Shear behaviour of synthetic fibre reinforced concrete beams reinforced with FRP rebars

Károly.P. Juhasz, Peter Schaul

Summary

FRP rebar has become considered more and more as an ordinary reinforcement in concrete structures, due to its main advantage of being corrosion-free. However, FRP bars can be bent only at the manufacturing stage and not on site, which makes the production of items such as stirrups difficult and uneconomical. As an alternative, shear reinforcement bars could be replaced by fibre reinforcement. In order to maintain the non-corrosive nature of the composite material synthetic fibre should be used in this case. In this paper beam tests were carried out to research the shear behaviour of these fully non-corrosive reinforced concrete beams.

1 Introduction

Nowadays in reinforced concrete structures FRP (fibre-reinforced polymers) rebars are becoming a significant alternative to steel bars. FRP bars are made of continuous fibers embedded in a matrix, which is made of a polymeric resin. The fibres bear the load and the matrix has the function of binding together the fibres and transferring the load to the fibers. The resin also protects the fibres from mechanical degradation caused by the concrete matrix. Moreover, this type of rebars have a serious advantage over steel alternatives in that they are not affected by corrosion [3, 10].

There are some standards and guidelines of calculation methods for concrete beams reinforced with FRP, such as *fib* Model Code 2010 [4] or ACI 440 [2]. *fib* defines the different types of FRP (or non-metallic) reinforcements and describes the important material behaviours, such as stress-strain diagram, fatigue and creep. ACI 440 gives semi-empirical calculation methods, but it emphasizes that the standard is only valid for rectangular and non-prestressed sections, in other cases real scale tests are needed to validate the design. More accurate and general calculation methods could be done with Finite Element Analysis (FEA). The advantage of the FEA is to model the real behaviour of the structure at any stage, such as crack propagation and crack width at any time. The difficulties of this type of calculation are to choose the proper material models and to model the connection/bond behaviour between the FRP and the concrete properly.

The FRP bars are manufactured with the help of thermoset polymeric resin, which is the matrix. This is one of the biggest disadvantages of using of the FRP bars, because the forming of the FRP bars, such as bent-up bars, hooks or links, cannot be done on site. The manufacturing of the bent bars is expensive and slow, moreover inaccuracies sometimes could not be handled in situ.

Based on the above the use of synthetic fibre could be a proper solution for the shear capacity of the structure. Some previous studies investigated the shear capacity of the synthetic fibre [8, 9] where all of the steel links were replaced. By combining the FRP and synthetic fibre reinforcement a totally rust-free structure could be developed, where the price and time of labour could be minimised as well.

2 Shear failure of RC section

The shear failure in concrete beams is rigid, the appropriate design therefore is mandatory. According to Kollár [6] the components of the shear capacity of the concrete section are the shear strength of the compressed zone (V_c); the aggregate interlock (A_y); the dowel-action (V_d) and the shear reinforcement (V_{wd} or V_{fy}) as shown in Fig. 1.

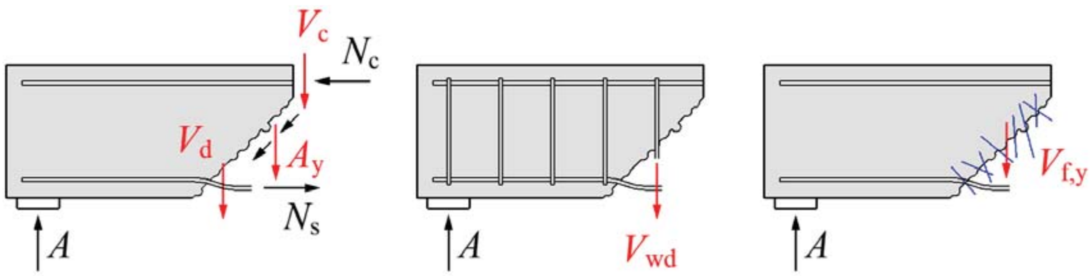

Fig. 1 Components of shear capacity in reinforced concrete

3 Shear failure of FRC section

The effect of the fibres manifests mostly in the increase of the fracture energy of the plain concrete (G_f), making the concrete a more ductile material. The effect of the fibre on the compression or tension strength is negligible. One way to model the concrete is the Modified Fracture Energy Method [5], where the added fracture energy of the fibres (G_{ff}) could be derived from the inverse analysis of the three points bending beam tests.

