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EFFECT OF LOADING RATE ON THE BEHAVIOUR OF FIBRE REINFORCED CONCRETE ELEMENTS

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Abstract

This paper deals with the influence of loading rate on testing of fibre reinforced concrete beams in the four point bending test. Two sets of specimens loaded with strongly different loading rates were compared.

Keywords: fibre reinforced concrete (FRC), flexure behaviour, load, deflection, loading rate

1. Introduction

The fibre reinforced concrete (FRC) is known as a structural material for decades but it is still investigated. In general two approaches of investigation are able to use – analytical and experimental. Only the suitable combination of these methods leads to satisfactory results.

Basic differences between plain concrete and fibre reinforced concrete are especially higher ductility and non-zero residual tensional strength of FRC after crack rises. These differences are well observed on the strength – strain diagram ($\sigma - \varepsilon$ diagram) of plain concrete and FRC in tension. The FRC residual tensional strength is highly dependent on mixture composition and its determination is now possible only by experimental tests. Testing of FRC material properties is based on methods for testing of plain concrete. The post-cracking behaviour of FRC in tension is different, than the arrangement of some tests is changed or updated. The main difference is the arrangement of beam bending tests, the loading have to be controlled by deformation of specimens (see [1]).

2. Methods

Tests of fibre reinforced concrete in compression and splitting are same as for plain concrete. These tests are performed on cylindrical or cube specimens with prescribed size (see [1] or ČSN EN 12390).

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The arrangement of the FRC bending test is based on four point bending test using for plain concrete. Specimens are prisms, recommended size is 150 x 150 x 700 mm. Tested beams had span 600 mm - see the arrangement on Fig. 1. In order to involve the influence material heterogeneity the specimens are made without any notch. On the upper face of specimen (between the specimen and loading device) the steel carrying pad is shouldered. This pad transfers the test loading to specimen in prescribed lines (in thirds of specimen span).

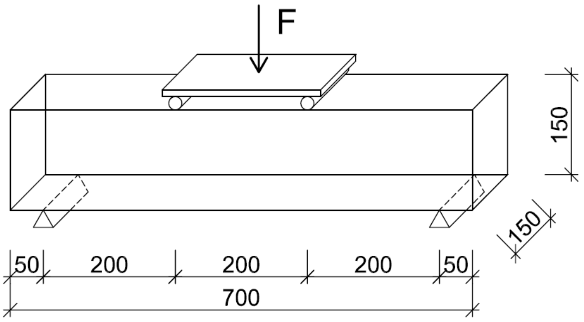

Fig. 1 - The four point bending test arrangement

The loading control could be realized by several methods below:

a) the force control
b) the piston movement control
c) the specimen deflection control

When the force control (a) is used, the down-current part of F_R-δ relation (after tensile macro-cracking) is not able to record. For the piston movement control (b) the very low loading rate (0,05 mm/min) must be used (mainly in time of crack rise) unless the recorded behaviour is not agreed the reality. Especially in case of FRC with low dosage of fibres high loading rate leads to quasi-brittle behaviour. Loading force decreases to zero immediately after cracking. Until then there is a delayed activation of fibres. The best description of the material post-cracking behaviour is obtained for loading controlled by specimen deflection (c).

The loading rate v_{fi} (the speed of the deflection increase in the middle of span) is given by formula:

$$v_{fi} = \frac{\Delta\delta_i}{\Delta t_i} \qquad (1)$$

where $\Delta\delta_i$ is middle span deflection addition in the appropriate loading step,
Δt_i is duration of the appropriate loading step.

