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Performance of Fibre Reinforced Concrete Specimens Subjected to Impact Loading

Alena Horská[1, a *], Pavel Jiříček[1,b] and Marek Foglar[1,c]

[1]Faculty of Civil Engineering, Czech Technical University in Prague, Thakurova 7/2077, 166 29 Prague, Czech Republic

[a]alena.horska@fsv.cvut.cz, [b]pavel.jiricek@fsv.cvut.cz, [c]marek.foglar@fsv.cvut.cz

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Abstract. Impact resistance of concrete structures gains high importance nowadays, as the man-made disasters (such as terrorism, car crashes, etc.) occur increasingly. Development and testing of blast and impact resistant materials is highly required. This paper shows outcomes of the experiments focused on FRC performance under impact loading.

Introduction

Besides tensile strength of plain concrete itself, both reinforcement and speed of loading influence tensile resistance of concrete specimen [1,2]. The dependence of concrete strength on strain rate is expressed by DIF (Dynamic increase factor). The issue of impact loading is studied in many publications [3,4,5], different results are observed for cases of different loading conditions (weight and velocity of the impacting burden). Also the experimental technique influences the impact performance of concrete samples [6]. To study the effect of high strain rates on FRC specimens, a drop-weight experiment was performed.

Experimental Set-Up

Tested Specimens. For the experiment, tile-shaped concrete samples were prepared. The samples with unified size of 300 x 300 mm differed in thicknesses, varying the values of 30, 60 and 120 mm. The samples were reinforced with polypropylene or steel fibres. Also samples with no reinforcement were prepared. The designation of each specimen consists of material indication (PB_ - Plain concrete; PP9 - Polypropylene fibre reinforced concrete, content of fibres 9 kg/m^3; FE8 - Steel fibre reinforced concrete, content of fibres 80 kg/m^3), thickness of the specimen (in mm) and weight of the burden (in 10 x kg). To each sample, ID number was assigned; sample IDs are categorized by their material, thickness and weight of burden (Table 1).

Table 1: Sample ID numbers assigned to sample specification.

Sample ID Number									
weight of burden [kg]	Plain concrete (PB_)			PP-FRC (PP9)			Steel FRC (FE8)		
	sample thickness [mm]			sample thickness [mm]			sample thickness [mm]		
	30	60	120	30	60	120	30	60	120
20.6	1	-	-	11	-	-	12	-	-
46.4	4	2	3	8	9	10	5	6	7
75.2	-	13	14	-	15	17	-	16	18

Dropping Device. Impact loading of specimens was induced using a drop-weigh mechanism. The steel drop-weight consisted of a central shaft and several disc attached to it (Fig. 1). Variable amount of steel discs enabled to regulate the impacting weight (reaching 20.6, 46.4 and 75.2 kg) (Fig. 2). At the bottom disc, the a hemispherical tip was attached, so that the impact load was concentrated. For the drop-weight could be lifted, a steel frame structure was built in the laboratory (Fig. 3). The structure consists of a horizontal base frame anchored to the laboratory floor and a vertical frame lifted up by a laboratory crane. Stability of the construction was provided by four bracing diagonals. The drop-weight was lifted by a hoist to its maximal height of approx. 2.8 m above the tested concrete sample. From its top position, the drop-weight was released reaching impact velocity of approx. 7.2 m/s. The specimens were supported on two of their edges by steel beams and were hit in the centre (Fig. 1).

Fig. 1 Specimen supported by beams.

Fig. 2 Burden discs of different weights.

Fig. 3 Steel frame with hoist.

Recording of the Experiment. The progress of deflection of the specimen was captured by a high-speed camera, speed of recording was 1000 fps. The video record was decomposed into separate frames. The frames were graphically processed to obtain instantaneous velocity of the steel burden. For each specimen, velocity-time dependence of the burden was plotted.

Evaluation

The deceleration of the burden after collision with the specimen represents the impact resistance of the specimen. Specimens causing grater deceleration of the burden prove themselves more impact resistant. To compare the behaviour of samples of different materials, the velocity curves of different materials and similar thickness and burden weight were plotted to joint diagrams, (Fig. 4 - 9.)