There are many recommendations on how the effect of the fibres could be calculated in case of shear load [1, 11]. These guidelines take the fibres into account in a manner similar to stirrups: calculating the residual strength of the fibres and the area of the cracked surface. However, there are many more advantages from the use of the fibres. Generally, fibres decrease the distances between the cracks thanks to the increased fracture energy [1]. Based on this the crack widths will also be smaller. The function of aggregate interlock determined by Kolmar [7] shows a precipitous slope during crack opening. Just a small decrease in the crack width could mean significant increase in the aggregate interlock effect. These were researched by using large specimen tests by Kovács and Juhász [8, 9].

4 Experimental setup

Two types of FRP were used: basalt (BFRP) and glass (GFRP). Both reinforcements were of 6mm diameter. The material parameters of the different FRPs can be seen in Table 1 and the size of the beams with the reinforcement can be seen in Fig. 2.

Tab. 1 Material parameters of the used FRP bars

Sign	Material	Elastic modulus, E	Tension strength, f_t	Maximum strain, ε
BFRP	Basalt	70 GPa	1100 MPa	2,2 %
GFRP	Glass	45 GPa	1332 MPa	2,44 %

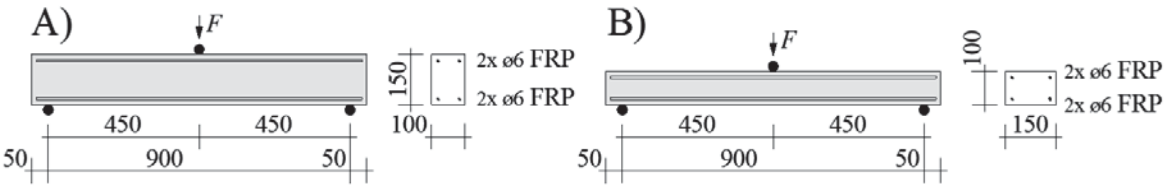

Fig. 2 Geometry and testing of the beams

The concrete strength was C30/37 according to Eurocode, with a maximum aggregate size of 8mm. The concrete mix can be seen in Table 2.

Tab. 1 Concrete mix

Cement type	Water (kg/m^3)	Cement (kg/m^3)	w/c ratio	Aggregates (kg/m^3)		Admixtures (kg/m^3)
				0-4	4-8	
CEM-I-52.5 N	175	345	0.50	814	1036	2.76

Two kinds of beams were made with both kinds of FRP reinforcements: plain concrete (BFRP-0, GFRP-0) and concrete with 5kg Barchip48 synthetic fibre reinforcement (BFRP-5, GFRP-5). There were 3 beams in one series. The test was performed at the Budapest University of Technology and Economics, Laboratory of the Department of Mechanics, Materials & Structures. The testing machine was a ZWICK Z150 universal testing machine with displacement controlled loading on a speed of 0.5mm/sec.

5 Test results

In most cases the shear failure was the dominant. The added fibres increased the failure by 34% in case of BFRP and 24% in GFRP in beam type A, but there was only 9% increase in beam type B. FRP bars were not ruptured in any tests. The failure method was different in type A and B; type A has a shear failure, while type B has a bonding failure between the concrete and FRP bars. The effect of the fibre depends mostly on the ratio between the width and height of the cross section. The dosage of the fibre was not enough to change the failure mode in any cases.

6 Numerical model

The numerical model was made with ATENA software (Cervenka Consulting). The material model of concrete consists of a combined fracture-plastic failure surface. Tension is handled herein by a fracture model, based on the classical orthotropic smeared crack formulation and the crack band approach. It employs the Rankine cube failure criterion with a rotated crack model. The plasticity model of concrete in compression uses the William-Menétrey failure surface. Aggregate interlock was taken into account by reducing the shear modulus with a growing strain along the crack plane, according to the law formulated by Kolmar [7].
The numerical model shows a good correlation with the real test results in case of using the proper bond-slip law. Neglecting this parameter could lead to significant inaccuracy (Fig. 3).

