ASPS Conference Proceedings 1: 195-200 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Behaviour of Hybrid Fiber Reinforced Geopolymer Concrete Beams under Flexural Loading

Addepalli Mallinadh Kashyap[1*], Tanimki Chandra Sekhar Rao[1], Naraparaju Venkata Ramana Rao[2]

[1*]Ph.D Scholar, Department of Civil Engineering, Jawaharlal Nehru Technological University, Hyderabad, India
[2]Professor, Department of Civil Engineering, Bapatla Engineering College, Bapatla, India
[3]Director, National Institute of Technology, Warangal, India

Paper Id - 020367

Abstract

This paper presents the behaviour of GPC beams with and without fiber under flexural loading. The work is presented in two parts. In the first part tests were conducted for mechanical properties of plain and hybrid fiber reinforced Geopolymer concrete to determine maximum strength characteristics of concrete. In the second part of the program two types of under-reinforced beams were cast with plain GPC and hybrid fiber reinforced GPC (HFRGPC)and tested under two points loading. The percentage of tensile rebar ratio is kept constant for two types of beams. The hybrid fiber reinforced GPC is prepared with 1.5%(1%Steel+0.5% Polypropylene) of fibers and used to cast the under reinforced beams .The cast specimens are tested after a specified curing period to determine first crack load, ultimate load, load-deflection behaviour and crack patterns. The results are compared with the theoretical values. From the test results, the fiber volume fraction has a compelling effect on the cracking load, ultimate load, crack pattern and failure mode. The flexural behaviour of the beams including the induced cracks, failure pattern, load deflection capacity and ductility index were compared. The ductility index of hybrid fiber reinforced beams is greater than that of GPC beams. The HFRGPC beams showed superior performance than that of GPC beams for parameters considered in this experimental study.

Keywords: Industrial waste exhausts, Hybrid fiber, Geopolymer concrete, Flexural loading

1.Introduction

Geopolymer concrete(GPC) is a sustainable concrete typology, whose novelty characteristic, compared to OPC, is constituted by the utilization of industrial waste exhausts like fly ash and GGBS as complete replacement of OPC. Industrial waste exhausts combined with an alkali activator solution and cured at ambient conditions react to form a binder material called "Geopolymer ". The gain of interest in utilizing GPC for structural applications takes place from the demand of minimizing the global demand of OPC, whose mass production is accountable for major emissions of anthropogenic CO_2. GPC has been considered over the recent past as a green material to OPC, whose manufacturing is subjected to 8 to 9% of CO_2 emissions globally [1]. GPC binders can be produced from various types of A-S precursors, with divergent costs, availability and reactivity worldwide [2]. Due to the requirements in terms of attentive formulation, difficulties in practice and limitations in supply chain, GPC is still away from complete replacement of OPC across its wide range of applications [3]. Significant works were performed by the researchers on flexural performance of reinforced GPC beams with various reinforcement ratios and concluded that GPC and RCC beams in the performance aspects evaluated for similar reinforcement ratio [4-6]. The normalized bending moments for reinforced GPC and RCC with varying reinforcement ratios were quite similar, while the normalized bending moment at first cracking of GPC beams was lower than that of RCC beams [7]. Some investigations studied the capabilities of existing analytical models, that are basically developed for RCC elements to anticipate the behaviour of GPC elements. Series of tests were performed on under reinforced beams so as to anticipate the behaviour of beams at service and ultimate limit state and concluded that the equations used to anticipate the elastic as well as flexural/shear strength of RCC beams can also be used to predict the responses of GPC beams [8-9]. It is established fact that OPC exhibits brittle nature due to its low uniaxial tensile strength and with random fiber addition to concrete matrix can significantly enhances the tensile strength along with toughness[10-13].Studies were carried out and proved that the inclusion of short hybrid polymeric fiber can significantly enhances the flexural performance aspect of GP mortar and concrete. Further, the fiber will increase the shrinkage effects [14-16].The enhancement of tensile nature of concrete because of the utilization of fiber can be used to increase the ultimate and serviceability aspects of various types of structures [17]. Extensive investigations have proven the sustainability of fiber to partial or complete replacement of conventional reinforcement in concrete characterized by an apparent higher degree of redundancy like slabs [18-19]. The test results of an investigation performed on GPC beams subjected to flexure are herein furnished. This investigation aimed at predicting the efficacy of GPC as a viable structural material in view of its

*Corresponding author. Tel: +91 9491728149; E-mail address: mallinadhkashyap@gmail.com

Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India | 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.495

utilization for the production of precast elements like beams, columns and other roofing elements. The test program included GPC beams with and without fiber and the aspects like first crack load, ultimate load, load-deflection behavior and crack patterns were studied.

