A Review of Fiber Reinforced Polymer Composite Rebar for Reinforced Cement Concrete

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ABSTRACT

Reinforced concrete is first invented in the middle of 19th century in France. It has given the breakthrough of using steel as a add-on reinforcement for improving the structural durability of infrastructures. Since then it is widely adopted by the humans in construction of bridges, buildings and modern infrastructure. The strength of construction in reinforced concrete is strongly depending on the steel reinforcement. Steel being a metal when comes in contact with the water start corrosion by electrochemical reaction which form the rust. This rust expands is volume and create further stresses in the concrete to fail. So ensure the durability of reinforced concrete construction it is important to prevents the corrosion of steel reinforcements. Some of the preventative measures used is additives in concrete and epoxy coated steel rebars. In both the cases steel rebar starting of corrosion is delayed but not completely eliminated. Fiber Reinforced Plastic (FRP) being structurally strong and excellent anticorrosive martial has found its way in the application. FRP rebar consisting the fibers mostly glass and a resin matrix such as epoxy and Vinylester is developed as replacement for steel rebar in concrete. FRP rebar completely eliminates the corrosion in concrete and increase its durability for sustainable infrastructure. In this paper, various developments in the field of FRP rebar are reviewed. The important standards used for qualifications and testing are summarized. Some of limitations of FRP rebar along with possible current research trends are discussed in the paper.

Keywords: - *FRP, GFRP Rebar, Steel Rebar, Reinforced Concrete, Corrosion*

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1 Introduction

Reinforced Concrete with steel as reinforcement is widely used in the construction of bridges, buildings and social infrastructures. The durability of such infrastructure is very much important considering the investment done for construction and impact of failures during accidents. There are various incidents all over the world regarding the failure of bridges, buildings etc. Most of the time reason for this failure is long term degradation of concrete due to steel rebar corrosion. FRP being the structurally strong and excellent non-corrosive material is used in various civil infrastructure applications such as repairing of historical Masonry, FRP plates as external reinforcements on existing structure, bridge decks, structural shapes and FRP rebar as reinforcement in concrete. (1) FRP is also used in (a) Bridge structure including deck, stringer, rebar sections (b) road pavement (c) utility poles for electrical transmission and street lights (d) pipelines for fuels, water, drainage and chemicals etc.(e) Big diameter modular tanks for Ocean thermal Energy conversions(OTEC) (f) Underground tanks and chemical storages (g) modular panels for erectable housing (h) marine walkways and shipbuilding (i) GFRP wraps for concrete structure maintenance. (2). Environmental factors affecting the durability of FRP rebar in concrete are moisture, use at elevated temperature and alkaline environment. These problems can be solved by use of higher glass transition temperature (greater than 30^0) than usage matrix and use of resin rich layers on the surface of FRP rebars. (3) The use FRP rebar is increasing based on assured durability in corrosion environment. Countries like Japan, Canada, USA and UK developed national guides for engineer’s to implement the FRP rebar in construction. (1) These standards have helped the engineers to bring the confidence in their design and ultimately promote the use of FRP rebar use.

2 Materials and Methods

2.1 Constituents of FRP rebar

Fiber Reinforced Plastic materials consist two main components first is fiber and second is matrix. Matrix is the polymer chemical which hold the fibres together. Various examples of thermosetting polymers are - Epoxy, Polyester, Vinyl ester, etc. The matrix serves the functions of aligning the Fibers, Transfer the Load between the Fibers, Assisting the Fibers in Providing Compression Strength and Modulus to the Composites, Assisting the Fibers in Providing Shear Strength and Modulus to the Composites, Protecting the Fibers from Environmental Attack. (4)The representative mechanical properties of some of the matrix are as mentioned in Table 2.1 (5)

Table 2.1 Mechanical Properties of Matrix

Sr. No.	Resin Type	Density (Kg/m^3)	Modulus of Elasticity (Mpa)	Tensile Strength (Mpa)
1	Polyester	1200	4000	80
2	Vinyl ester	1150	3300	75
3	Epoxy	1200	4500	130

