FIBER CONCRETE: FROM TECHNOLOGY TO INNOVATIONS

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Abstract

In the paper an experimental studies including investigation of performance of concrete members reinforced with conventional steel bars and with synthetic/steel fibers are presented. Several sets of members have been tested to determine the influence of polypropylene/steel fiber reinforcement on the mechanical behaviour of conventionally reinforced concrete members. The present study proves that fiber reinforcement generally can reduce crack width and deflections and improve ductility and toughness of members and that the combination of polypropylene/steel fibers, longitudinal steel bars (without stirrups) may meet strength, ductility and serviceability requirements.

The basic material characteristics were obtained from laboratory tests and by an inverse analysis procedure the load-deflection relations were transformed into constitutive relations used in simulation. The tests were simulated by means of a non-linear program system using various constitutive relations, which accomodates changes in fiber concrete modelling. Behaviour of a member was optimized to the demand and the process was adjusted to the conditions in the factory manufacturing.

Keywords: (fiber concrete, precast members, experimental verification, simulation, innovation)

1 Introduction

In the last decade rapid development in the sphere of structural concrete run up including introduction of progressive technologies and applications of innovative materials like various types of fiber concrete. Fibers affect resulting properties of concrete composites to the great extent and enable innovative procedures to be introduced into technology and production of concrete members and structures. Significance of fibers in fiber concrete is not only in improvement of the performance of FRC in comparison to the plain concrete but also in application in reinforced concrete structures, high strength and ultra high strength concretes. For application of FRC in structural members it is necessary to ensure not only appropriate technique for production but also adequate guidelines for design. Material properties of fiber concretes have been investigated since 70´s and benefits of fiber concrete are beyond all doubt. Lately a utilisation of fiber concrete in structural elements has been focused, as fibers in a structure improve structural behaviour under service load, fatigue resistance, enhance service life and provide advantageous failure

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mechanism due to higher ductility. It is also proved that thanks to fibers the amount of shear reinforcement may be reduced.
For extension of fiber concrete utilisation more investigations of structural behaviour have to be provided. Research presented in this paper intends to be a contribution to the structural fiber concrete development.

2 Fiber concrete structural analysis

Generally, the FRC characteristics for tension largely influence the bending resistance and the shear resistance properties of the structure. By estimating tensile characteristics adequately, it is encouraged to produce the structure with efficient safety and also with the economical rationality.

Prior to proposing a suitable methodology for fiber concrete structures design, demands on FRC analysis should be stated. Designing of FRC elements must be compatible to concrete structures analysis. Benefits of fiber concrete must be taken into account. A general routine for fiber concrete member is not standardized yet. There are many types of fibers and concretes with diverse behaviour. These are the reasons to find methodology as simple and low-cost as possible.
Analysis of any structure must be based on realistic material properties and suitable material model. The basic material characteristics shall be determined in common laboratory tests: compression test, tension test, flexural test.

3 Research of FC properties and behaviour

In an experimental programme fiber concrete with polypropylene/steel fibers has been investigated. The effect of a dosage and a type of fibers on load bearing capacity and service load behaviour with different types and amount of fibers was monitored. The programme was focused on finding of proper material model for design and evaluating material model influence on the structural analysis.
These positives of polyprpylene material was proved [1] in an analysis or are commonly known: concrete with 1% volume content of polypropylene fibers showed good workability of the mixture with common fiber content, proper fiber dispersion was observed, no balling occurred. High tensile strength of the fiber enables effective use. With a small diameter of fibers is needed aspect ratio obtained with relatively short fibers. Polypropylene fibers ensure both good control of shrinkage and induced cracking (<0.5%) and enhancement of the tensile and flexural strength of FC. And an important positive of polypropylene fibers is contribution to fire safety of FS elements. In initial stages of research project a dosage of fibers was examined. A one percent volume content of fibers showed convenient properties of resultant material (ductility, residual strengths) and satisfactory met demands on both shrinkage cracking and layout of cracks at ultimate loading. In a following stage of the project a structural element was inquired into. More mixtures were prepared to compare benefit of fibers in the concrete matrix: a conventional concrete and corresponding fiber concrete with polypropylene fibers Forta Ferro. Fibers Forta Ferro have strength 700 MPa, length 50 mm and bulk density 910 kg/m^3. A set of test beams 1800 x 150 x 100 mm reinforced with two steel bars of 8 mm diameter both from concrete and fiber concrete were manufactured. Properties of the steel used as a longitudinal reinforcement were determined in a tensile test. The yield strength was

603 MPa. The steel had relatively low increase of strength from the value of yield strength to ultimate strength.
The beams were bended in a laboratory test and a deflection at midspan was measured and development of cracking was observed. The beams were loaded and controlled with deformation. The speed of loading was low at first stages of experiment after crack formation the speed was increased. The load was applied until a failure was reached.

