EXPERIMENTAL ANALYSIS OF HIGH PERFORMANCE FIBRE REINFORCED CONCRETE PLATES

Piotr Smarzewski

Lublin University of Technology, Faculty of Civil Engineering and Architecture,
Department of Civil Engineering, Nadbystrzycka St. 40, 20-618 Lublin, Poland
e-mail: p.smarzewski@pollub.pl

Summary:
The article presents the experimental results of bent plates made of high performance concrete and high performance fibre concrete. The test was performed for plate elements with reinforcement mesh of Φ8 mm rods. The main aim of the test was to define the influence of adding polypropylene and steel fibres on carrying capacity and deformability of fibre reinforced concrete plates. All plates had identical reinforcements and differed by the percentage of fibres. The research was performed into Zwick/Roell hydraulic press, with the load range from 0 to 3000 kN. During the tests, the rate of displacement increment was controlled. The load and deflection were registered. The analysis of the results was made on the basis of crack development, damage images and load – deflection relations. Experimental tests proved the usefulness of steel and polypropylene fibres in order to improve the ultimate tensile strength of high performance concrete in plates. Adding fibres changes the characteristics of high strength concrete – from a brittle, into elastic-plastic material. The analysis of the results proves that cooperation between the concrete matrix and fibres is very effective. With the increase of the number of fibres increased concrete tensile strength and maximum deflection of plates.

Keywords: reinforced concrete elements, high performance fibre concrete, plates

Introduction

The development of concrete technology and the research on its properties together with the idea to build safe and durable structures contributed to the development of numerous new building materials. In various cases they are the effect of improving previous solutions based on innovations in concrete properties. Such was the case of fibre concrete, in which the key element is to improve concrete tensile parameters by adding steel and synthetic fibres. More information concerning composite properties with fibre reinforcement and the directions of their improvement can be found in the works (Banthia, Gupta 2004, Brandt 1996, 2008, 2009, Chiaia et al. 2009, Domański, Czkwianianc 2006, Foster 2009, Glinicki et al. 2002, Glinicki 2008, 2010, Jamroży 2000, Prisco et al. 2009, Walraven 2009).

At the same time, searched for methods to improve concrete strength and durable through its modifications in dosing ingredients and concrete curing. The problems concerning the design and production of high performance concrete were described in papers (Aïtcin 1998, 2003) and (Kaszyńska 2002).

Experimental tests on plates made of reinforced high performance concrete with addition of steel and polypropylene fibres have been the subject of few works so far (Fairbaim et al. 2012).

Experimental investigations

Analysis of aggregate grading curve

Marking the gradations of aggregate was conducted in accordance with the norm EN 933-1:1997 for coarse aggregate and sand.

Prior to grade analysis the coarse aggregate was dried. The test samples weighting 3200 g was divided into 2 equal samples, 1600 g each. The test sieves meshes 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, which were graded from the smallest to the largest was conducted. As a result of hand sieving, the agregate was segregated into fractions. The residue of each fraction was weighted. In order to examine quartz sand, an sample of 800 g was prepared. A sieves with meshes sized 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm were used. In order to prepare the plates, the aggregate was mixed in the following proportions: 66% of granodiorite aggregate and 34% of quartz sand, so that the contents of each fraction was within the range curves of the norm. Figure 1 presents the grading curves of aggregate within the norm curves.