Fibers consist of thousands of filaments, each filament having a diameter of between 5 and 15 micrometers, allowing them to be producible using textile machines. (5) It provides the strength and stiffness to the Composite. Examples of Fibers are glass, carbon, aramid, etc. The four main factors that govern the fiber's contribution are the basic mechanical properties of the fiber itself, the surface interaction of fiber and resin (the 'interface'), the amount of fiber in the composite ('Fiber Volume Fraction'), the orientation of the fibers in the composite (4) The representative mechanical properties of some of the fibers are as mentioned Table 2.2- (5)

Table 2.2 Mechanical Properties of Fiber

Sr. No.	Fiber Type	Density (Kg/m^3)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
1	E Glass	2600	74	2500
2	Carbon	1750	230	3200
3	Kevlar	1450	130	2900

As per Table 2.3 glass fiber is most used material for the manufacturing and experimentations of GFRP rebars by researcher. This is because the economic advantage in use of GFRP rebar compared to other types of fibers. However, carbon fiber and aramid rebars are also tested for bond behavior evaluation. (6) The basalt fiber rebars are used for pullout and beam bending test evaluation. (7) Basalt fiber rebars are also used for tensile test and beam bend test evaluation (8). Polyester, Vinylester and Epoxy resins are commonly used for research and experimentations. Urethane modified vinyl ester resin is also evaluated for temperature and environmental effects. (9)

Table 2.3 Cosntituents of FRP Rebar

Reference	Type of Fiber	Type of Resin
Young-Jun You (10)	Glass Fiber	Polyester / Vinyl ester
Edoardo Cosenza (6)	Glass Fiber / carbon Fiber / Aramid Fiber	Polyester / Vinyl ester / Epoxy
Shahad AbdulAdheem Jabbar (11)	Glass Fiber	Polyester

Renata Kotyniaa (12)	Glass Fiber	-
Hamid Abbasi (9)	Glass Fiber	High grade Isophthalic polyester / Vinyl ester / Urethane modified vinyl ester
Hakan Sarikaya (13)	Glass Fiber	Vinyl Ester
Zarina Saidova (14)	Glass Fiber	Epoxy
G. Yuan (15)	Glass Fiber	Vinyl Ester
Hamzeh Hajiloo (16)	Glass Fiber	-
Yulia O (7)	Basalt Fiber	-
Marek Urbanskia (8)	Basalt Fiber	

2.2 Manufacturing of FRP Rebar

FRP manufacturing consist involvement of matrix and fiber. The ingredients involve the matrix and fiber materials. This processing requires Good bonding between matrix and fiber, Proper orientation of the fibers, Good amount of volume fraction of fibers, Uniform distribution of fibers within the matrix material, proper curing of the resin, Limited amount of voids and defects, Good dimensional control for the final part for getting the desired mechanical properties. Pultrusion is one of the manufacturing processes used in FRP composite. It is very similar to the extrusion in metals and plastics and used to manufacture the constant cross section profiles. It uses the fiber in continuous roving form and resin in liquid form. Fiber in fabric or chopped strand mat form can also be used in pultrusion. As shown in Figure 2.1 fibers are stored in rack and it in then preformed to desired shapes using guides. After this fibers are dipped in resin bath for impregnation and finally entered in pultrusion die which controls the final shape of the profile. Pultrusion die is manufactured using tool steel and electrically heated to the desired temperature for curing of the resin matrix. Profiles are pulled through the pulling mechanisms and cut in the required length at the end of pultrusion machine by circular saws. (4) (17) (18)

