RIGA TECHNICAL UNIVERSITY
Faculty of Building and Construction Engineering
Faculty of Transport and Mechanical Engineering

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SHORT FIBERS REINFORCED CONCRETE QUASI-PLASTIC FRACTURE ANALYSIS

Doctoral Thesis (PhD) Summary

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CONTENTS

GENERAL CHARACTERIZATION OF THESIS

Significance of the topic

Fiber reinforced concrete has undergone rapid development during the last years, and this composite material has been successfully used in various applications in civil engineering. Affordable prices and flexibility in forming lead to think seriously for enhanced production methods regarding the mechanical and physical properties of different fiber types and concrete matrices.

During the last years, the compressive strength of the concretes used in construction industry has significantly increased. Concrete with a compressive strength of 50-60 MPa was traditionally classified as „high" strength concrete, but now it is changing to 120-150 MPa for skyscrapers and other heavily loaded constructions. Unfortunately, with increasing the strength, concrete becomes more brittle. To overcome this situation, one effective solution is to use short small fibers for concrete reinforcement. While the propagation of unstable cracks arises soon in a loaded unreinforced concrete matrix, cracks can be bridged by fibers in the case of a fiber reinforced concrete, and the material can carry loads far beyond the crack-resistance capability of a plain concrete matrix. Such fibers may be metallic — steel, and non-metallic — glass, carbon and aramid. This research is devoted to an experimental investigation of glass and carbon fiber reinforced concrete (FRC), its development, and the investigation of the casting and the matured material strength properties ~~investigation~~.

Aim of the research

The aim of this research is to practically investigate the mechanical and technological properties of straight short fiber reinforced concretes regarding the theoretical methods to obtain a quasi-plastic fracture analysis with suitable solutions for the development of fiber concrete composites as important construction materials with conditions to retain the fibers properties undamaged and to find out the main parameters influencing the mechanical and structural behaviour of this material.

Investigation methodology

This investigation was done according to an experimental program in accordance with ~~to~~ national standards and international recommendations for pull-out experiments and bending tests. Depending on the present investigation, a test of the theory is obtained concerning different theoretical methods the experimental results of which lead to predict the parameters that influence the mechanical and physical properties of fiber reinforced concrete.

Pull-out experiments for glass, carbon and straight steel fibers are precise~~ly~~ experiments that require the use of suitable methods for preparing specimens in the laboratory under precise conditions and equipments with a flexibility of load applying, in addition to bending test regulations in the lab.

Subject of investigation

To investigate high strength fiber concretes, to enhance the problematic mixing workability and to find solutions for it by applying better mixing methods with new recommendations in order to keep the fibers properties. The pull-out mechanism of the fibers needs a more clear procedure to understand the real behaviour of the fibers embedded into concrete matrix.

The post cracking in fiber concrete beams starts at cross section where the fiber content is lower, therefore this presents an investigation concerned with decreased fiber contribution to obtain better flexural strengthening and better fiber distribution inside concrete matrix.

Finally, to look at more precise parameters concerning the mechanical and structural behaviour of FRC.

Scientific novelty of the research

Special wet mixing procedure with vibration was elaborated and fiber concretes with $0<V_f<4\%$ of glass and carbon fibers were obtained. Analytical model of single fiber sinking in concrete subjected to external vibrations was elaborated and numerically realized for glass, carbon and steel fibers. Experiments showed that it is not possible to obtain a homogeneous premix fiber concrete in dry way if the glass and carbon fiber content V_f is higher than 0.4%.

Analytical and numerical (FEM) single fiber and fiber bundle 2D and 3D models were created for perfect bond between fiber (fiber bundle) and matrix, partially debonded fiber (fiber bundle) and matrix and sliding motion of fiber with different friction coefficients between fiber and matrix and fiber to fiber in bundles. Numerical results were compared with experiments and micro-mechanical parameters: fiber–concrete friction coefficient equal to 0.2; critical length equal to 1 mm for single glass fiber and 10 mm for glass fiber bundle; pull-out force and stress; pull-out displacement was obtained for single fiber and fiber bundle.