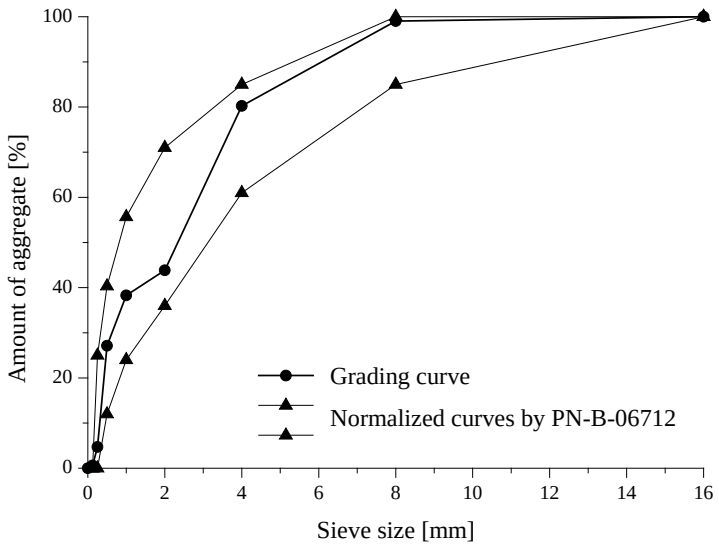


Fig. 1. Grading curves of aggregate

Properties of reinforcement steel

The test of a steel reinforcement bar, 8 mm in diameter and 300 mm of the length, was conducted with a material test system MTS 810 with the load range 0-100 kN, Fig. 2.



Fig. 2. MTS 810 material test system and steel bar during the axial tensile test

The bar was fixed with special holding jaws which prevented potential slide and incorrect measures. During the test current force, bar elongation and transverse displacement at rupture were measured. The graph load-axial displacement steel bar was shown in Fig. 3.

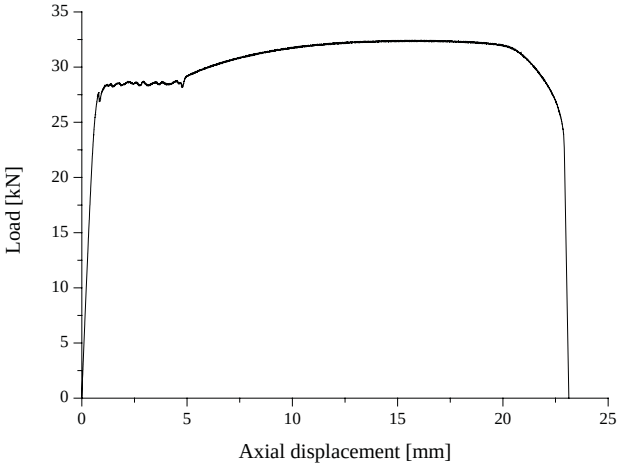


Fig. 3. Load-axial displacement relation for the 8 mm reinforcement bar

On the basis of these results yield stress f_{yk} = 567 MPa, ultimate tensile strength f_{tk} = 644 MPa and modulus of elasticity E_s = 206 GPa were calculated.

Properties of concrete and preparation of HPFRC plates

Table 1 presents composition of concrete mixtures for three reinforced concrete plates.

Table 1. Composition for concrete mixtures

Component		Mixture 1	Mixture 2	Mixture 3
		[kg/m^3]	[kg/m^3]	[kg/m^3]
Cement CEM I 52.5R	C	596	596	596
Granodiorite 2-8 mm	K	990	990	990
Quartz sand	P	500	500	500
Condensed microsilica	M	59.6	59.6	59.6
Superplasticiser	S	20	20	20
Water	W	196	196	196
Steel fibres	W_{sf}	–	39	78
Polypropylene fibres	W_{pf}	–	0.5	0.5

The prepared concrete mixes are characterised by the following coefficients: water and the components of the bond $W/(C+M)=0.212$, aggregate to cement and condensed microsilica quantity $K+P/(C+M)=2.3$; $S\rho_s/(C+M+K+P)=1.1\%$, $\rho_s=1150$ kg/m^3, percentge of steel fibres for mixture 2 (M2), $V_{sf}=W_{sf}/\rho_{sf}=0.5\%$, $\rho_{sf}=7800$ kg/m^3, percentge of steel fibres for mixture 3 (M3), $V_{sf}=1\%$, percentge of polypropylene fibres for M2 and M3 $V_{pf}=W_{pf}/\rho_{pf}=0.056\%$, $\rho_{pf}=900$ kg/m^3.

Concrete samples were prepared according to the mixture 1 in the forms that meet the requirements of the standards. Compression tests were conducted on 150 mm cube samples. Bending tensile strength tests were performed on beam elements sized 600 x 150 x 150 mm. Concrete compression and tension strengths for M1 were f_c = 99.4 MPa and $f_{ct,fl}$ = 8.2 MPa respectively. Figure 4 presents load – displacement relation for three bent beams.