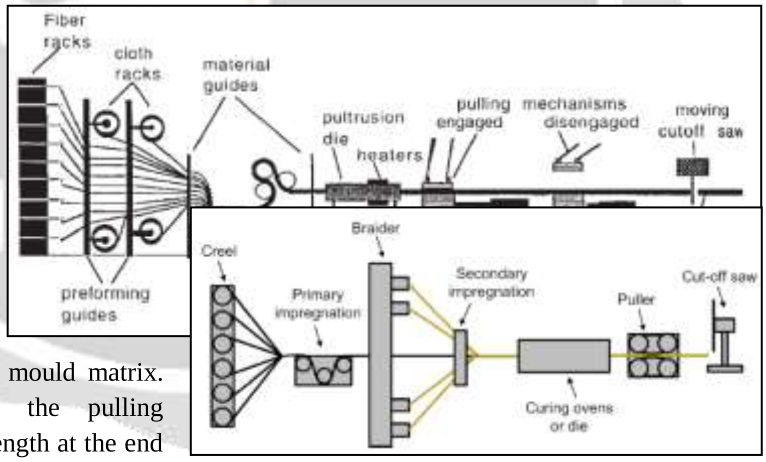

Figure 2.1 Pultrusion Process (4)

As per Table 2.4 pultrusion is most commonly used process for FRP rebar manufacturing.FRP rebar can also manufactured by fiber immersion in resin then excess resin is removed manually without use of mould matrix. (6) Profiles are pulled through the pulling mechanisms and cut in the required length at the end of pultrusion. Braidtrusion is the combination of pultrusion and braiding process. Braidtrusion produces the helical surface finish on FRP rebars to improve the bonding strength with concrete. (10). Figure 2.2 shows the schematic of Braidtrusion process. (19)

Table 2.4 Manufacturing of FRP Rebar

Reference	Manufacturing Process
Young-Jun You (10)	Braidtrusion (combination of pultrusion and braiding) process
Edoardo Cosenza (6)	Braidtrusion (combination of pultrusion and braiding) process
Shahad AbdulAdheem Jabbar (11)	Fiber is immersed in resin then excess resin is removed manually without use of mould
Renata Kotyniaa (12)	Braidtrusion (combination of pultrusion and braiding) process
Hamid Abbasi (9)	Pultrusion with helically wrapped glass fiber
Hakan Sarikaya (13)	Pultrusion
Zarina Saidova (14)	Pultrusion
G. Yuan (15)	Pultrusion
Hamzeh Hajiloo (16)	Pultrusion

2.3 FRP Rebar Finishing's

FRP rebar finishing is important for bond of FRP rebar with concrete. Bond of FRP rebar to concrete is controlled by several factors- chemical bond, friction due to surface roughness of FRP rods, mechanical interlock of rod with concrete, hydrostatic pressure on FRP due to concrete shrinkage, sealing of FRP rods due to temp change and moisture absorption. (6) To improve the bonding between GFRP rebar and concrete, the helical fiber braiding is carried out on GFRP rebar using modified Braidtrusion process. (10) Bond strengths is generally evaluated using direct pullout tests where rebar embedded in concrete is pulled on universal testing machine. (10) (6) (7) (20). Bond Strength can also be evaluated using four point bend test. (12). Researcher have developed different finishes of the FRP rebars such as helical fiber braiding (10), ribbed type rebar, braided rebar, twisted strand, spiral glue (6) and sand coated (20).

2.4 Design Guidelines Standards

2.4.1 Steel Rebar

Steel Rebar are commonly used in all types of civil infrastructure applications. In order to maintaining the uniformity among all manufactures they are bound to follow the ASTM A615 and steel rebars are given certain grades based on their achievable strengths. Table 2.5 shows the different grades of steel rebars as per ASTM A615 (21)

Table 2.5 Tensile Strength Requirements as per ASTM A615

Description	Grade 40	Grade 60	Grade 75
Minimum Tensile Strength psi(MPa)	60000 (420)	90000 (620)	100000 (690)
Minimum Yield Strength psi(MPa	40000 (280)	60000 (420)	75000 (520)

2.4.2 FRP Rebar

FRP rebar are being utilized in many civil infrastructure but still there are concerns regarding the durability. In order to builds the civil engineers confidence in FRP rebars researchers around the world has developed the design guidelines standards. Features of two such standards ACI440.6M-08(17) and ASTM D7957M-17 (22) (23) are summarized in Table 2.6