The model of a structural crack's growth ~~model~~ in fiber concrete in correspondence with the quasi-plastic behaviour of the material were elaborated, based on the experimentally measured pull-out of a single fiber (for steel fibers) and fiber bundle (for glass and carbon fibers). Fiber concrete strength and post-cracking quasi-plastic behaviour prediction were realized. Prediction results were validated by fiber concrete 4 point bending tests. Numerical model successfully describes mechanical processes in fiber concrete and allows to predict the necessary fiber content in the concrete depending on the expected strength and construction member fracture behaviour.

Practical value of the research

Practical value has:

a- The developed premix glass, carbon and steel fiber concrete wet mixing **procedures**. Knowledge about mix granulometry for such fiber concretes.

b- The developed numerical **models:** single fiber sinking in concrete; micromechanical 2D and 3D orthogonal and inclined single fiber pull-out models (with perfect fiber-matrix bond, with partial debonding, for fiber sliding (with contact elements)); 2D and 3D fiber bundle pull-out models (with perfect fiber-matrix bond, with partial debonding for outer bundle fibers, for fiber bundle sliding (with one friction coefficient between fibers and matrix and another between fibers)); macro-crack growth model.

c- Numerical results obtained for (realizing the above mentioned models): glass, carbon, steel fiber motion in concrete under applied external vibrations. **Numerical results** obtained for the pull-out micromechanics (stresses, forces, displacements) of single glass, carbon and steel fiber and glass and carbon fiber bundles.

Thesis structure

The present PhD thesis consists of an abstract, 6 chapters, the seventh being devoted to conclusions, and two appendices. The thesis comprises 281 pages, 199 figures, 16 tables, and a list of references consisting of 32 items.

Research approbation and publications

The results of this research are reported and published in the following international conferences and scientific seminars:

- The 5th International Conference "Fibre Concrete 2009: Technology, Design, Application" on 17 – 18 September 2009, Prague.
- The 18th conference of Latvian Concrete Association, Riga Technical University, on 28 May 2009.
- Seminar in the Civil Engineering Council on 27 May 2009.
- Seminar in the Institute of Mechanics on 25 May 2009.
- International conference of Riga Technical University on 15 October 2008.
- The 17th conference of Latvian Concrete Association, Riga Technical University, on 12 June 2008.
- The 15th international conference "Mechanics of Composite Materials", on 26-30 May 2008 in Riga, Latvia.
- The seminar in Institute of Mechanics on 4 March 2008

The main conclusions were presented in 1 patent and 7 publications.

Work was done within the scope of FP6 European research project SCOUT (Sustainable Construction of Underground Transport Infrastructures). Investigation results were exploited in 4 regional scientific projects.

THESIS CONTENTS

This PhD dissertation consists of seven chapters; the first one is devoted to a literature review that introduces the initial evaluation for fiber reinforced concrete benefits for construction and its application possibilities together with the latest research results obtained in this scientific field, as well as to defining the main problems of fiber concrete production that need to be solved. Chapter 2 describes the mixing casting problems of fresh concrete and provides suitable solutions with the application of a new way of mixing (wet way) and vibration control for casting. The third chapter speaks about the matured concrete development during the micro and macro-mechanical investigations in accordance with ~~on~~ the experimental program and finite element models up until obtain successfully new procedure explains precisely pull-out mechanism in addition to find-out the real value of friction coefficient at the interface. The fourth chapter is devoted to an elaborated experimental program of beams in comparison with the theoretical methods, where the bending stress was developed with good results for different fiber types. Failure prediction is analyzed in Chapter 5, in which it was found that straight short steel fibers and glass fibers have a similar behaviour, while carbon fibers have hardening behaviour. Recommendations and standards are analyzed in Chapter 6, where new suggestions have been introduced for more precise safety factors verified by our experimental data. At last, the final conclusions of this research are laid out in Chapter 7 with a suggestion to European standard for fiber reinforced concrete.