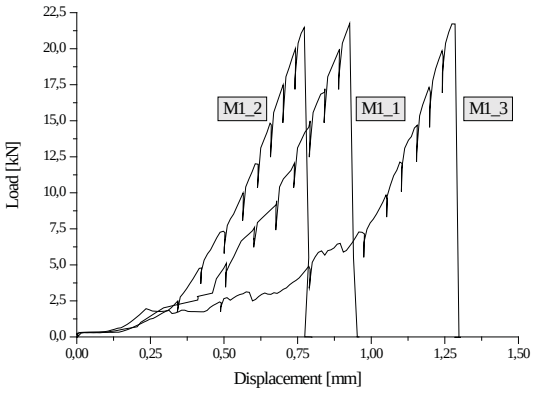


Fig. 4. Load – displacement relation for beam samples

The moulds of reinforced concrete plates were made of plywood. Reinforcement was prepared in a form of grids made of rods of 8 mm in diameter. The moulds were covered with antiadhesive liquid before concreting. After placing the mixtures in moulds, its were condenced on the vibratory table and the members were covered and cured for 7 days in damp conditions.

Investigations of HPFRC plates

The investigations of high performance fibre reinforced concrete (HPFRC) plates were carried into Zwick/Roell hydraulic press, with the load range from 0 to 3000 kN. During the tests, the rate of displacement increment was controlled and the load and deflection were registered.

The main aim of the test was to define the influence of adding polypropylene and steel fibres on carrying capacity and deformability of fibre reinforced concrete plates. All plates had identical reinforcements with grids and differed by the percentage of fibres.

Reinforced concrete plates were locally loaded with a centrally located steel plate, according to the scheme presented in Fig. 4.

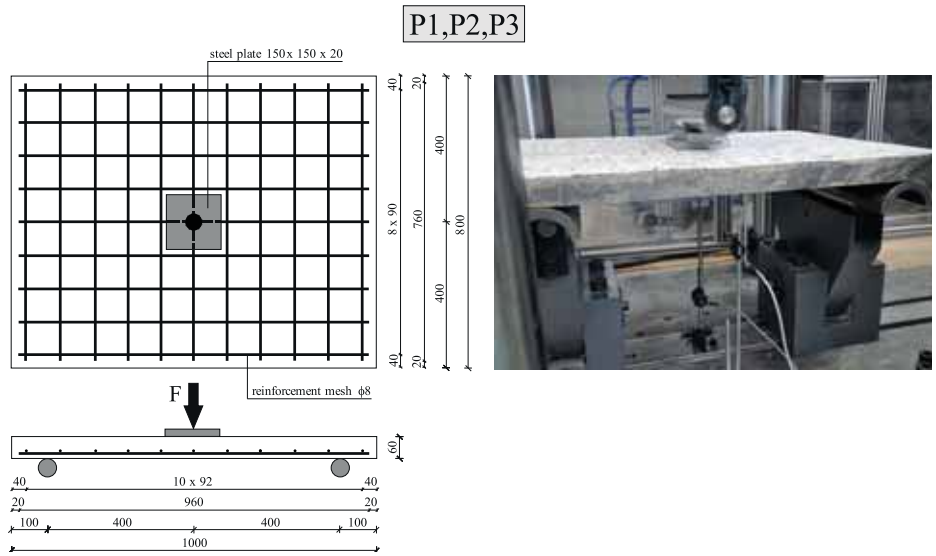


Fig. 4. Scheme of load and support plates

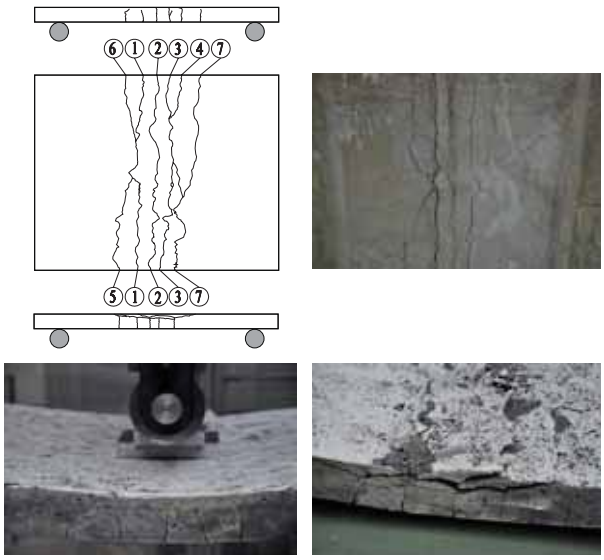
The plates were loaded at constant increment of press piston displacement. During the test, piston displacement and current load were measured.