There are two loading methods recommended in [1]. The first one - variable loading rate method - is composed of three steps:

1st step: the specimen stabilization

Loading rate: $v_{f1} = 0{,}01\,\text{mm/min}$ Duration: $\Delta t_1 = 20\,\text{min}$

Deflection range: $\Delta\delta_1 = 0{,}0 \div 0{,}2\,\text{mm}$

2^{nd} step: the specimen resistance (F_R-δ relation) identification for common deflection range

Loading rate: $v_{f2} = 0{,}2\,\mathrm{mm/min}$ Duration: $\Delta t_2 = 30\,\mathrm{min}$

Deflection range: $\Delta\delta_2 = 0{,}2 \div 6{,}2\,\mathrm{mm}$

3^{rd} step: the specimen resistance (F_R-δ relation) identification for large deflections

Loading rate: $v_{f3} = 0{,}5\,\mathrm{mm/min}$ Duration: $\Delta t_3 = 20\,\mathrm{min}$

Deflection range: $\Delta\delta_3 = 6{,}2 \div 16{,}2\,\mathrm{mm}$ $\delta_2 = 6{,}2 \div 16{,}2$ mm

This step is not required, but it is used for high ductility materials.

The second method presented in [1] used constant loading rate $v_f = 0{,}2 \pm 0{,}05$ mm/min. The minimal final middle-span deflection is $\delta_{min} = 4{,}0$ mm.

The minimal time of the testing with variable loading rate is 50 minutes and in case of the constant loading rate it is 20 minutes. Shorter test period is the advantage of the constant loading rate method. But the loading rate (0,2 mm/min) is “agreed value” and nowadays there are not many studies of loading rate impact on results of testing. Therefore the experimental program was propounded. The aim of this experimental program was the comparison of the resistance forces obtained for different loading rates. Two loading rates were chosen, 0,2 mm/min and 0,02 mm/min.

3. Experimental program

Six beams 150 x 150 x 700 mm (span 600mm) and ten cubes 150 x 150 x 150 mm were made for the experimental program. One type of FRC was used - the maximal size of aggregate $D_{max} = 16$ mm, water/cement ratio was $w/c = 0{,}31$ steel fibres Dramix RC 80/30 BP (high-strength steel), dosage 1% of volume, i.e. 78,6 kg/m^3.

Fig. 2 - Test arrangement

The compressive strength and the splitting strength were derived by cubes testing. FRC strength class (corresponding to EN 206 and EN 1992-1-1) was **C 75/85**. The tensile strength in bending was derived from $(F_R - \delta)_i$ diagrams (the four point bending test - see above). The piston movement controlled loading was used by the reason of laboratory equipment and high fibres dosage.

Two sets of 3 beams specimens were established and each one was exposed to different constant loading rate. The first set (specimens 1, 2 and 3) was tested with loading rate 0,2 mm/min, the second set (specimens 4, 5 and 6) was tested with loading rate 0,02 mm/min. There were three deflection pickup devices shouldered, two for recording of the specimen middle-span deflection and one for loading control (see Fig. 2). The specimen deflection (F_R-δ relation) was recorded in time period $\Delta t = 0{,}1$ s.

4. Results

The load-deflection diagrams for tested beams are shown on Fig. 3. The evaluation of mean and characteristics values for each loading rate was made - see Fig. 4.