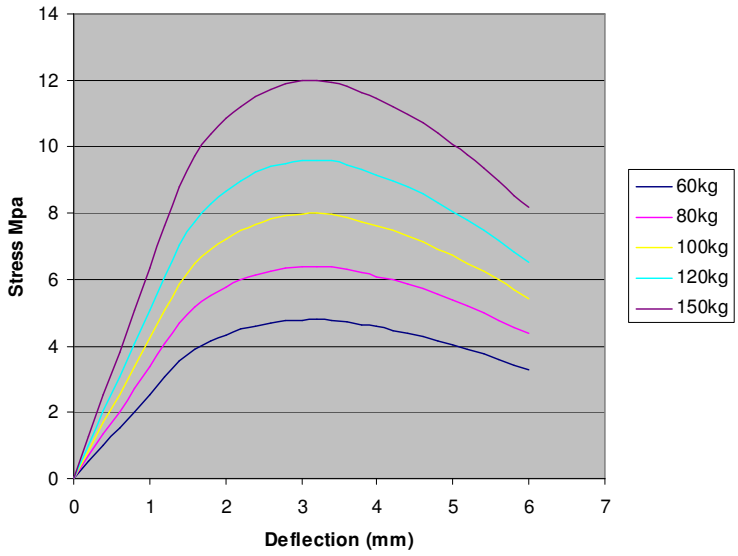

Figure 1. Stress-midpoint deflection diagrams for straight steel fiber concrete (subjected to 4-point loading) with different fiber content in weight from 60 to 150 kg, and the fiber length equal to 6 mm with a diameter 0.16 mm.

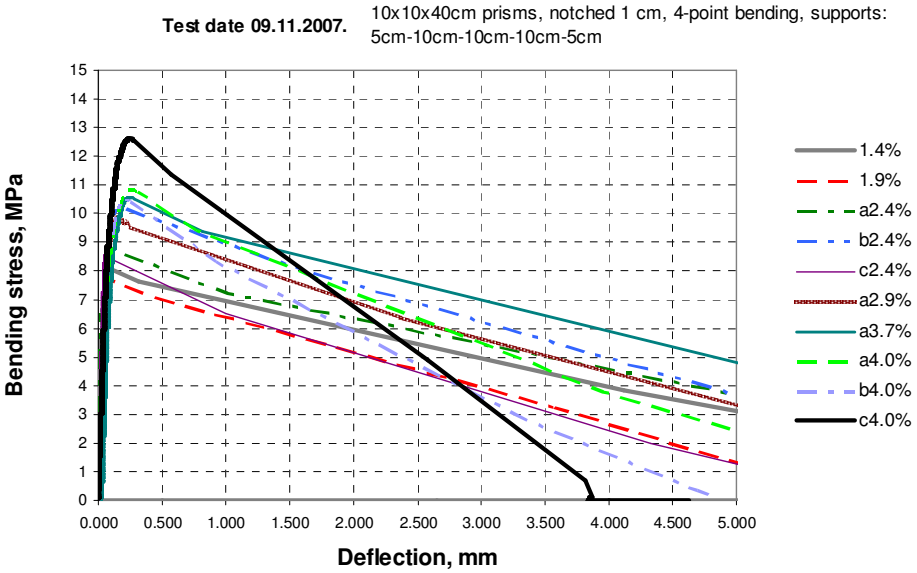

Figure 2. Stress-midpoint deflection diagrams for glass fiber concrete (subjected to 4-point loading with the fiber content V_f from 1.4% to 4%, and fiber strand length equal to 12 mm.