Guaranteed property is the characteristic value provided by the manufacturer less than or equal to the mean minus three standard deviations of the samples tested according to a specified method. (23) ACI440.6M-08 standard suggest the use of GFRP and CFRP rebars and specifies recommended fibers in unidirectional ravings forms, matrix as epoxy and vinyl ester with glass transition temperature of ≥100°C. Manufacturing of rebars is through pultrusion and its variations are recommended. GFRP Tensile strength is range from 480MPa for 32.2mm diameter to 760MPa for 6.4mm diameter. CFRP Tensile strength is range from 1100MPa for 19.1mm diameter to 1450MPa for 6.4mm diameter. Tensile Modulus of GFRP and CFRP are 39.3GPa and 124GPa respectively. (22) ASTM D7957M-17 standard suggest the use of GFRP rebars and specifies recommended fibers in unidirectional ravings forms, matrix as epoxy and vinyl ester with glass transition temperature of ≥100°C. There is a not specific manufacturing process recommendation however manufacturing of particular batch should follow same process. GFRP Tensile Force is range from 437KN for 32.3mm diameter to 27KN for 6.3mm diameter. Tensile Modulus of GFRP is 44.8GPa. (23)

2.5 Testing Standards

FRP Rebar Qualification and Testing done on various parameters as summarized in Table 2.7. Test Methods for the measurement of characterizes are mentioned below in Table XX (23)

Table 2.6 ACI and ASTM Standard Comparison

Description	ACI440.6M-08 (22)			ASTM D7957M-17 (23)	
Title	Specification for Carbon and Glass Fiber Reinforced Polymer Bar Materials for Concrete Reinforcement			Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement	
Fibers	Unidirectional Roving forms			Unidirectional Roving forms	
Matrix Resins	Vinylester and Epoxy			Vinylester and Epoxy	
Glass Transition Temperature	≥100°C			≥100°C	
Manufacturing process	Variations of the Pultrusion Process			No specific manufacturing process recommended	
Fiber Content (%)	Volume – ≥55%			Mass ≥70 %	
Minimum Guaranteed Tensile Strength (MPa) / Guaranteed Ultimate Tensile Force (KN)	Diameter (mm)	GFRP (MPa)	CFRP (MPa)	Diameter (mm)	GFRP (KN)
	6.4	760	1450	6.3	27
	9.5	760	1310	9.5	59
	12.7	690	1170	12.7	96
	15.9	655	1100	15.9	130
	19.1	620	1100	19.1	182
	22.2	586	N/A	22.2	241
	25.4	550	N/A	25.4	297
	28.7	517	N/A	28.7	365
	32.2	480	N/A	32.3	437
Nominal Tensile Modulus of Elasticity (GPa)	GFRP -39.3	CFRP-124		GFRP -44.8	

Table 2.7 Testing Standards for FRP Rebar

Parameter	Test Method
Fiber Volume Fraction	ASTM D3171-09-2009: - Standard Test Methods for Constituent Content of Composite Materials (24)
Tensile Strength and Modulus	ASTM D7205-06-2016: - Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars (25)
Glass Transition Temperature	ASTM E1356 - 08(2014): - Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry

3 Results and Discussion

GFRP Rebars are now well established and used in civil construction applications. (1) (2). As summarized in Table 3.1 the tensile strength of GFRP Rebar is ranging from 586MPa to 1281MPa. Tensile strength of GFRP rebar is mainly depends upon type of fiber, resin matrix bond, fiber volume fraction, voids and pre-tension during pultrusion and arrangement of core fibers. (10). Also as generic glass fiber strand tensile strength is 2500MPa (5) which is very high compared to the requirement of steel rebar requirement in the range of 280MPa to 690MPa (21). So it is very oblivious if the desired fiber volume fraction in GFRP Rebar, the tensile strength of GFRP rebar meets the desired range 480MPa to 760MPa as per ACI440.6M-08 (22). Tensile Modulus of the generic glass fiber 74GPa (5) and resultant GFRP rebar modulus summarized in Table 3.1 is 38.7GPa to 50.5GPa. The desirable Tensile Modulus as per ACI440.6M-08 and ASTM D7957M-17 is 39.3GPa and 44.8GPa respectively.

