of CFRP bar is more than any other polymer. carbon fibers are manufacturing by PAN based in which carbon fibers are delivered by transformation of polyacrylonitrile (PAN) and Pitch based carbon fibers in which Fibers are spun from coal tar (pitch). PAN based antecedent carbon fiber has higher strength than pitch based carbon fiber which has higher stiffness. Carbon fiber is always utilized as it is in matrix. In pole making and vessel building we ordinarily consider epoxy or polyester resin, yet carbon fiber is utilized as reinforcement for thermoplastics, concrete and ceramics.

KEY WORDS: CFRP bar, GFRP bar, compressive strength, deformation, ductility

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1. INTRODUCTION

Carbon Fiber Reinforced Polymer (CFRP) is a Polymer Matrix Composite material reinforced by carbon fibers. It is one of the indispensable and modern materials. The most common types of fibers used in structural applications are glass fiber reinforced polymer, aramid fiber reinforced polymer, and carbon fiber reinforced polymer The GFRP is the slightest costly however has bring down Strength and fundamentally bring down firmness contrasted with different choices. CFRP is the stiffest, tough, and costly one. AFRP has enhanced sturdiness and great effect obstruction. FRP fortification is accessible in various structures, for example, bars, grids, prestressing tendons and covers to serve an extensive variety of purposes. The fortifying scattered stage might be in type of either persistent or irregular carbon strands. Carbon fiber is extremely costly however they have the most noteworthy (weight proportion). The primary weakness of carbon strands is cataclysmic method of failure that is carbon fibers are brittle. So In recent years using the polymer materials in strengthening the concrete elements is on the developing process.

CFRP bars are made by resin Epoxy. It is utilized to stick whatever strengthening fiber is being utilized and to secure them position. Although the fundamental reason for the epoxy resin is to stick and transfer load on fibers. It shields the fibers from harm.

Carbon fiber properties given in ACI Code 2008[1], EGYPTIAN Code 2001[2] and British Standards Institution 1997, Indian Standard code 456-2000 but IS code only specified the properties of CFRP; it does not provide any recommendations for FRP. Carbon Fiber has High Strength to Weight Ratio (called specific strength) Due to the arrangement in which the crystals of carbon fiber arrange in long level lace or restricted sheets of honeycomb crystals. We can say that if any structure where we require a given strength with lighter ratio we made out of carbon fiber than if made out of glass. By testing we can see that glass fiber is almost twice than carbon fiber or we can say that the strength of glass fiber is half than the carbon fiber as compared to its weight. This property is called strength weight proportion.

Table 1: Density of different fiber and epoxy resin

Fiber	Density (gm/cc)
Carbon fiber	1.58
Glass fiber	2.66
Kevlar	1.44
Epoxy	1.25

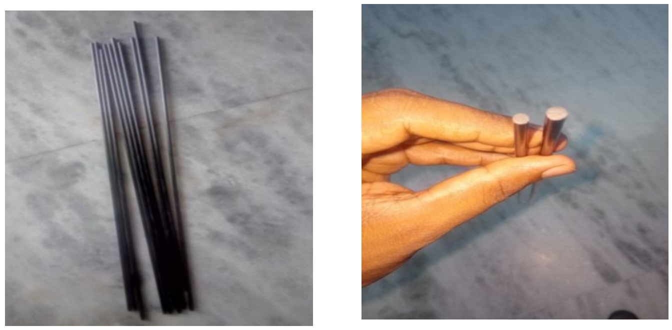

Figure 1: Carbon fiber bar with cross section

Carbon Fiber also extremely Rigid, stiff (rigidity and stiffness of material is estimated by its Young Modulus), No effect on chemicals but epoxy affected slightly, Protection from Fatigue in Carbon Fiber Composites is great but when carbon fiber fails it never gives any warning and it fails suddenly i.e. brittle, great Tensile Strength, Non Flammable, Low Coefficient of Thermal Expansion, Non Poisonous and X-Ray Permeable, less abrasion resistance, constantly black in colour, Relatively Expensive but low maintenance necessity of carbon fiber is a further preferred of this material.

2. LITERATURE REVIEW

Afifi et al (2013) concluded that instead of increasing the diameter and spacing we should decrease the diameter of CFRP and spacing should be closure for improving confinement efficiency. By doing this ductile behavior also little bit increase by Closure spacing and decreasing diameter of CFRP[3].