Analysis of HPFRC plates experimental results

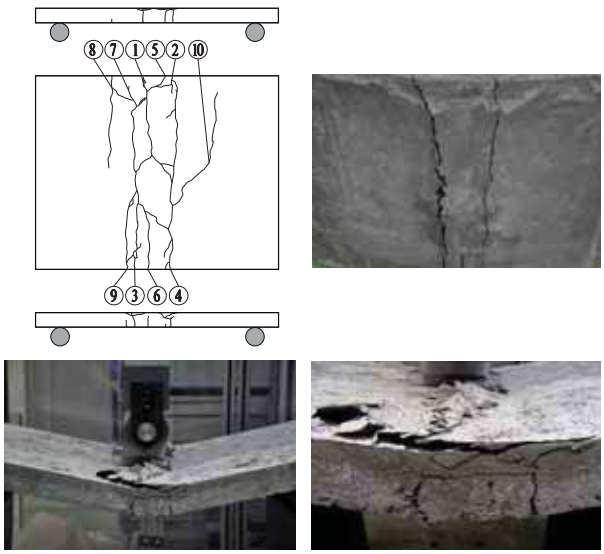
The images of failure development were made on the basis of detailed photographic documentation. Cracks propagations and damage images were presented in Fig. 5. The first cracks appeared at midspan of all elements. In case of plate P2 and P3 the cracks

appeared after the time that was twice as long as in plate P1. With the increase of load, the cracks were perpendicular to the width of the plate. The number and width of cracks were correlated with the percentage of fibres. At further stages of loading, was observed spalling of the concrete at upper surface of the plates.

(a)



(b)



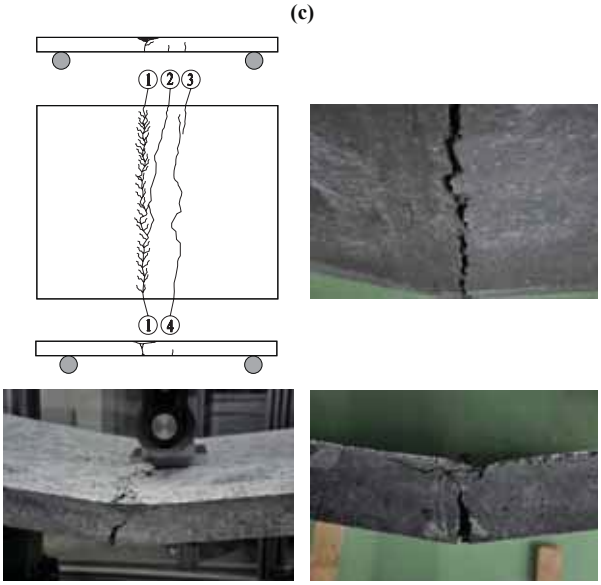


Fig. 5. Maps of crack development and images of damage in the final stage for plate a) P1, b) P2, c) P3.

The plate with 1% of steel fibres had a significantly different image of cracks. During the test only one crack increased width. Additionally in the final stage of loading small radial cracks appeared along its length, Fig. 5c. The research was carried out until the compression zone layers were completely crushed and the cracks in the tensile area were over 5 mm in plates P1, P2 and over 15 mm in plate P3.

Graphs of the load – deflection for the three research elements are shown in Fig. 6.