2 Experimental Program

2.1 Materials

The experimental program comprises of two phases of work. In the first phase, mechanical properties of plain GPC and Hybrid fibre reinforced GPC mixes were studied. The constituent ingredients of the mixes are industrial waste exhausts i.e. Class F fly ash and GGBS procured from VTPS Thermal power station and Vizag Steel industry, India. The oxide composition of pozzolanic materials is presented in Table 1 and the specific gravity values of the two inert materials are 2.65 and 2.86 respectively. Local river sand with specific gravity 2.67 in compliance to Zone-II of IS:383-1978 and crushed granite with specific gravity 2.60 were used as fine and coarse aggregates. The alkaline initiator solution is prepared with a combination of sodium silicate (liquid form) and sodium hydroxide(pellet form) in a mass ratio of 2.5. A 12 Molar concentration of NaOH is used in the alkaline liquid proportion. The ratio of alkaline liquid to binder ratio of 2.5 is adopted for GPC mix proportions. To attain a homogeneous mixture, the alkali initiator solution is prepared one day prior to casting. To improve the workability of Hybrid fibergeopolymer mixes, CONPLAST SP 430 obtained from Fosroc Chemicals was utilized.

2.2 Preparation of GPC specimens

2.2.1 Mechanical Properties

The GPC mix constituents for estimation of mechanical properties were weigh batched as per the quantities in Table2.

Table-1 : Oxide composition in Class F-FA and GGBS

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
Class F-FA	66.80	24.50	4	1.50	0.45	0.40
GGBS	39.18	10.18	2.02	32.82	8.52	1.1

Table 2 : Mix Ingredients of GPC concrete

S.No.	Constituents	M20 grade Quantity(kg/m^3)	
1.	Binder(FA+GGBS) (50%+50%)	380.68	
2.	Na_2SiO_3	122.36	
3.	NaOH	49 (8M)	
4.	SP (1.5%)	5.7 lit/m^3	
5.	Fine aggregate	554	
6.	Coarse aggregate	1294	20mm----776.4Kg 12mm----388.2Kg 6mm ------ 129.4Kg
7.	Steel+PPfiber	(0.5%+0.5%)	3.8
		(1%+0.5%)	5.71
		(1.5%+0.5%)	7.62

As a first step, the aggregates were mixed in a pan mixer in dry condition for about 2 minutes. Later, the blended binder was mixed along with aggregates and the prepared alkaline initiator solution was mixed along with SP and the mixing continued for a period of 3 minutes until homogeneity in mixture was identified. Later, steel and polypropylene fiber were mixed slowly into the mix and proper fibre content distribution is ensured without the effect of balling.

The slump cone test is conducted for all mix proportions to ascertain required workability condition to structural elements as per IS code specifications. The cube, cylindrical and prism specimens were cast to examine mechanical properties. For hybrid fibergeopolymer matrices, the fiber was composed of hooked end steel and polypropylene (PP) fiber. The aspect ratio steel fiber is 60 of length 30 mm and diameter 0.5 mm and fibrillated PP of length 12 mm with 1050 deniers are considered in the study. The GPC test specimens were demolded after one day of casting and cured under ambient environment conditions for 28 days. Figure.1 shows the cast and cured specimens. The workability and mechanical strength characteristics are tabulated in Table 3.
From Table.3, it observed that the percentage of fiber content is indirectly proportional to the workability, because the inclusion of fiber makes the fresh concrete harsh and thus affects the slump value. The hybrid fiber reinforced beam elements were cast with a GPC mix composed of 1.5% fiber fractions. The reason is the mechanical characteristic property of GPCHFR1.5 mix is better than other fiber mix proportions.