Tobbi et al (2012) explore 23 full scaled square concrete columns reinforced transversely with CFRP and GFRP ties, longitudinally with CFRP, GFRP and Steel bars. They found that FRP ties fundamentally increment concrete strength and ductility. He observes that better strength and confinement increment are accomplished by decreasing tie space and conclude that CFRP gives preferable results over GFRP[4].

A Lotfy (2010) test square reinforced concrete column with GFRP bars to research the RC column axial behavior. Columns were 250 x 250 mm and 1250 mm stature. Three distinctive reinforcement proportions; 0.723% (4 No.12 mm), 1.08% (6 No.12 mm), and 1.45% (8 No.12 mm) were utilized. He explores examination of axial behavior of square reinforced concrete columns with fiber reinforced polymer (FRP) bars. Column with steel reinforcement is more ductile than column with GFRP reinforcement but by increase the reinforcement of GFRP bar ductility also increases. The expanding of GFRP reinforcement proportions from 0.723 to 1.08% has a perceptible critical impact on the all conduct of columns more than the expanding of reinforcement proportions from 1.08 to 1.45%[5].

Luca et al (2009) investigation full-scale concrete columns reinforced with glass FRP bars under the pure axial load. Lateral tie spacing provided in column were 12 inch (305 mm) and 3 inch (76 mm). They found that lateral spacing having 12 inch fail in brittle while 12 inch spacing column gave some ductility. So he concluded that brittle failure can avoid by providing the less spacing[6].

De Luca et al. (2010) researched the compressive actions of RC columns reinforced with GFRP hoops commitment to the concrete core confinement. In view of the results of 5 RC square sample (610x610x3000 mm) tried under axial load, there is no distinction in action between columns inside reinforced with GFRP bars and columns inside reinforced with steel bars if the longitudinal reinforcement proportion is equivalent to 1.0%. Test results also indicate that steel are fail due to the buckling and GFRP bars are failed due to the crushing[7].

Faheemuz Zafar et al (2016) experiment concluded twenty one number of column manufactured and test under axial load. Size of the columns was kept same of all columns as 600 mm in height and 150 mm in diameter. Results concluded that a critical increment in axial limit of CFRP confined specimen and also watched Failure of CFRP confined column was brittle[8].

Lee et al (2004) investigation the action of concrete column restricted with both steel spiral and fiber composites. Two parameters were viewed as one material (FRP or Steel) and two materials (FRP and Steel) constrainment compose. They found that compressive strength of concrete limited with both CFRP and steel winding was around the same to the total of increments of the compressive strength of CFRP-confined concrete and spiral confined concrete[9].

Prachasaree et al (2015) test about the behaviour of GFRP reinforced concrete column with different kinds of stirrups. They found that distinctive kind of stirrups reinforcement had little contrast in strength; the spiral lateral reinforcement was the best as far as inelastic deformation and confining pressure [10].

Ehab Abdul Majeed Ahmed (2009) explores shear conduct of concrete beam reinforced with shear stirrup. Seven substantial scale T-bars were test with FRP and steel stirrup. Three bars reinforced with FRP stirrups, three with GFRP stirrups and one with steel stirrups. beams were test in four places bending over a range of 6 meter till failure to research the methods of failure and extreme limit of stirrups in beam activity. Result infers that six shafts flopped in shear because of FRP (carbon and glass) stirrup crack or steel stirrup yielding. Seventh shaft, reinforced with CFRP stirrups divided at d/4, fail in flexure because of yielding of the longitudinal reinforcement taken after by crushing of concrete[11].

L.ding et al (2010) studies on the pile which confined with CFRP and concluded that continuous layer is more efficient than using two separate layers[12].

Jaya et al (2012) study the CFRP and GFRP warping column on reverse cyclic loading and concluded that by comparison both CFRP and GFRP, CFRP is good in strength capacity while GFRP gives ductile behavior[13].

Seffo et al (2012) researches the conduct of concrete cylinder externally wrapped with carbon fiber-reinforced polymer (CFRP). They watched that the rate increment in compressive strength and malleability was more for ordinary strength concrete than that in high-strength concrete[14].

