Experimental Investigation of the Fracture Behaviour of Reinforced Ultra High Strength Concrete

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FRACTURE & DYNAMICS
PAPER NO. 75

To be presented at the Eleventh European Conference on Fracture, Poitiers-Futurescope, France, September 3-6, 1996

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EXPERIMENTAL INVESTIGATION OF THE FRACTURE BEHAVIOUR OF REINFORCED ULTRA HIGH STRENGTH CONCRETE

J. P. Ulfkjær, M. S. Henriksen* and B. Aarup#

In the last fifteen years new types of cement based materials have been developed in Denmark at the Aalborg Portland Cement Factory. These types of new materials are characterized by a very high strength even when mixed at room temperature and using conventional mixing techniques. In this paper the structural behaviour of a very high strength cement based material with and without steel fibres is investigated. A simple structural geometry has been tested, namely a beam subjected to three point bending. The results show that the increase of ductility of the material also gives a more ductile behaviour of the beam. In some cases even the structural failure modes change from shear failure to bending failure.

INTRODUCTION

As new types of materials and new kinds of structures are developed, also new design methods are needed, Modéer (2). When designing concrete structures of normal strength concrete (with compressive strength below 50 MPa), the conventional design codes can be used. These codes are usually restricted to certain strength limits imposed on the compressive strength and other empirical rules. During the last three decades research tools such as fracture mechanics have been developed for concrete structures, Karihaloo (3). One of the main results of this research is, that the ductility of the concrete is just as important as the compressive strength. At Aalborg Portland Cement Factory new types of concrete have been developed, Bache (1). This new material has a very high strength and a very high ductility. In order to illustrate the importance of the ductility of concrete, beams of the new material are tested both with and without steel fibres.

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EXPERIMENTS

Materials

Concrete. Two types of concrete were tested. A high strength concrete and the same concrete with 6 % by volume of steel fibre added. The mix of the concrete with steel fibres is (units are [kg/m^3]): Densit© Binder: 650; Water 102; Steel Fibre 324; Sand 0 - 0.25 mm: 113; Sand 0.25 mm - 1.0 mm: 230; Sand 1.0 mm - 4.0 mm: 461.The concrete is mixed using conventional methods. In the rest of the paper the mix without steel fibres is called the ultra high strength concrete (UHSC) and the one with fibre is called steel fibre concrete (SFRC).

The compressive strength and the modulus of elasticity of the concrete are determined on 100 mm by 200 mm cylinders and the fracture energy was determined on beams in three point bending with the dimensions: span 800 mm depth 100 mm and thickness 100 mm. At the midsection a notch of half the beam depth was saw cut. Refer to Ulfkjær and Brincker (4) for a detailed description of the determination of the fracture energy. The mechanical properties of the concrete are shown in table 1.

TABLE 1. Mechanical properties of the two types of concrete.

Test type		Mean	S.Dev	Coef. of Var.
Compressive Strength	UHSC	173.3 MPa	4.0 MPa	2.29 %
	SFRC	152.4 MPa	6.64 MPa	4.36 %
Bending Tensile Strength	UHSC	9.63 MPa	0.51 MPa	5.27 %
	SFRC	30.0 MPa	2.72 MPa	9.11 %
RILEM Fracture Energy	UHSC	73.7 N/m	18.0 N/m	7.37 %
	SFRC	19.000 N/m	1.300 N/m	6.86 %

Steel. Two different ribbed steel diameters were used ø8 and ø16. The constitutive parameters for the steel were determined by uni-axial tensile tests and are summarised in table 2. The yield capacity is the horizontal part of the stress strain curve until hardening occurs.

TABLE 2. Mechanical properties of the steel used.

Steel type	Young Modulus MPa	Yield strength MPa	Yield capacity %	Ultimate strength MPa
ø8	2.04E5	777	0	777
ø16	2.07E5	610	1.84	725

Specimens

The dimensions of the beams were thickness 100 mm, depth 100 mm and span 1200 mm. Three different reinforcement ratios (the steel area divided by the cross sectional area) were tested: 1.0 % (two ø8), 2.0 % (four ø8) and 6.0 % (three ø16). The cover of the reinforcement is 10 mm for all beams. There were no stirrups or compressive reinforcement in the beams.

Testing equipment and procedure

The beams were submitted to three point bending in a specially designed servo-controlled material testing system. All the experiments were performed in displacement control. A photo of the test set-up is shown in figure 1. At both supports horizontal displacements and rotations were allowed and at one end also rotations around the beam axis were allowed. At the load point rotations were allowed around two axes. This should reduce the influence of axial forces and torsion. The stroke was measured using the built in LVDT (Linear Variable Differential Transformer) with a base of 100 mm and a sensitivity of 10 mm /V. The vertical displacements were also measured along the beam axis at eight points. The base of these LVDTs was 5 mm, 20 mm or 50 mm with a sensitivity of 0.5 mm/V, 2.0 mm/V or 5.0 mm/V, respectively. The horizontal displacement of the beam was measured at both beam ends using two LVDTs with a base of 10 mm and a sensitivity of 1 mm/V. The force was measured using a 63 kN load cell with a sensitivity of 6.3 kN/V or a 250 kN load cell with a sensitivity of 25.0 kN/V. All signals with the time t were recorded using a data logger every third second on a personal computer.