Table 3.1 GFRP Rebar Mechnical Properties

Reference	Diameter (mm)	Tensile Strength (MPa)	Tensile Modulus (GPa)
Young-Jun You (10)	12.7	1132	49.4
Renata Kotyniaa (12)	12	1281	50.5
	16	1205	50.5
	18	1109	50.5
Maria (20)	8.5	822	46.8
	12.7	600	41.5
A Abbasi (27)	9	760	40.8
	12	690	40.8
	22	586	40.8
Khorramian, Koosha (28)	16	629	38.7
Hamid Abbasi (9)	12.7	655	40.8
Nestore Galatia (29)	9.53	760	40.8
G. Yuan (15)	13	663.7	39.2

The lesser modulus of GFRP rebar, GFRP reinforced concrete beam are having less ductility compared to steel reinforced concrete beam. Ductility is important for giving early alarm for failure. The experimental research carried for ductility improvement of FRP reinforced contrite beam by using additional steel reinforcement. Ductility improvement in the beam obtained using hybrid steel-GFRP reinforced beam. (30) Finite Element

Analysis of Hybrid reinforcement combination shows that, (a) Increase in steel rebar content with GFRP rebar concrete beam increases the stiffness more compare to CFRP rebar beam. (b) Providing the steel rebar in top and bottom of the FRP rebar reinforced concrete beam results in desired ductile failure (c) Overall strength of the beam is decreased if GFRP rebar percentage is more than steel rebar percentage. (31) Hybrid GFRP and steel rebar combination is also used for improving the blast performance of concrete beams. (32) Through there is a positive result obtained in ductility improvement but still there is compromise on the main benefit of GFRP rebar which is corrosion resistance.

Modulus improvement by maintaining the durable and excellent corrosion resistance of GFRP is need of future. This has been tried by very few researchers by fiber hybridization within the FRP rebar. Steel core and glass fiber covers has improved the modulus of FRP rebar upto 129.2GPa. (33) Carbon core and Aramid sleeve has improved modulus of FRP rebar upto 10ksi (68.9GPa) (34)

Also as seen from the Table 2.1, Table 2.3 and Table 2.6 resin systems used in manufacturing of rebar are of thermosetting types. As thermosetting resins undergoes one direction reactions for curing. Hence, once cured cannot be soften by any means. This results that FRP rebars cannot be bend to the required shape as it in case of steel rebars. (5) (4) (21) The GFRP stirrups required in the continuous rectangular forms are specifically molded to net shape as per required dimensions. (35)

4 Conclusion

Reinforced concrete durability is affected by corrosion of steel rebars FRP Rebars are successfully developed and use as replacement of steel rebars. Based on its performance evaluations design guidelines such as ACI440.6M-08 and ASTM D7957M-17 are being developed to maintain the uniformity among the manufactures. These standards also build the confidence and promote the of use of FRP rebars for civil constructions. Qualifications of FRP rbar is being done based on certain parameters such as fiber volume fraction, glass transition temperature, tensile strength and tensile modulus which are evaluated based on physical testing of materials. GFRP rebars are mostly used because of lesser cost and easy availability all over. Lesser modulus of elasticity of GFRP rebars creates challenges for structural designers which are either solved by using extra amount of GFRP rebars and or addition of some steel rebars along with GFRP rebars. The use of steel rebars along with GFRP rebars further creates challenges for corrosion protection of steel rebars. Some of the researchers have attempted modulus improvement through fiber hybridization and results are quite successful. Also stirrup used in reinforcement are being specifically manufactured to near net shape using molds as GFRP rebars cannot be bend. So there is need for further research in modulus improvement of GFRP rebar and onsite bending of GFRP rebars.