Katarina Gajdosova (2011) experiment CFRP reinforcement as CFRP strips in sections, CFRP confined sheet and in their mixtures. Results concluded that increment in load conveying capacity is 1.3% for columns strengthened by CFRP strips, 10.8% for columns strengthened by confinement with a CFRP sheet, and 12.6% for a blend of these two strategies[15].

Rahai et al (2008) experiments of concrete chambers bound with CFRP composites. Result demonstrates to improvement in the ductility, compressive strength and stiffness of the CFRP-wrapped concrete cylinders when compared with unconfined concrete cylinders[16].

Sharma et al (2005) researches the action of high strength concrete column under axial pressure. They locate that greater containment is required in columns of high strength concrete than in low strength concrete[17].

Shunde Qin et al(2015) examines the structural conduct of uncorroded and also corroded RC T-shafts strengthened in shear with either externally bonded CFRP sheets or implanted with CFRP bars. Nine tests were completed on RC T-beams having an effective depth of 295 mm and a shear length to effective depth proportion of 3.05. They explored parameters are the shear interface erosion level. The shear strength improvement given by the CFRP poles and externally confined CFRP sheets decreases from 19% to 12% and 15% to 11% respectively, with an expansion in shear interface consumption level from 7% to 12%. Erosion of the shear joins did not significantly affect the bar solidness[18].

Pando et al (2002) examine lot of test of FRP placed in pile load test. Axial pile load experiment showed good FRP performance instead of concrete steel pile[19].

Richard D. lacobucci et al (2003) examined the retrofit of square concrete columns with Carbon Fiber Reinforced Polymer (CFRP) for seismic opposition. It was discovered that additional constrainment with CFRP at basic areas upgraded ductility, energy dissemination limit and strength of every single substandard part[20].

Karabinis et al(2002) When wrapped with FRP composites, axially loaded concrete columns show higher strengths and flexibility and also bigger energy dissipation limits[21].

Ränby et al(2001) The assault of polymers by poisons has been investigated by a portion of the toxins themselves are photolytic, prompting further items that may cause debasement. For instance, so_2 oxidizes responds with water to create H_2SO_4 [22].

Paramanantham (1993) tried 14 concrete bar columns reinforced with GFRP reinforcement bars. The investigation detailed that the GFRP strengthening bars would just be stressed up to 20 to 30% of their definitive pressure strength in pure axial pressure, and up to 70% of their tensile strength in pure flexure. (Kawaguchi, 1993) performed comparable tests with concrete part reinforced with AFRP reinforcing bars. The two examinations demonstrated that concrete pressure individuals reinforced with FRP fortifying bars can be experiment by applying similar standards and strategies as utilized for concrete columns with steel reinforcement[23].

Mirmiran et al (2002) Fiber reinforced composites, because of their high strength to weight and stiffness to weight proportions, vast deformation limit, and corrosion protection from natural corruption introduced[24].

Bogdanovic et al (2002) Carbon sheets of reinforced concrete columns relies upon various parameters like the grade of concrete, steel reinforcement, thickness of the FRP coats (number of layers) and stiffness (kind of FRP) and loading conditions[25].

Huang et al (2000) CFRP has very less probability to harm resulting from fire, any type of vandalism, mechanical harm and aging effects[26].

Richa Pateriya et al (2015) examines reinforced concrete columns with GFRP. According to ACI and BS-8110 code, for a similar reinforcement proportion GFRP does not influence an ultimate load of the column. While according to Egyptian code, for a similar reinforcement proportion GFRP fundamentally increase the ultimate load of the column[27].

Richa Pateriya et al (2015) This paper exhibits the consequences of a diagnostic examination done on the conduct of concrete columns reinforced with steel, GFRP and CFRP bars utilizing ANSYS programming. CFRP a definitive load bearing limit of the column is fundamentally expanded (32% to 181%). For a similar load CFRP gives 18% less deformation when contrasted with steel[28].

Young-Jun You et al (2015) look at Tensile Strength of GFRP Reinforcing Bars of Hollow Section. Test demonstrates the stress strain conduct of the hollow GFRP rebar was average of that of FRP material that the bend amongst anxiety increments directly up to most extreme load and flops abruptly. The ideal (i.e. less in cost) tensile execution is accomplished for an empty zone proportion of 36% when utilizing the amount of fiber, that is, the material proportion, as target work[29].