Fig. 1 Cube, cylindrical and prism specimens of GPC mixes

S.No	Mix Designa-tion	% of fiber content (Steel+ Polypropylene)		Slump (mm)	Compressive strength (MPa)	Split-tensile strength (MPa)	Flexural strength (MPa)
1.	GPC	0	0	122	26.12	2.41	2.48
2.	GPCHFR1	0.5	0.5	118	27.52	2.77	2.58
3.	GPCHFR1.5	1	0.5	115	28.43	2.92	2.71
4.	GPCHFR2	1.5	0.5	114	28.00	2.65	2.67

Fig.2 Test setup for mechanical properties of GPC specimens

2.2.2 Response of beam elements under flexural loading

This phase is considered as the second part of an experimental program in which two sets of under-reinforced beams (each set consist of two beams) were cast and tested under two point loading. The first set contains under reinforced beams cast with plain GPC matrix and are designated as GPCR. In the second set similar under reinforced beams were cast with two different concrete mixes plain and hybrid fibergeopolymer concrete(HFRGPC) and are designated as GPRCB.In this set the, beam is divided into two zones namely, pure flexure zone(distance between two load points, Zone-I) and flexure and shear zone(distance between support and load point, Zone-II).The plain GPC is used in the zone-II and in zone-I hybrid fiber reinforced GPC with 1.5% fiber volume fraction is used for casting of beam. In this study, 2-12mmΦ, Fe415 grade steel reinforcement bars (re-bar) are used as tensile reinforcement in two sets of beam specimens. The size of beams is 1500 X 125 X 200 mm. The clear cover adopted is 20 mm. The reinforcement details of beams are presented in Fig.3.

The test setup arrangement for flexural testing of beam specimens is shown in Figure.4. The beam is placed in a UTM of 400kN capacity. All the beams are with simply supported end conditions and the beam supports are placed on stiffened steel girder of length 2500 mm and 1350 mm is the beam effective span. The load was applied on two points each 225 mm away from the centre of the beam towards the support. Dial gauges of 0.001 mm least count were used for measuring the deflections under the load points and at mid span. The dial gauge readings were recorded at an interval of load increment till the beam reaches its ultimate load carrying capacity. The load interval is 2.5kN.

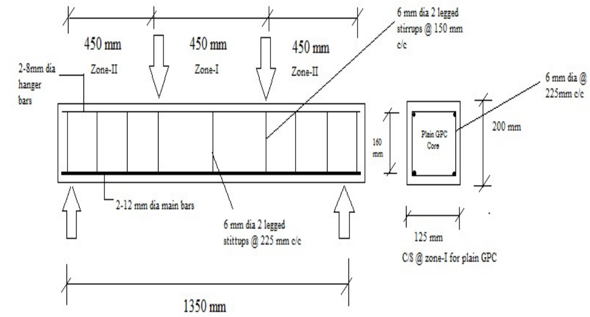
3 Test Results of beam specimens

3.1 Load Carrying capacity of Beams

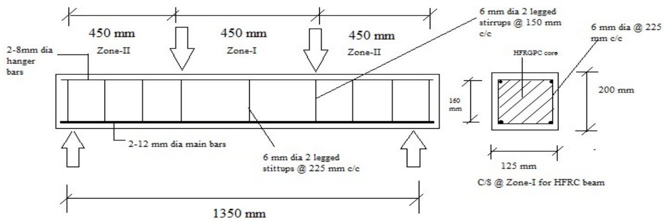
The initial cracking in two types of (GPCRB and GPRCB) beams took place in the constant moment region. The cracks initiated in GPCRB beams penetrate more deeply into the compressive zone rapidly when the load application reaches its ultimate value, but in GPRCB beams, the formation and propagation of cracks are delayed much compared to GPCR beams at the same applied load values.

This result shows that the fibers in the GPRCB beams apprehended the crack formation and propagation. After formation of the first crack, several new cracks are initiated along the longitudinal surface (Lxd) and the width of existing cracks open widely in both GPRCB and GPCRB beams. It is observed that the crack width in the GPCRB beams was larger than that in the GPRCB beams. This result indicates that the addition of fibers in the flexure zone affected the width of the cracks in the GPRCB beams. The reason is due to fibers played a role in bridging the cracks and redistributing the stress in the GPRCB.

In GPCRB beams the failure at ultimate load occurred by a sudden crushing of the concrete in the compressive zone, while the typical failure of the GPRCB beams occurs from the steel fibre pulling out of the fibre matrix. The theoretical value of maximum flexural crack width for plain GPC matrix beam specimen GPCRB is calculated as per IS: 456-2000 (Annexure-F) using the following formula.