4 Material properties optimization

So far concretes with fibers were not commonly used for structural members, as utilisation of such material had low financial benefits. But steps are being undertaken to prepare for conditions when use of this material would bring savings or earnings to contractors. The database of material properties including material parameters for numerical simulation in FEM is being compiled based on tests of concretes with various fibers and different dosage, without and with limited bar reinforcement.

The structural analysis of a particular structure or structural element would consist of preliminary analysis where the stress-state of the element due to loading would be calculated. On the basis of required properties of the structure, database of material properties convenient concrete mixture would be chosen and numerical simulation performed to predict behaviour of the structure. Decisive would be finding of optimal proportion of fibers for any application in terms of Performance Based Design. An optimization problem is solved to meet demanded properties and to design realistic mixture with good workability at favourable price. The advantage is that it is not necessary to test different types of concretes in a laboratory, what saves time and money.

A case study [2] within the project mentioned above was developed for choice of parameters for different groups of structural members. Parameters of simulation depend on the type of the structure, namely if the reliability of the structure depends on the behaviour before cracking or after cracking and on acceptable simplification of the structure.

5 Application of FC in precast elements

5.1 Bridge accessories from FRC

In a pilot project conducted in the frame of the project supported by ministry of industry and trade in cooperation with construction industry concerning design methods and practical application of various types of fiber concrete seweral types of simple precast elements for bridge accessories in the sphere of bridge construction were tipped for testing in the production plant.
For more groups of precast concrete members intended for application of FRC (and not in that project only) it is necessary to choose different efficient type of fiber concrete with suitable mix composition. The reasons were differences in loadings and conditions acting on members during their service life. Precast elements of bridge cornices - covering plates are auxiliary elements without load-bearing function, but crash barriers have to resist impact loads of vehicles and safety of their design is very important. On the other hand both elements have in common that they are usually designed only according to constructional provisions so that they should resist mechanical damages caused by traffic and various environmental exposures including areas subject to freeze thaw.

The result of the study was that concrete with structural synthetic fibers was the best solution for cornice plates and concrete with steel fibers is the most suitable material for barriers due to its greater toughness and increased tensile strength in comparison to plain concrete. Both selected fiber concrete materials have good ductility needed for elements exposed to severe conditions on bridges concerning changes of temperature and humidity.


Fig. 1 and Fig. 2 Casting of fiber concrete member

5.2 Production of selected FRC elements

Transition from an intention of an FRC application to the actual production of an element was very demanding process. Therefore only simple elements were tipped for the first phase of production. Operating conditions in a production plant are different from conducting laboratory studies. Harmonized components of concrete mixture had to be adjusted and technological process should be verified for selfcompacting type of concrete. By concreting of plate elements real applicability of production for cornice plates was proved. The procedure of production of fresh fiber concrete and casting concrete into the form is documented on the following photos the (Fig. 1 a 2).

5.3 Surface

Smooth concrete surface was observed on the bottom of the two cornice plate elements after their lifting from the form, the appearance of the elements was not affected by used fibers and the flat plane showed no visible signs of single polypropylene fiber. An inspection showed that visual impact of the element is distinguished with no deterioration on the exposed side of element.

5.4 Further benefits

A design study was carried out to enhance the capacity of the cornice plate to carry all the loads with lower conventional reinforcement [3]. The thickness of the member was smaller and therefore the weight decreased and the overall dimensions of the element were optimized. Cost on the more expensive material (due to cost of fibers) was compensated by decreasing of its lower total volume (savings of of concrete 40%) and by partial removal of conventional bar reinforcement and by cut down of armouring labour. The cost on transport and handling was also lower due to lower self weight.

Fig. 3 Placing concrete into the form

The FRC elements are cost effective due to lower consumption of material and energy. Mechanical resistance of the plates during transport and manipulation were verified after a longer time period. Total economical efficiency of FRC plates was evaluated after testing in the field area on larger number of elements. Further benefit in performance of the FRC elements can be seen in higher durability, lower maintenance cost and longer lifespan of the structure. Proper material characteristics are ensured by production of common concrete with synthetic polypropylene fibers of efficient dosage per cubic metre. FEM analysis of the plate element model verified the values of maximum tensile stresses in the area of joint hanger that do not exceed tensile strength of the fiber concrete in fact the stress is as low that the element could be produced even from the concrete of lower grade. The requirements on durability of such elements however prefer the concretes of higher grades. All simulations were well within the typical safety factors used for structural design of the elements.

6 Conclusions

Innovation consisted in a transition from current concrete to fiber concrete when an optimization procedure is necessary: starting from selection of proper type of fiber concrete, adjusting shape and thickness of the member and experimental verification of structural behaviour of the new member. The procedure included optimization of amount of fibers so that it was ensured that the member would not fail or be damaged during function or transport under conditions prescribed for precast elements of common type and common reinforcement. The manufacturing in real factory conditions was verified and successful production of members was started. The product was given Innovation of the year 2008 Award by Association of innovative entrepreneurship of the Czech Republic that regularly appreciate an improved product, technology or service effectively located into the market.

Fig. 4 and **Fig . 5** Front side of the hardened cornice plate and a factory stock-yard

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