Abdeldayem Hadhood et al (2017) examine the experiment result of 10 circular high strength column (HSC) for check the behaviour of the axial moment capacity and failure mechanism reinforced with either CFRP or steel bars and tried under various place of eccentricity. Every specimen is in size 305 mm in diameter and 1500 mm in height. At low eccentric loading (e/D = 8.2% and 16.4%), the compressive stressed opposed by the concrete were prevent. At high eccentric loading (e/D = 32.8% and 65.6%), the CFRP bars on the pressure side created higher strains than the steel bars[30].

Hamdy M. Mohamed et al **(2018)** Conduct Circular Concrete Members of beam Reinforced with CFRP Bars and Spirals under Shear. The test outcomes that if using same proportion of reinforcement of spirally and longitudinally then CFRP gives more shear resistance than steel bars. beam having spiral CFRP not provided are brittle in failure. However spiral reinforcement also enhances the contribution of concrete. The test outcomes show the shear strengths fundamentally increases as reinforcement proportion of spiral CFRP increased. Expanding the CFRP spiral reinforcement proportion from 0.26 to 0.52 expanded the shear strength of the specimen by 47%[31].

Khoathane et al (2015) However, the Young's modulus of the normal fiber reinforced polymer composites increment with expanding fiber loading. They found that the tensile strength and Young's modulus of composites reinforced with faded hemp fibers expanded very well with expanding fiber loading[32].

Hany Tobbi et al (2012) presents an experimental study of the behavior of 350 * 350*1400 mm square cross-section paper displays a trial investigation of the conduct 350 * 350*1400 mm square cross-area concrete columns reinforced with GFRP bars under concentric loading. The GFRP bars utilized contributed 10% of column limit, which is sufficiently close to steel's commitment (12%). This demonstrates that GFRP bars could be utilized in compression member gave sufficient confinement to remove the chances of bar buckling[33].

Kobayashi and Fujisaki (1995) tried carbon, aramid, and glass strengthening bars in compression. Test results demonstrated that the compressive strengths of the carbon, aramid, and glass-fiber strengthening bars were 30%, 10% and 30% of their relating tensile strengths, individually[34].

Martin KURTH et al (2010) examine total 24 number of beams of without shear reinforcement and shear reinforcement with GFRP bars. GFRP showed the failure with lower shear reinforcement proportion as ratio 0.75%. In the bar tests with higher proportion of 1.26% and 2.26% separately, contingent upon the concrete strength, either GFRP shear reinforcement burst or web smashing failure happened[35].

Norris et al. (1997) strengthened concrete beams in tensile areas with FRP and logically and with experiment concentrated the outcomes. They found that CFRPs connected vertically to breaks expanded the continuance and unbending nature. They revealed that, due to tension accumulation, brittle failure was watched[36].

Perera et al. (2004) connected a strengthening technique to 60*120*500 mm beam tests. The CFRP reinforced examples were presented to the 3-point bending test. CFRP was wrapped as a solitary layer around the beam inside the whole tensile locale and half of the sides. Results demonstrated that the reinforced beams conveyed 80% more load carrying capacity[37].

Maalej and Leong (2005) review the bonding action of CFRP and concrete squares. Adherence surfaces of different examples were presented to test and the failure tests were analyzed with the finite element display. they conclude that connection is good between's computational arrangements and experiment results[38].

Mehmet Mustafa Önal (2014) Strength increases of the beam strengthened with CFRP was 84% and displacement decrease was observed to be 39.5%. Strength increase of the beams strengthened with GFRP was 45%, and the displacement decrease was observed to be 53.6%[39].

S Sreenath et al (2017) In axial loading the yield point load appeared by the steel reinforced column was 37% more than that of GFRP reinforced column and a ultimate load appeared by the steel reinforced column was 34% more than that of GFRP reinforced column. At the point when loaded eccentrically, the yield load appeared by steel reinforced column was 31% progressively that of GFRP reinforced columns and an ultimate load at failure of the steel reinforced column was 34% more than that of GFRP reinforced column. The lack of GFRP reinforced columns is because of the small scale buckling of fibers in the bars. The energy consumed by steel reinforced column was 40% more than that of GFRP reinforced column when loaded axially and it was 55% more than GFRP reinforced column when eccentricity loaded. The poor energy assimilation limit is additionally ascribed to the small scale buckling of the fibers in the bars. When axially loaded the GFRP reinforced column demonstrated a superior ductility conduct but when loaded eccentricity steel reinforced column demonstrated better ductility[40].