As the velocity-time dependence of the burden cannot be approximated by one well-defined function through the whole recorded time of 10 ms, the velocity curves were divided into four separate time intervals - initial major deceleration, reduction of deceleration, stabilization of burden velocity and secondary deceleration. For each time interval, the average value of burden deceleration was established. The deceleration of the burden was expressed as a percentage, comparing samples of different material and similar thickness and weight of burden (Table 2).

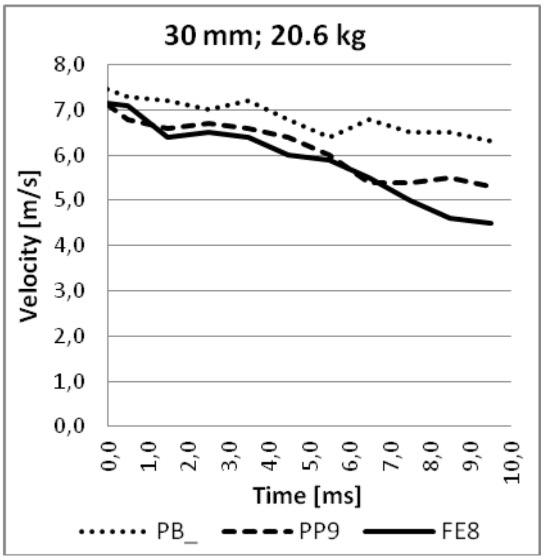

Fig. 4 Material comparison, sample thickness 30 mm, burden weight 20.6 kg.

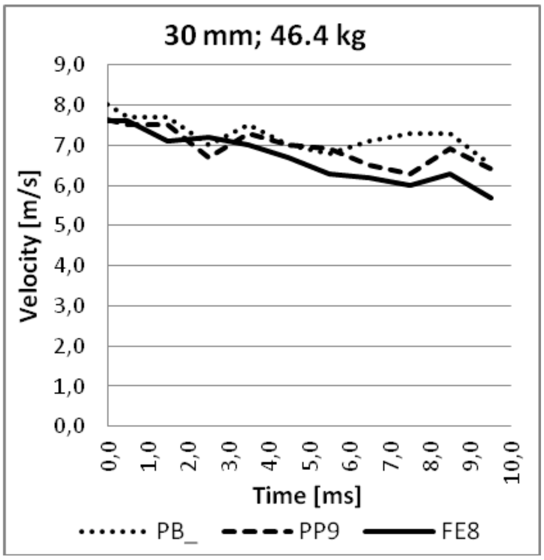

Fig. 5 Material comparison, sample thickness 30 mm, burden weight 46.4 kg.

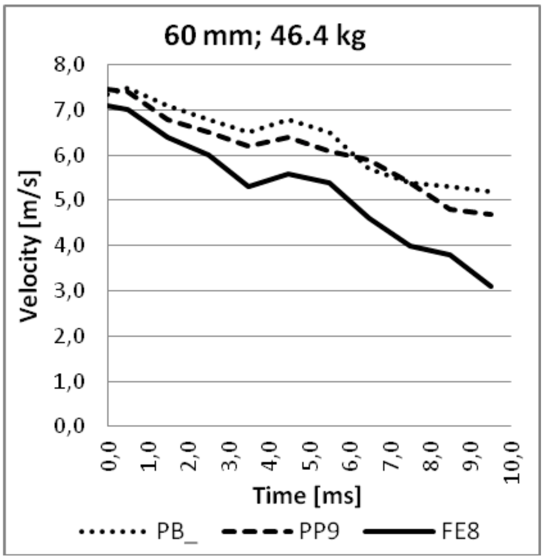

Fig. 6 Material comparison, sample thickness 60 mm, burden weight 46.4 kg.