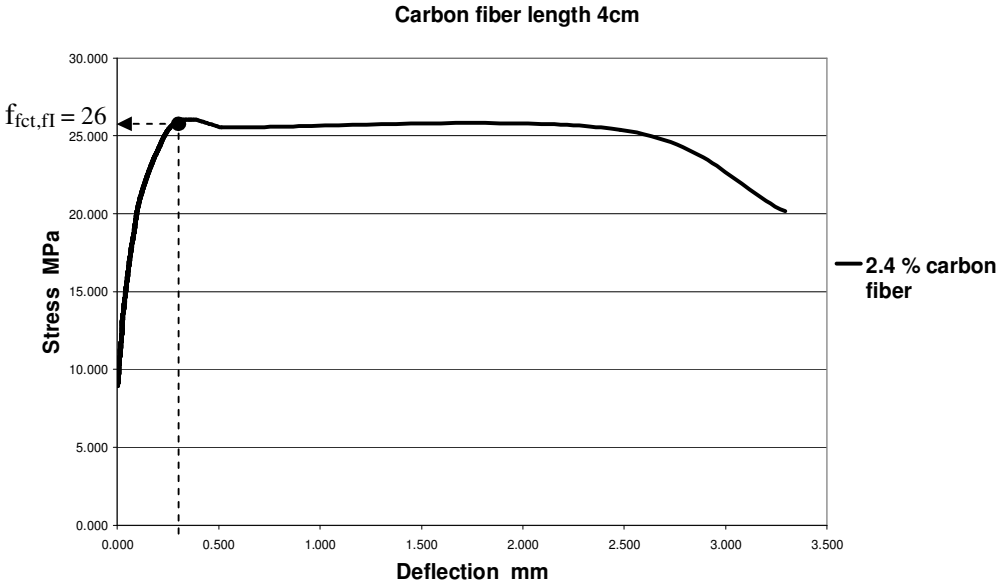

Figure 3. Characteristic experimental values for failure behaviour of CFRC.

CONCLUSIONS

- Conditions for workability were recognized, and a solution to its improvement was found (wet mixing).
- The volume fracture of fibers was increased from 0.4% to 4%.
- Vibration provides for a convenient casting and an acceptable distribution of fibers.
- The expected real value of the friction coefficient between the glass fiber and the concrete matrix is equal to 0.2.
- The critical lengths of a single glass fiber and a glass bundle are 1 mm and 10 mm respectively.
- Some parameters in the recommendations need to be modified (it is suggested to use $\eta 2 = 0.25$ instead of 0.4).
- Numerical models for failure prediction were obtained with good agreement.
- It is suggested that a generally applicable European standard for fiber concrete be obtained.

A. KHABAZ PUBLICATION LIST

Patents:

1. *V.Lapsa, A.Krasnikovs, M.Eiduks, A.Khabaz, "Rotational rheometer", Latvian patent for invention Nr. 13919, October 10, 2007.*

Publications:

1. *A.Krasnikovs, A. Khabaz, G.Shahmenko and V.Lapsa. "GLASS AND CARBON FIBER CONCRETE MICROMECHANICAL AND MACROMECHANICAL PROPERTIES", Sc. Proceedings of Riga Technical University, Transport and Engineering, 6 Vol.28, Latvia, 2008, p.132-141.*

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DOCTORAL THESIS
NOMINATED FOR DOCTORAL DEGREE RECEIVING IN ENGINEERING SCIENCE IN RIGA TECHNICAL UNIVERSITY

Doctoral thesis for doctoral degree receiving in engineering science is presented for public discussion and defended on …..…… 2009 in Riga Technical University, Ezermalas str. 6, room …….

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CONFIRMATION

I hereby confirm, that I am the author of the present doctoral thesis that has been submitted for reviewing at Riga Technical University in order to obtain doctoral degree in engineering science. Doctoral thesis has not been submitted to any other university for obtaining scientific degree.

Amjad Khabaz …….(Signature)

Date: ……

Doctoral thesis has been written in English, it contains an abstract, 6 chapters, conclusions, 2 appendices, 199 figures and 16 tables, a total of 281 pages. There are 32 references in the reference list.