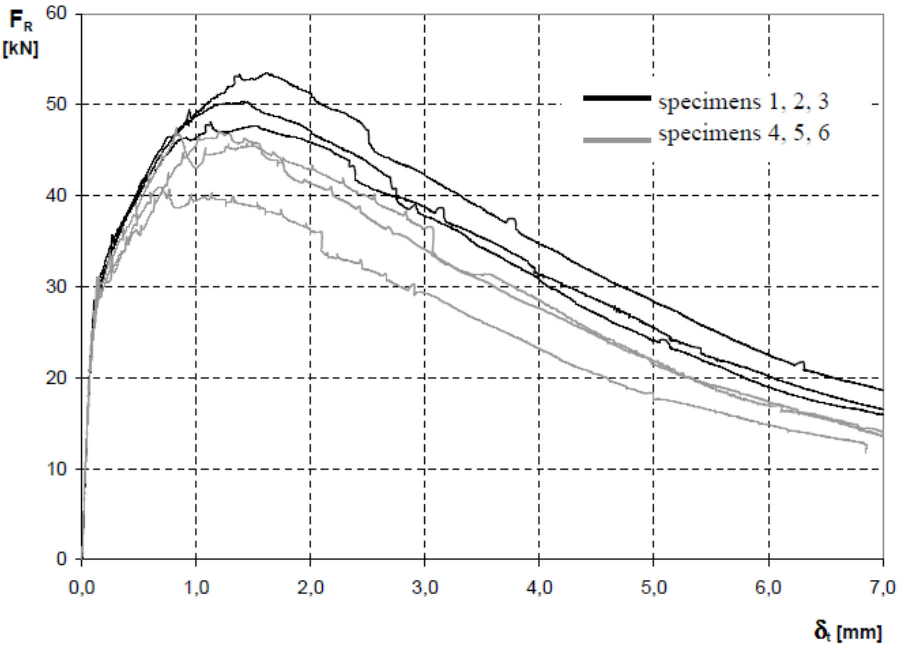

Fig. 3 - $(F_R - \delta)_i$ diagrams

Experimental results show the crucial influence of loading rate on material behaviour and derived tensile strength. Lower loading rate cause the lower force F_R (deflection δ_t) at the crack initiation and lower residual resistance of the specimen (maximal value of $F_{R,res}$ in post-crack stage). Reduction of the load F_R at the crack initiation for the lower loading rate is about 15 % for mean value and about 23% for characteristic value. The deflections at this macro-crack point are about 45% lower. The maximal residual load max.$F_{R,res}$ is about 13% lower for mean value and about 19% lower for characteristic value (see Tab. 2). The residual load $F_{R,res,1}$ (at deflection $\delta_{t1} = 3{,}5$ mm) is 19% lower for mean value and about 25% lower for characteristic value. The diagrams are in Fig. 4, numeric data are shown Tab.1 and Tab.2.

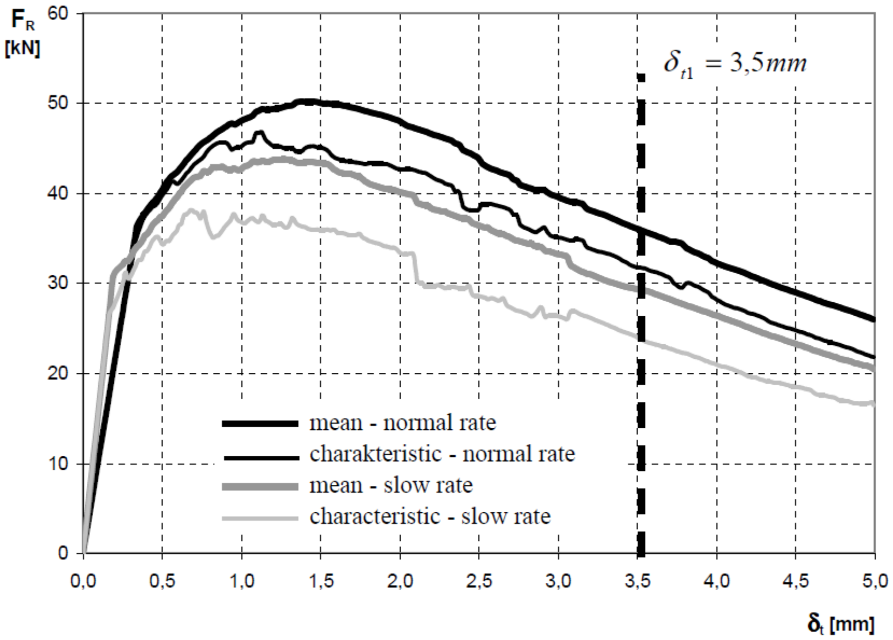

Fig. 4 - Mean and characteristic values of F_R-δ relations

Tab. 1 – Loads F_R and deflections δ_t at cracking

specimen	loading rate [mm/min]	$F_{Ri,c}$ [kN]	$F_{Rm,c}$ [kN]	$\delta_{tm,c}$ [mm]	$F_{Rk,c}$ [kN]	$\delta_{tk,c}$ [mm]
1	0,2	37,67	36,30	0,329	34,60	0,314
2		35,55				
3		35,78				
4	0,02	30,04	31,01	0,190	26,64	0,166
5		33,63				
6		29,36				