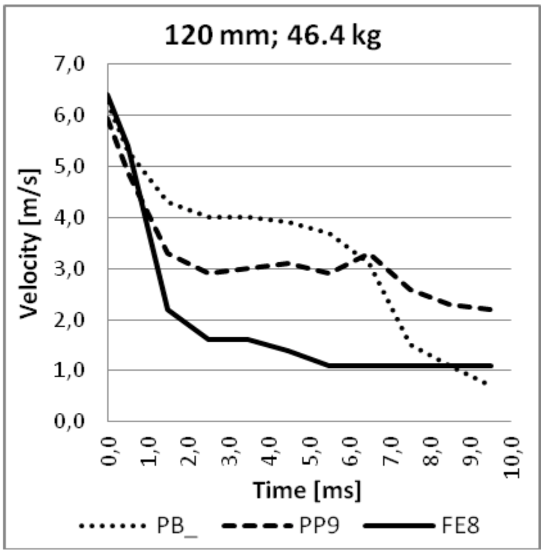

Fig. 7 Material comparison, sample thickness 120 mm, burden weight 46.4 kg.

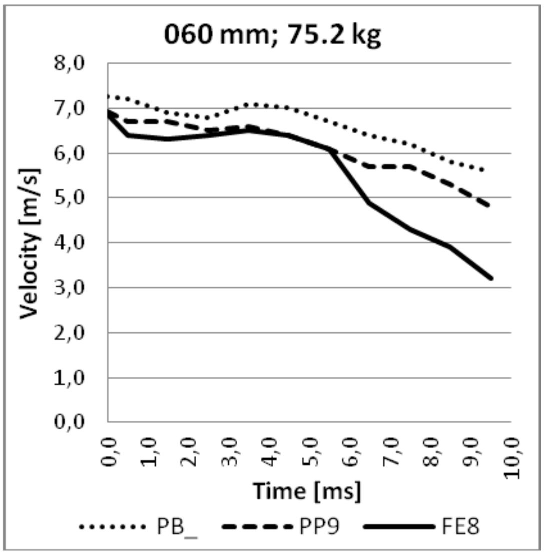

Fig. 8 Material comparison, sample thickness 60 mm, burden weight 75.2 kg.

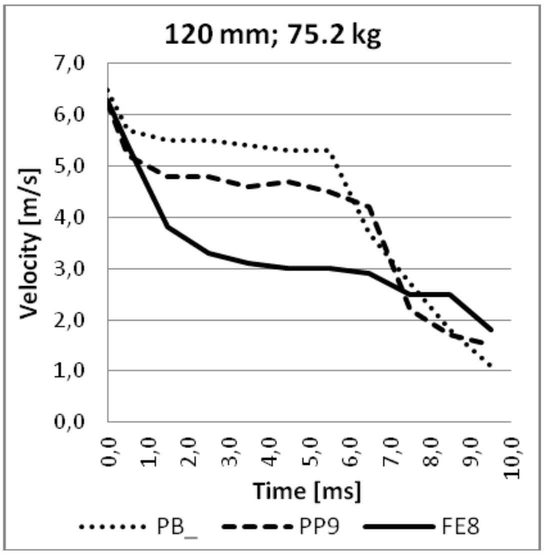

Fig. 9 Material comparison, sample thickness 120 mm, burden weight 75.2 kg.

Table 2: Deceleration of the burden

Sample group	Material	Burden deceleration [%]			
		Interval1	Interval2	Interval3	Interval4
30 mm; 20.6 kg	PB	-	100	-	100
	PP9	100	85	-	260
	FE8	107	133	-	740
30 mm; 46.4 kg	PB	-	100	-	100
	PP9	-	64	-	150
	FE8	-	130	-	275
60 mm; 46.4 kg	PB	-	100	100	100
	PP9	-	129	167	130
	FE8	-	143	250	180
120 mm; 46.4 kg	PB	-	100	100	-
	PP9	-	160	46	-
	FE8	-	320	185	-
60 mm; 75.2 kg	PB	100	100	-	100
	PP9	46	200	-	107
	FE8	78	58	-	243
120 mm; 75.2 kg	PB	100	100	100	-
	PP9	56	200	117	-
	FE8	81	800	317	-

Besides the velocity-time curves, the different response of concrete specimens to impact loading was clearly visible through crack pattern on damaged specimens. In general, cracks were observed in three different crack patterns - radial orientation, perpendicular orientation and single-line orientation (Fig. 10 – 12). In the experiment, the radial crack pattern was observed in case of 30 mm thick samples, the perpendicular crack pattern was observed in case of 60 mm thick samples and the single-line crack pattern was observed in case of 120 mm thick samples. The exact cause of differently developed crack patterns will be the subject of future research. Similar specimens, as used in the drop-hammer experiment, were casted and subjected to a three-point bending test (loading speed 0.2 mm/min). The crack pattern observed in this test was single-line for samples of all used thicknesses.