Reference

1. *Fiber-Reinforced Polymer Composites for Construction—State-of-the-Art Review.* **C. E. Bakis, L. C. Bank, F.ASCE, V. L. Brown, M.ASCE, E. Cosenza, J. F. Davalos, A.M.ASCE5.** s.l. : American Society of Civil Engineers, 2002.

2. *ADVANCED FIBER REINFORCED POLYMER COMPOSITES FOR SUSTAINABLE CIVIL INFRASTRUCTURES.* **Liang, Gangarao Hota and Ruifeng.** s.l. : International Symposium on Innovation & Sustainability of Structures in Civil Engineering Xiamen University, China, 2011, 2011.

3. *Durability Gap analysis for Fiber-reinforced composites in civil infrastructure.* **VM Karbhari, J W Chin, D Hunston, B. Benmokrane, T. Juska, R. Morgan, J. J. Lesko, U. Sorathia and D. Reynaud.** s.l. : Journal o Composites for Contruction, 7(3), 238-247, 2003, 2003.

4. **Hoa, Suong V.** *Priniciples of the Manufacturing of Composite Materials.* s.l. : DEStech Publications, 2009.

5. **Daniel Gay, Suong V. Hoa, Stephen W. Tsai.** *Composite Materials Design and Applications.* s.l. : CRC PRESS, 2003.

6. *Behavior and Modeling of Bond of FRP Rebars to Concrete.* **E Cosenza, G Manfredi, R Realfanzo.** s.l. : journal of Composite for Construction, 1997.

7. *Application FRP-rebar in the manufacture of reinforced concrete Structure.* **Kustikova, Yulia O.** 2016, ELSEVIER, pp. 361-365.

8. *Investigation on Concrete Beams Reinforced with Basalt Rebars as an Effective Alternative of Conventional R/C Structures.* **Marek Urbanskia, Andrzej Lapkob, Andrzej Garbaczc.** s.l. : 11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013, Elsevier Procedia Engineering 57 (2013) 1183 – 1191, 2013.

9. *Temperature And Environmental Effects On Glass Fibre Rebar: Modulus, Strength And Interfacial Bond Strength With Concrete.* **Hogg, Hamid Abbasi and Paul.** 5 / Page - 394-404, s.l. : Composite Part B Engineering, 2005, Vol. 36.

10. *Methods to enhance the guaranteed tensile strength of GFRP rebar to 900 MPa with general fiber volume fraction.* **Young-Jun You, Jang-Ho Jay Kim, Sung-Jae Kim, Young-Hwan Park.** 2015.

11. *Replacement of steel rebars by GFRP rebars in the concrete structures.* **Shahad AbdulAdheem Jabbar, Saad B.H. Farid.** s.l. : ScienceDirect, 2018.

12. *Bond behavior of GRFP bars to concrete in beam test.* **Renata Kotyniaa, Damian Szczecha, Monika Kaszubskaa.** s.l. : ScienceDirect, 2017.

13. *The Effect Of Glass Fiber Rebar Reinforcement On Flexural Behaviour Of Reinforced Concrete Structural Elements.* **BALCIOGLU, Hakan SARIKAYA and H Ersen.** s.l. : EGE University, Izmir, Turkey / IV. International Ege Composite Materials Symposium KOMPEGE 2018, 2018.

14. *Thermal Analysis Of Glass-Fiber Reinforced Polymer Rebars.* **Zarina SAIDOVA, Valery GRAKHOV, Grigory YAKOVLEV, Anastasiya GORDINA, Andrey ZAKHAROV.** s.l. : Engineering Structures And Technologies ISSN 2029-882X / eISSN 2029-8838 2017 9(3): 142–147, 2017.

15. *Study Of Coaxial FRP Sleeve / Expansion Cement Connection Of FRP Rebars.* **G. Yuan, G. Dong, J. Ma.** s.l. : The 18th International Conference on Composite Materials, S korea/ ICCM/ Aug 2011/ Paper ID-M6-4-IF1287, 2011.

16. *Mechanical properties of GFRP reinforcing bars at high temperatures.* **Hamzeh Hajiloo, Mark F. Green, John Gales.** s.l. : Elsevier / Construction and Building Materials 162 (2018) 142–154, 2018.