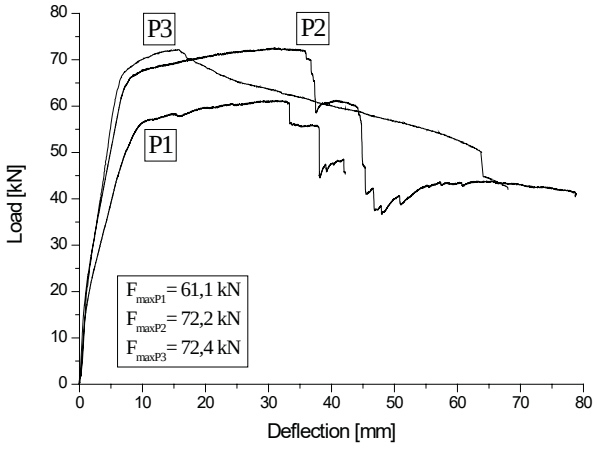


Fig. 6. The load – deflection relation for plates

On the basis of load – deflection relation, it was stated that at maximum load 61.1 kN, deflection plate P1 was equal to 31.2 mm. In case of plate P2 with 0.5% of steel fibres the response of the element was similar, but the largest load is higher by 18.5% at 31 mm deflection. In case of plate P3 with 1% of steel fibres it was observed that the deflection for the load of 72.2 kN was only 15.6 mm. After yield of the reinforcement, the decrease of load capacity is mild, without significant refractions, as steel fibres inhibit the evolution of cracks.

Conclusions

Experimental tests proved the usefulness of steel and polypropylene fibres in order to improve the ultimate tensile strength of high performance concrete in plates. The analysis of the results proves that cooperation between the concrete matrix, fibres and the reinforcement mesh is very effective. With the increase of the number of fibres increased the tensile strength of concrete and maximum deflection. The range of elastic work for all plates is similar covered in the range between 0 and 9 mm. In plate P3, with the contents of steel fibres of 1%, different character of element response was observed. Adding fibres changes the characteristics of high strength concrete – from a brittle, into elastic-plastic material. The evolution of cracks is slow progress, because each crack is bridged by fibres, what translates into a mild failure mechanism and high ductility of the elements.

References:

1. Brandt A.M. (1996), *Toughness of fibre reinforced cement based materials.* Archives of Civil Engineering, XLII, 4.
2. Jamroży Z. (2000), *Concrete and his technologies*. PWN, Warszawa-Kraków (in Polish).
3. Glinicki M.A., Litorowicz A., Zieliński M. (2002), *Experimental analysis of fracture mode I behaviour of fibre concrete*. Building Materials, No 3, 74-76 (in Polish).
4. Banthia N., Gupta R. (2004), *Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices*. Materials and Structures, Vol. 37, 707-716.
5. Domański T., Czkwianianc A. (2006), *Influence of fibre reinforcement on the mechanical parameters of the concrete.* Building Review 6 (in Polish).
6. Brandt A.M. (2008), *Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering.* Composite Structures 86, 3-9.
7. Glinicki M.A. (2008), *Investigation of fibre concrete property with the macro synthetic fibres, designed on industrial floors*. Cement Lime Concrete. No 4, 184-195 (in Polish).
8. Brandt A.M. (2009) *Cement Based Composites: Materials, Mechanical Properties and Performance*. Taylor and Francis. London and New York.
9. Foster S.J. (2009), *The application of steel-fibres as concrete reinforcement in Australia: from material to structure*. Materials and Structures 42: 1209-1220.

10. Walraven J.C. (2009) *High performance fiber reinforced concrete: progress in knowledge and design codes.* Materials and Structures 42: 1247-1260.
11. Prisco M., Plizzari G., Vandewalle L. (2009), *Fibre reinforced concrete: new design perspectives.* Materials and Structures 42: 1261-1281.
12. Chiaia B., Fantilli A.P., Vallini P. (2009), *Combining fiber-reinforced concrete with traditional reinforcement in tunnel linings.* Engineering Structures 31 1600-1606.
13. Glinicki M.A. (2010), *Concrete with the structural reinforcement*. XXV the Polish Workshops of Work of the Structural Designer, Szczyrk (in Polish).
14. Aïtcin P.C.: *High-Performance Concrete.* E & FN SPON 1998.
15. Aïtcin P.C.: The durability characteristics of high performance concrete: a review. Cement & Concrete Composites 25 (2003) 409-420.
16. Kaszyńska M. (2002), *HPC: possibilities, properties, applications*. XVII the Polish Workshops of Work of the Structural Designer, Ustroń (in Polish).
17. Fairbairn E.M.R., Toledo Filho R.D., Formagini S., Rosa J.I., Battista R.C. (2012), *Experimental analysis and modeling of ultra high performance fiber reinforced concrete plates*. 1-8.

Acknowledgment

This work was financially supported by Ministry of Science and Higher Education within the statutory research number S/15/2013.