Fig. 10 Radial crack pattern.


Fig. 11 Perpendicular crack pattern.


Fig. 12 Single-line crack pattern.

Numerical Simulations

According to the experimental conditions, numerical simulations were prepared. For all samples, velocity-time dependence was plotted, e.g. sample ID 1. and 18. (Fig. 13 – 14).

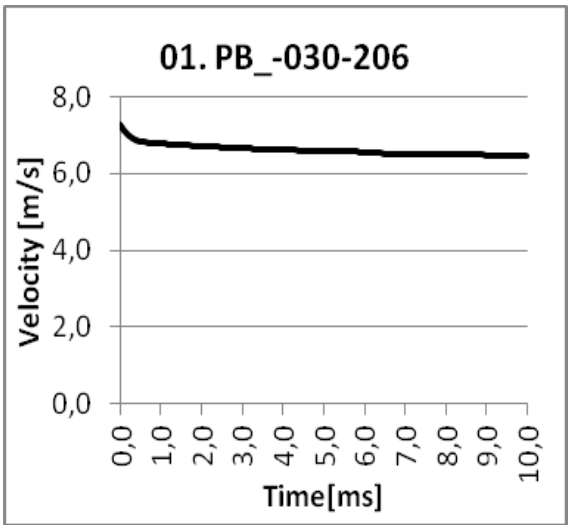

Fig. 13 Numerical simulations - velocity-time dependence of burden, Plain concrete, sample thickness 30 mm, weight of burden 20.6 kg.

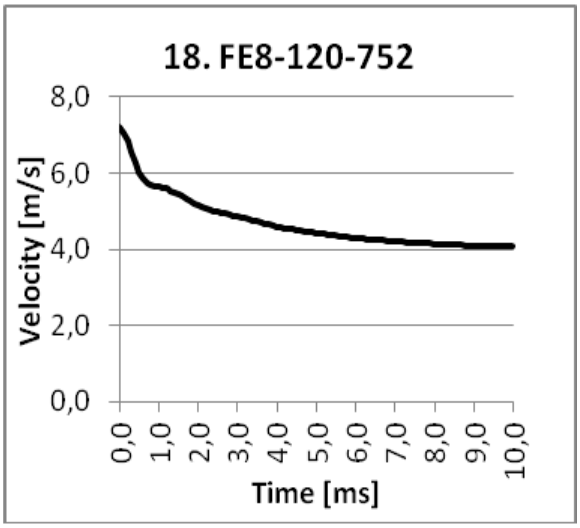

Fig. 14 Numerical simulations - velocity-time dependence of burden, Steel FRC, sample thickness 120 mm, weight of burden 75.2 kg.

Material models were adopted from previous impact loading experiments. The aim was to validate used material models in conditions of current experiment and in case of discrepancy between experimental data and simulations, to calibrate the material model. The adjustment of material models will be the subject of future research.

Conclusions

The aim of this paper is to compare the behaviour of differently reinforced FRC samples subjected to impact loading. According to the experimental results, the main factors influencing FRC impact resistance are type, material and volume of the dispersed reinforcement.

The deceleration of impacting burden is a quantitative expression of impact resistance of the concrete specimen. Proportional values of burden deceleration for three compared materials (plain concrete, polypropylene fibre reinforced concrete and steel fibre reinforced concrete) demonstrate the contribution of fibre reinforcement of concrete to its impact resistance.

The crack patterns observed in the drop-hammer experiment differed for varying sample thickness. Nevertheless, the issue of crack patterns will be subject of further research. The effect of sample characteristics and properties of impacting burden on crack pattern will be studied.

Acknowledgements

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