3. FUTURE PROSPECTS:

Steel gives less strength and corrosion resistive than CFRP so using of CFRP as jacketing and as a sheet has being used widely and successfully. Some researcher analysis and provided the CFRP bar as reinforcement and concluded that CFRP bar gives better strength. We know that CFRP have 3400 N/mm^2 tensile strength but when it used as reinforcement due to epoxy and other properties it is not gives their full strength so we need to research how much actual CFRP bar are use to follow which grade property of steel. So we should find a recommendation between steel and carbon fiber bar. Also cost is required to reduce to used as reinforcement in construction.

4. REFERENCES

1. American Concrete Institute Committee 440, Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement, 2008;440.6-08.
2. Egyptian Code Committee, The Egyptian Code for the use of fiber reinforced polymer bars in the construction field, 2005.
3. Mohammad z afifi; hamdy m Mohammad, strength and axial behavior of circular concrete column reinforced with CFRP bars and spiral, ASCE 2013.
4. Hany tobbi, Ahmad sabri farghally, Strength model for concrete column reinforced with FRP and ties, ACI structural journal July 2012; 109(4).
5. Ehab M. Lofty, Ehab M. Lofty, Behavior of reinforced concrete short columns with Fiber Reinforced polymer bars, International Journal of Civil and Structural Engineering, 2010; 1(4): 707-722.
6. Antonia de luca, Fabio mata Antonia nanni Behavoiur of full scale concrete column internally reinforced with glass FRP bars under pure axial load, composite and polygon, 2009.
7. De Luca A., Matta, Behaviour of full scale glass fiber reinforced polymer concrete column under axial load, ACI structural journal, 2010; 107 (5): 589-596.
8. Faheemuz Zafar, Zishan Raza Khan, Sabih Ahmad, Performance of Carbon Fiber as Lateral Ties in Short Axially Loaded Concrete Columns, International Journal of Civil Engineering and Technology, 2016; 7(3): 122–128.
9. Jung yoon lee, Ji sun park, Y. Mansour, Behavior of Concrete Columns Reinforced with Fiber Reinforced both spiral and fiber composite, 13th world conference of earthquake engineering, Canada, 2004.
10. Waraphote Prachesarry, Sitthichai, Awasthi, Behavior and performance of gfrp concrete columns with various types of stirrups, International journal of polymer science, 2015.
11. Ehab abdul mageed, Shear behavior of concrete beam with fiber reinforced polymer stirrups, 2009.
12. L. Ding, H.M.Seliem, S.H.Rizkalla, Behavior of concrete pile confined with CFRP grid, 2010.
13. K.P.Jaya and Jessy Mathai, Strengthen of RC column using GFRP and CFRP, 15WCEE, 2012.
14. M Seffo, Hamcho, Behavior of Concrete Columns composite material, Elsevier, Energy procedia, 2012; 19: 276-285.