(a) GPCRB beam reinforcement detailing



(b) GPRCB beam reinforcement detailing

Fig.3 Detailing of steel reinforcement in beam specimens

Fig.4 Test setup arrangement of beams

$$W_{cr} = \frac{3a_{cr}\varepsilon_m}{1+\dfrac{2a_{cr}-C_{\min}}{(h-x)}} \quad \text{----(1)}$$

Where

$$a_{cr} = \sqrt{\left[(S/2)^2 + d_c^{\,2}\right]} - \frac{d_b}{2}; \varepsilon_m = \varepsilon_1 - \frac{b(h-x)(a-x)}{3E_sA_s(d-x)}$$

x = Depth of neutral axis, h =section depth, b = section width, C_{min}= minimum clear cover, d_b = diameter of main tension bar, S=spacing of bars, d_c =effective cover,ε_m= avg.strain of steel at selected position,ε_1= €$_s$(a-x)/(d-x), A_s=Area of tension steel reinforcement, E_s=Young's modulus of steel.

The theoretical value of maximum crack width for fiber matrix beam specimen GPRCB is calculated from the equation proposed by RILEM as per ENV 1992-1-1:1991[20] using the following formula

$$W_k = S_{r,max}(\varepsilon_{sm} - \varepsilon_{cm}) \quad \text{----- (2)}$$

Where, $S_{r,max=}$ max.spacing of cracks; $\varepsilon_{sm=}$ the mean strain in the reinforcement; $\varepsilon_{cm=}$ the mean strain in the concrete between the cracks.

$$S_{r,\max} = \left(50 + 0.25k_1k_2\frac{\phi_b}{\rho_r}\right)\left(\frac{50}{L/\phi}\right); \left(\frac{50}{L/\phi}\right) \le 1$$

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t\dfrac{f_{ct,eff}}{\rho_{p,eff}}\left(1+\alpha_e\rho_{p,eff}\right)}{E_s} \ge 0.6\frac{\sigma_s}{E_s}$$

Where Φ_b=reinforcement bar diameter, K_1= Coefficient in the regard of reinforcement bond properties (0.8 for high grade steel), K_2= Coefficient depends on distribution of strain(0.5), ρ_r = effective reinforcement ratio,μ=aspect ratio of fiber, σ_s=tension reinforcement stress, α_e= E_s/E_{cm}, k_t – factor depending on load duration, $\rho_{p,eff}$– reinforcement ratio for longitudinal reinforcement ($\rho_{p,eff}$= ρ_r).

The proposed RILEM coefficient appraises only the impact of steel fibre on the avg. Spacing of crack. But the limitation with this is that, it considers only the impact of aspect ratio of steel fiber, but the volume fraction of fiber(V_f) is not considered. The crack patterns were shown in Figure.5.The test results of beams are presented in Table 4 , 5 and 6.

Fig.5 Mode of failure of GPC specimens

3.2 Ductility ratio of GPC beams

The flexural ductility of beams is predicted by the recorded mid-span deflection of the beams during the tests. Table 5 presents the yield and ultimate deflections and corresponding ductility ratio of the beams.

$$\text{Ductility ratio } \mu = \frac{\Delta u}{\Delta y} \quad \text{---------(3)}$$

3.3 Comparison of theoretical and experimental deflections

The young's modulus for hybrid fiber reinforced concrete of specified grade is calculated using the following expression proposed by Neves et al[21].

$$E_i = (10.5 - 0.22V_f)\, f_c^{\,0.33} \quad \text{----- (4)}$$

where V_f is volume fraction of fiber;f_c is compressive strength of concrete and the value of Young's modulus for specified hybrid fiber reinforced concrete is found to be 27.255MPa.

The theoretical and limiting deflections at service loads of the beams are calculated as per the recommendations of IS:456-2000.

Service load, $W_{S=}$ Ultimate load (W_u)/ 1.5

$$\Delta_{Theor} = \frac{23WL^3}{648E_iI}$$

Where, Δ_{The}= Mid-span theoretical deflection in mm, W = Load acting on the beam in kN

L= Effective span of the beam in mm, EI = Flexural rigidity in Nmm^2 ,E_i = Modulus of elasticity N/mm^2 , Limited deflection = Span / 250 in mm as IS-456-2000.