Tab. 2 – Resistance forces $F_{R,res}$ and deflections δ_t after cracking

specimen	loading rate [mm/min]	max $F_{Rm,res}$ [kN]	$\delta_{tm,c}$ [mm]	max $F_{Rk,res}$ [kN]	$\delta_{tm,c}$ [mm]	$F_{Rm,res,1}$ [kN]	$F_{Rk,res,1}$ [kN]
1, 2, 3	0,2	50,237	1,38	46,839	1,12	36,049	31,783
4, 5, 6	0,02	43,815	1,26	38,163	0,68	29,338	23,912

The piston movement controlled loading was used, than specimen middle-span deflection and piston movement were compared. There are two phases notable when higher loading rate was used (see Fig. 5). At the first one the growth of piston movement (constant for whole test) is higher then growth of the middle-span deflection. It is caused by pushing the supports into specimen material. When the specimen is stabilized the growth of middle-span deflection rises and takes constant value (second phase) which is higher then growth of the piston movement. It is caused by four point bending test arrangement (see Fig. 1).

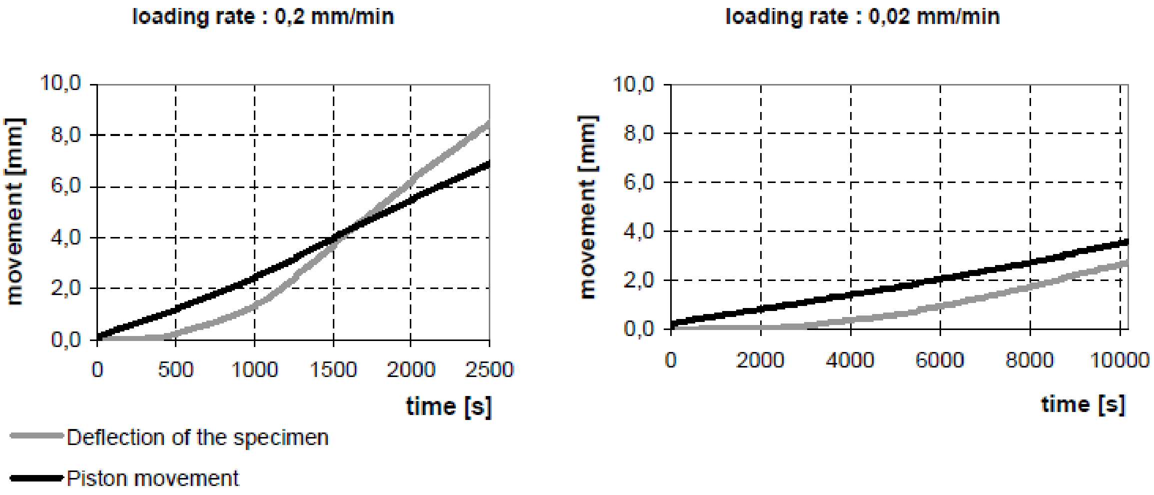

Fig. 5 - Relations piston movement - time and midspan deflection - time

5. Conclusions

Experimental tests with different loading rates were realized and results were compared. The sudden drop of the F_{R}-δ relation (typical for quasi-brittle materials) was not marked because high fibres dosage was used. Test results show the crucial influence of loading rate on material resistance and derived tensional strength which are the basis of structural design. It is necessary to define setup of tests and loading rate for the tests used to deriving of FRC tensile material parameters.

Acknowledgements

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