17. **Gurit, M/s.** *Guide to Composite.* s.l. : M/s Gurit, 2013.

18. **Starr, Trevor F.** *Pultrusion for Engineers.* s.l. : Woodhead Publishing Ltd and CRC Press LLC, 2000.

19. **M. Ivey, C. Ayranci, J.P. Carey.** Braidtrusion. [book auth.] Jasson P Carey. *Handbook of Advances in Braided Composite Materials.* s.l. : Woodhead Publishing, 2017.

20. *Bond Performance of FRP Rebars-Reinforced Concrete.* **Maria, Leone,Marisa.** s.l. : Journal of Materials in Civil Engineering, 2007.

21. **ASTM.** Standard Specification for Deformed and Plain Carbon steel Bars for Concrete Reinforcement. s.l. : ASTM, 2004.

22. **ACI.** *ACI440.6M-08(17) – Specification for Carbon and Glass Fiber Reinforced Polymer Bar Materials for Concrete Reinforcement.* s.l. : American Concrete Institute, 2017.

23. **ASTM.** ASTM D7957M-17 Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement. *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement.* s.l. : ASTM, 2017.

24. —. Standard Test Methods for Constituent Content of Composite Materials. s.l. : ASTM, 2009. ASTM D3171-09.

25. —. Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars. s.l. : ASTM, 2016. ASTM D7205-06.

26. —. Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry. *ASTM E1356 - 08(2014).* s.l. : ASTM, 2014.

27. *Fire Testing of Concrete Beams With Fibre Reinforced Plastic Rebar.* **Hogg, A. Abbasi and P.J.** 8 / Page - 1142-1150, s.l. : Composite Part A: Applied Science and Manufacturing, 2006, Vol. 37.

28. *Short Concrete Columns Reinforced with GFRP Rebars Under Eccentric Loading.* **Khorramian Koosha, and Sadeghian Pedram.** s.l. : CSCE Canada/ May-June 2017/Page 532-1to 532-7, 2017.

29. *Thermal effects on bond between FRP rebars and concrete.* **Nestore Galatia, Antonio Nannia, Lokeswarappa R. Dharanib, Francesco Focaccic, Maria Antonietta Aiello.** s.l. : Composites: Part A 37 (2006) 1223–1230, 2006.

30. *Experimental study of hybrid FRP reinforced concrete beams.* **Pamb, Denvid Lau and Hoat Joen.** s.l. : Elsevier / Engineering Structures 32 (2010) 3857–3865, 2010.

31. *Behavior of concrete beams reinforced with hybrid steel and FRP composites.* **Suzan A.A. Mustafa, Hilal A. Hassan.** s.l. : Housing and Building National Research Center, 2018.

32. **Johnson, David Tse Chuen.** *Blast Performance of Hybrid GFRP and Steel Reinforced Concrete Beams.* s.l. : Department of Civil Engineering, University of Toronto, 2009.

33. *HYBRID FRP REINFORCING BARS FOR CONCRETE STRUCTURES.* **Ki-Tae Park, Hyeong-Yeol Kim, Young-Jun You, Sang-Yun Lee,Dong-Woo Seo.** s.l. : Fourth Asia-Pacific Conference on FRP in Structures (APFIS 2013), 2013.

34. *Design Methodology Of A Ductle hybrid Kevlar Carbon Reinforced Plastic for Concrete Structures By The Braidtrusion Process.* **Hoa Lam, Frank Hampton, Frank K. Ko, and Harry G. Harris.** s.l. : The 13th International Conference on Composite Materials,China/ ICCM/ June 2001/ Paper ID-1444, 2001.

35. *An Overview Of The Use Of Composite Rebars As Reinforcement In Geo-polymer Concrete Structures.* **Ginghis B. Maranan, Allan C. Manalo, Warna Karunasena, Brahim Benmokrane, Priyan Mendis, Darren Lutze.** s.l. : Composites Australia And CRC ACS April 2015 Composites Conference, 2015.