Table 4: Experimental results of the beam specimens

S.No	Beam Designation	First crack load (kN)	Service load (kN)	Yield load (kN)	Ultimate load (kN)	Deflection at ultimate load (mm)	Max. crack width (mm) (Theor)	Max.crack width(mm) (Exp)	Mode of failure
1.	GPCRB	20.4	33.63	37.81	50.61	8.62	0.396	0.52	Flexure
2.	GPRCB	32.7	41.33	48.24	62.12	12.10	0.190	0.21	Flexure-shear

Table 5: Ductility ratio of beams

S.No	Beam Designation	Yield deflection Δ_y(mm)	Ultimate deflection Δ_u (mm)	Ductility ratio $\mu = \Delta_u/\Delta_y$
1.	GPCRB	8.32	8.60	1.03
2.	GPRCB	10.58	11.45	1.09

Table 6: Comparison of theoretical and experimental deflections of beams

S.No	Beam Designation	Service load (kN)	Δ_{Theor} @ Service load (mm)	Δ_{Exp} @ Service load (mm)	Limiting deflection as IS-456 span/250 (mm)	Ultimate load (kN)	Δ_{Theor} @ Ultimate load (mm)	Δ_{Exp} @ Ultimate load (mm)
1.	GPCRB	33.63	3.58	3.71	5.4	50.61	7.75	8.60
2.	GPRCB	41.33	4.96	5.12	5.4	62.12	9.28	11.45

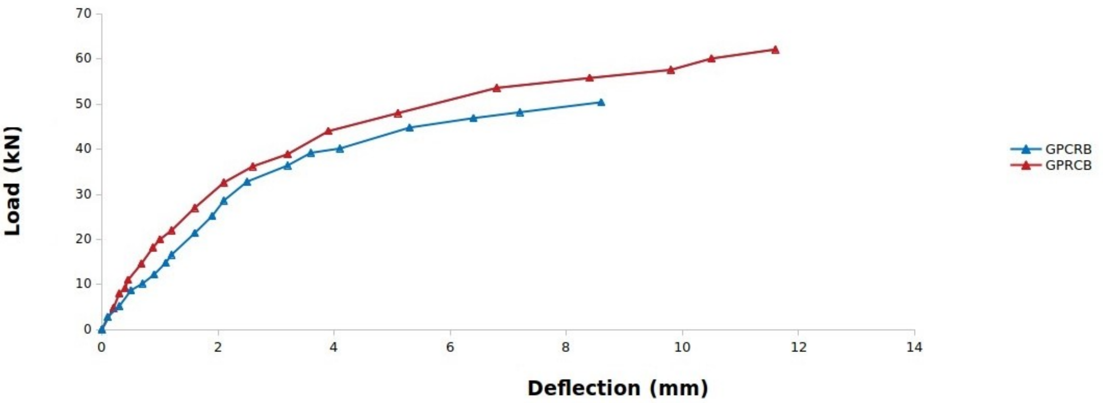


Fig.6 Load-Deflection responses of GPC specimens with and without hybrid fibers

The load-deflection curves of the test beams with different types of GP concrete are shown in Figure 6.However; the maximum loads of the GPRCB beams were much greater than those of the GPCRB beams due to the contribution of the fiber to the bending strength of the GPRCB beams. Additionally, use of hybrid fiber improved the bending strength of the beams remarkably.

4 Conclusions

From the experimental program, the following conclusions can be drawn:

1. Significant mechanical strength characteristics are achieved by the cast GPC concrete with better workability property under ambient curing.
2. The load-deflection response was similar up to some portion for two types of beams and later the effect of fiber was found. The hybrid fiber reinforced GPC beams exhibit superior behaviour than control GPC beams.
3. The ultimate load carrying capacity of hybrid fiber reinforced GPC beams is higher than that of GPC beams with same main reinforcement and the percentage is found to be 34.16%. .
4. The failure of beams was initiated by tensile steel yielding followed by the concrete crushing in compression face in plain GPC beams.
5. The ductility ratio of hybrid fibre reinforced GPC beams is higher than that of GPC beams and the percentage increase is found to be 5.82%.

6. The failure pattern of GPCRB and GPRCB beams at ultimate loads is found to be flexure and flexure shear mode respectively for the same loading conditions.

Disclosures
Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. Malhotra, V.M., "Role of Supplementary Cementing Materials in Reducing Greenhouse GasEmissions", in Concrete Technology for a Sustainable Development in the 21st Century, O.E. Gjorv and K. Sakai, eds., E&FN Spon, London, 2000.

2. McLellan B.C., Williams R.P., Lay J., Van Riessen A., Corder G.D "Costs and carbon emissionsfor geopolymer pastes in comparison to ordinary portland cement. Journal of Cleaner Production. 19(9- 10), 1080-1090 (2011).