15. Katarina Gajdosova, Juraj Bilcik, Slender reinforced concrete columns strengthened with fibre reinforced polymers, Slovak Journal of Civil Engineering, June 2011; XIX(2): 27-31.
16. A.R. Rahai, P. Sadeghian and M.R. Ehsani, Experimental behavior of concrete cylinders confined with CFRP composites, 14th world conference on earthquake engineering, Beijing, china, October 2008.
17. Umesh K Sharma, S.S. Kaushik, Behavior of high strength Concrete Columns Reinforced with Fiber Reinforced Under axial compression, Journal of advanced concrete technology, June 2015.
18. Shunde Q in, Samir, Jian, CFRP shear strength of reinforced concrete T Beams with corroded shear links, 2015.
19. Pando AM, Flitz MG, Dove JE, Interface shear test on FRP Composite piles, international deep foundation congress, Orlando, 2002.
20. Richard D. Lacobucci, Retrofit of square concrete columns with carbon fiber reinforced polymer for seismic resistance, ACI Structural Journal, 2003.
21. Karabinis AI, Rousakis TC, Concrete Confined by FRP Material a Plasticity Approach, Engineering Structures, 2002; 24: 923-932.
22. Ränby and Rabek, The attack of polymers by pollutants, Springer, Verlag Berlin Heidelberg New York, 2001.
23. Paramanantham, N. S., Investigation of the Behavior of Concrete Columns Reinforced with Fiber Reinforced Plastic Rebars, MS thesis, Lamar University, Beaumont, Tex, 1993.
24. Mirmiran, A., Yuan, W. Chen, X., Design for Slenderness in Concrete Columns Internally Reinforced with Fiber-Reinforced Polymer Bars, ACI Structural Journal, January – February 2002; 116-125.
25. Bogdanovic, A, Strengthening Circular Concrete Columns Using FRP Sheets-Applications, The University of Manitoba, Composite Materials in Civil Engineering, 2002.
26. Huang, P.C. Hsu, Y. Nanni, Assessment and Proposed Structural Repair Strategies for Bridge Piers, In Proc., 3rd Inter. Conf. on Advanced Composite Materials in Bridges and Structures, Ottawa, Canada, J. Humar and A.G. Razaqpur, Editors, 2000.
27. Richa Pateriya et al, Finite Element Analysis of Different Types of Composite Column, International Journal of Emerging Technology and Advanced Engineering, May 2015; 5(5).
28. Richa Pateriya, Dr. Saleem Akhtar, Prof. Nita Rajvaidya, Analysis of Compressive Strength of Columns Reinforced with Steel & FRP Bars; June 2015; 4(6).

29. Young-Jun You, Ki-Tae Park, Dong-Woo Seo, Ji-Hyun Hwang, Tensile Strength of GFRP Reinforcing Bars with Hollow Section, 2015.
30. Abdeldayem Hadhood, Hamdy M. Mohamed, Brahim Benmokrane, Strength of circular HSC columns reinforced internally withcarbon-fiber-reinforced polymer bars under axial and eccentric loads 2017.
31. Hamdy M Mohamed, Mohammad A, Brahim Benmokrane, Strength and Axial Behavior of Circular Concrete Columns Reinforced with CFRP Bars and Spirals, Journal of Composites for Construction, October 2013; 18(2).
32. Khoathane et al, Surface modification of natural fiber composite and their potential applications, Surface modification of biopolymers, USA john valy and sons Inc, 2015.
33. Hany Tobbi, Ahmed Sabry Farghaly, Brahim Benmokrane, Concrete Columns Reinforced Longitudinally and Transversally with Glass Fiber-Reinforced Polymer Bars, Aci Structural Journal, July 2012; 109(4).
34. Kobayashi, K., and Fujisaki, T., Compressive Behavior of FRP Reinforcement in Non-Prestressed Concrete Members, Proceedings of the 2nd International RILEM Symposium on Non-Metallic (FRP) Reinforcement for Concrete Structures, Ghent, Belgium, 1995; 267-274.
35. Martin KURTH et al, Experimental and theoretical study on shear capacity of concrete beams with frp reinforcement. Institute of Structural Concrete, Aachen, Germany Mies-van-der-Rohe Strabe 1, 52074.
36. T. Norris, M. Lean, H. Saadetmenesh, M. R. Ehsani, Analytical and experimental studies on strengthening of reinforced concrete beams with carbon FRP, Journal of Structural Engineering, Arizona, 1997; 903.
37. R. Perera, A. Recuero, A. de Diego, C. López, Adherence analysis of fiber-reinforced polymer strengthened RC beams, Computers and Structures, 2004; 82(23–26): 1865–1873.
38. M. Maalej, K. S. Leong, Effect of beam size and FRP thickness on interfacial shear stress concentration and failure mode of FRP-strengthened beams, Composites Science and Technology, 2005; 65(7-8): 1148–1158..
39. Mehmet Mustafa Önal, Strengthening Reinforced Concrete Beams with CFRP and GFRP, Vocational School, Ahi Evran University, 40100 Kırşehir, Turkey, 13 July 2014.
40. S Sreenath et al, Behaviour of axially and eccentrically loaded short columns reinforced with GFRP bars, IOP Conf. Ser. Earth Environ. Sci. 80 012030