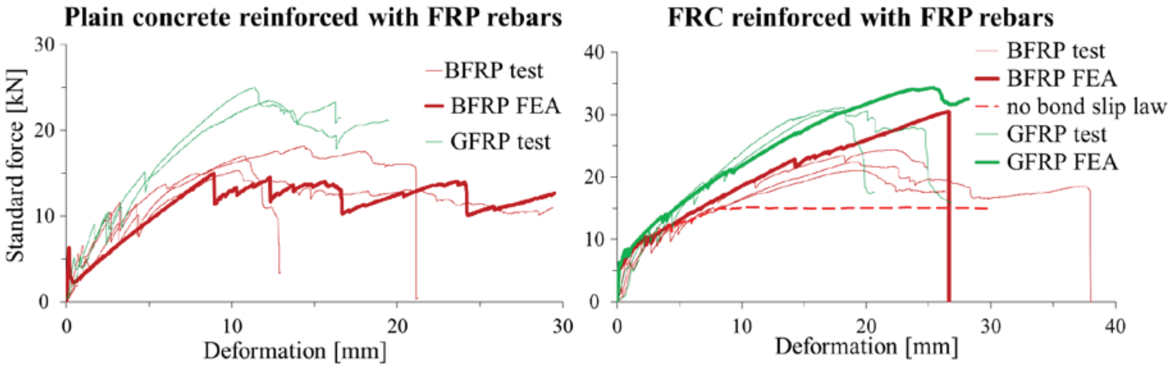

Fig. 3 Numerical and test results of BFRP and GFRP, with and without fibre reinforcement

7 Conclusion

Reinforced concrete beams were made by using only corrosion-free synthetic reinforcements: Basalt Fiber Reinforced Polymer (BFRP) or Glass Fiber Reinforced Polymer (GFRP) bars in a synthetic fibre reinforced concrete (FRC). With the help of the synthetic fibres the shear capacity was increased. With advanced numerical modelling and by selecting the proper material model the test was modelled obtaining very close results. Although the load bearing capacity was increased by 24%-34%, the failure mode was still due to shear. Further researches could be done in order to clarify whether synthetic fibres could replace the whole reinforcement.

References

[1] Advisory Committee on Technical Recommendations for Construction (2006): “CNR-DT 204/2006: Guide for the Design and Construction of Fibre-Reinforced Concrete Structures”.

[2] American Concrete Institute (2003): ACI 440.1R-03: Guide for the Design and Construction of Concrete Reinforced with FRP Bars

[3] Bank, L.C. (2006): “Composites for Construction – Structural Design with FRP Materials”, John Wiley & Sons Inc.

[4] International Federation for Structural Concrete (*fib*) (2012): “Model Code 2010 (Final Version), fib Bulletins 65 & 66”, Lausanne, 2012, pp.145-148.

[5] Juhász K.P. (2013): “Modified fracture energy method for fibre reinforced concrete”, in: Fibre Concrete 2013: Technology, Design, Application. Prague, Czech Republic 2013, pp. 89-90.

[6] Kollár L. (1997): “Vasbetonszerkezetek I.”, Műegyetem Kiadó

[7] Kolmar, W. (1986): “Beschreibung der Kraftuebertragung über Risse in nichtlinearen Finite-Element-Berechnungen von Stahlbetontragwerken”, Dissertation, T.H.

[8] Kovács G. and Juhász K.P. (2013): “Precast, prestressed grandstand of PFRC in Stadium, Hungary”, in: CCC 2013, Concrete Structures in Urban Areas.

[9] Kovács G. and Juhász K.P. (2014): “Synthetic and steel fibres in prestressed, precast long span beams”, in: CCC 2014, Concrete Offers for Period of Economic Recovery. Liberec, Czech Republic 2014.

[10] Nanni, A., De Luca, A. and Zadeh, H.J. (2014): “Reinforced Concrete with FRP Bars – Mechanics and Design”, CRC Press

[11] Österreichische Vereinigung für Beton- und Bautechnik (2008): “Richtlinie Faserbeton.” Österreichische Vereinigung für Beton- und Bautechnik

Károly Péter Juhász
✉ Technical University of Budapest
Department of Mechanics, Materials & Structures
Műegyetem rakpart 1-3. K.II.61.
Budapest 1111, Hungary
☎ +36 1 463 1317
🗐 +36 1 463 1773
☺ juhasz@szt.bme.hu
URL www.szt.bme.hu

Peter Schaul
✉ JKP Static Ltd.
Reitter Ferenc utca 73.
Budapest 1135, Hungary
☎ +36 30 276 1890
🗐 +36 1 239 9368
☺ peter.schaul@jkp.hu
URL www.jkpstatic.com