3. Attanasio, A.; Pascali, L.; Tarantino, V.; Arena, W.; Largo, A. "Alkali-activated mortars forsustainable building solutions: Effect of binder composition on technical performance", Environments 2018, 5, 35.

4. Hardjito, D.; Wallah, S.E.; Sumajouw, D.M.; Rangan, B.V, "On the development of fly ashbased geopolymer concrete" ACI Materials Journal, Vol: 101, 467-472.

5. Sumajouw, D.M.J.; Hardjito, D.; Wallah, S.E.; Rangan, B.V, "Behaviour and Strength ofReinforced Fly Ash-Based Geopolymer Concrete Beams", In Proceedings of the Australian Structural Engineering Conference, Newcastle,Australia, 11–14 September 2005.

6.Sumajouw, M.D.J.; Rangan, B.V "Low-calcium fly ash-based geopolymer concrete: Reinforcedbeams and columns", In Research Report GC 3; Faculty of Engineering, Curtin University of Technology: Perth,Australia, 2006.

7. Dattatreya.J.K , Rajamane N.P , Sabitha.D , Ambily.P.S , Nataraja M.C, "Flexural behaviour ofreinforced Geopolymer concrete beams", International Journal of Civil And Structural Engineering,Volume 2, No 1, 2011.

8. Yost.J.R, Radlinska.A, Ernst.S,Salera.M., "Structural behavior of alkali activated fly ash concrete.Part 1:Mixture design, material properties and sample fabrication", Materials and Structures,Vol:46,No.3,2013.

9. Yost.J.R, Radlinska.A, Ernst.S,Salera.M., "Structural behavior of alkali activated fly ash concrete.Part 2:Structural testing and experimental findings.", Materials and Structures,Vol:46,No.3,2013.

10. Balaguru, P.N.; Shah, S.P. Fiber-Reinforced Cement Composites; McGraw-Hill Inc.: New York,NY, USA, 1992.

11. Rossi.P, Acker.P, Malier.Y, "Effect of steel fiber at two different stages: the material and thestructure", Materials and Structures, Vol:20,No.120,1987.

12. Minelli, F. Plizzari, G, "Derivation of a simplified stress–crack width law for Fiber ReinforcedConcrete through a revised round panel test", Cement Concrete Composites, 2015, 58, 95–104.

13. Conforti, A.; Minelli, F.; Plizzari, G.A.; Tiberti, G. "Comparing test methods for the mechanicalcharacterization of fiber reinforced concrete", Structural Concrete, 2018, 19, 656–669.

14. Mastali, M.; Abdollahnejad, Z.; Dalvand, A. "Increasing the flexural capacity of Geopolymerconcrete beams using partial deflection hardening cement-based layers: A numerical study",Sci.Iranica. Trans. ACiv. Eng. 2017, 24, 2832–2844.

15. Kheradmand, M.; Mastali, M.; Abdollahnejad, Z.; Pacheco-Torgal, F. "Experimental andnumerical investigations on the flexural performance of geopolymers reinforced with short hybrid polymeric fiberCompos.",Part B Eng. 2017, 126, 108–118.

16. Chilwesa, M.; Facconi, L.; Minelli, F.; Reggia, A.; Plizzari, G. "Shrinkage induced edge curlingand debonding in slab elements reinforced with bonded overlays: Influence of fiber and SRA" Cement Concrete Composites, 2019, 102, 105–115.

17. Facconi, L.; Minelli, F. "Verification of structural elements made of FRC only: A criticaldiscussion and proposal of a novel analytical method", Engineering Structures, 2017, 131, 530–
541.

18. Facconi, L.; Plizzari, G.; Minelli, F., "Elevated slabs made of hybrid reinforced concrete:Proposal of a new design approach in flexure", Structural Concretes, 2019, 20, 52–67.

19.Germano, F.; Tiberti, G.; Plizzari, G. "Post-peak fatigue performance of steel fiberreinforced concrete under flexure", Material Structures, 2016, 49, 4229–4245.

20.ENV 1992-1-1:1991. Eurocode 2: Design of concrete structures –Part 1: General rules and rules for buildings.

21.Neves.R,Carlos .A "Compressive behaviour of steel fibre reinforced concrete", Structural Concrete · January 2005, DOI: 10.1680/stco.2005.6.1.1