EXPERIMENTAL RESULTS

Two types of failure modes were observed: a ductile bending failure and a brittle shear failure where the cracks were running from the top of the beam near the loading point down to the reinforcement bar, along the reinforcement bar and further to the end of the beam. In figure 2 an example of the two failure modes is shown. The top photo shows a beam made of high strength concrete, and the beam on the photo below is of steel fibre reinforced concrete, both reinforced with 4 ø8. In figure 3 and figure 4 load displacement curves for the three high strength concrete beams and the three steel fibre reinforced concrete beams are shown. The maximum force, the maximum stroke and the failure modes are shown in table 3.

It is seen that the load carrying-capacity is increased by approximately 50 % when steel fibres are added. For a reinforcement ratio of 2 % even the failure mode is changed from a shear failure to a more ductile bending failure by adding steel fibres.

Table 3. Maximum force, maximum stroke and failure mode for the six tested beams.

Reinforce ment ratio	Maximum force		Maximum stroke		Failure mode	
	UHSC	SFRC	UHSC	SFRC	UHSC	SFRC
1 %	19.6	30.9	7.3 mm	14.5 mm	Bending	Bending
2 %	34.5	48.4	9.39 mm	32.8 mm	Shear	Bending
6 %	53.3	83.1	33.2 mm	-	Shear	Shear

CONCLUSIONS

In this paper the structural behaviour of a very high strength cement based material with and without steel fibres were investigated. Six small beams were subjected to three point bending. The results show that the increase of ductility of the material also gives a more ductile behaviour of the beam. The load-carrying capacity of the beams with steel fibres is increased by approximately 50 %. In some cases even the structural failure modes change from shear failure to bending failure.

ACKNOWLEDGEMENTS

Dr. Henrik Stang from the Danish Technical University in Copenhagen is greatly acknowledged for performing the deformation controlled compression test.

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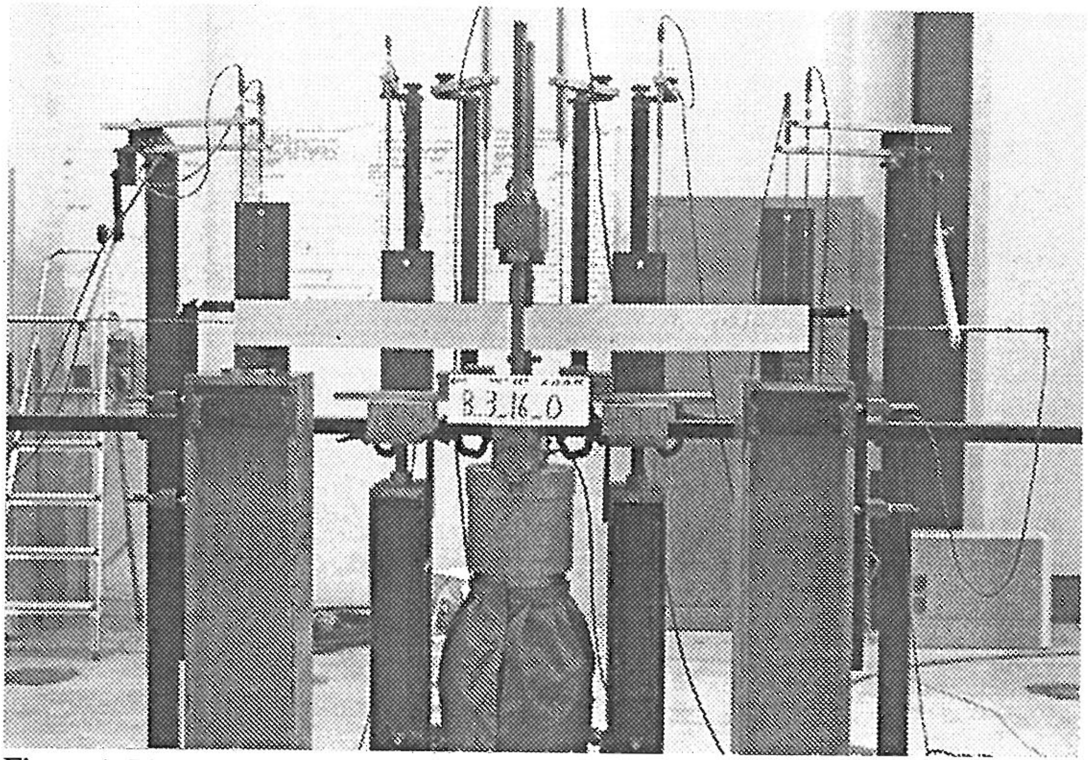

Figure 1. Photo of test setup.

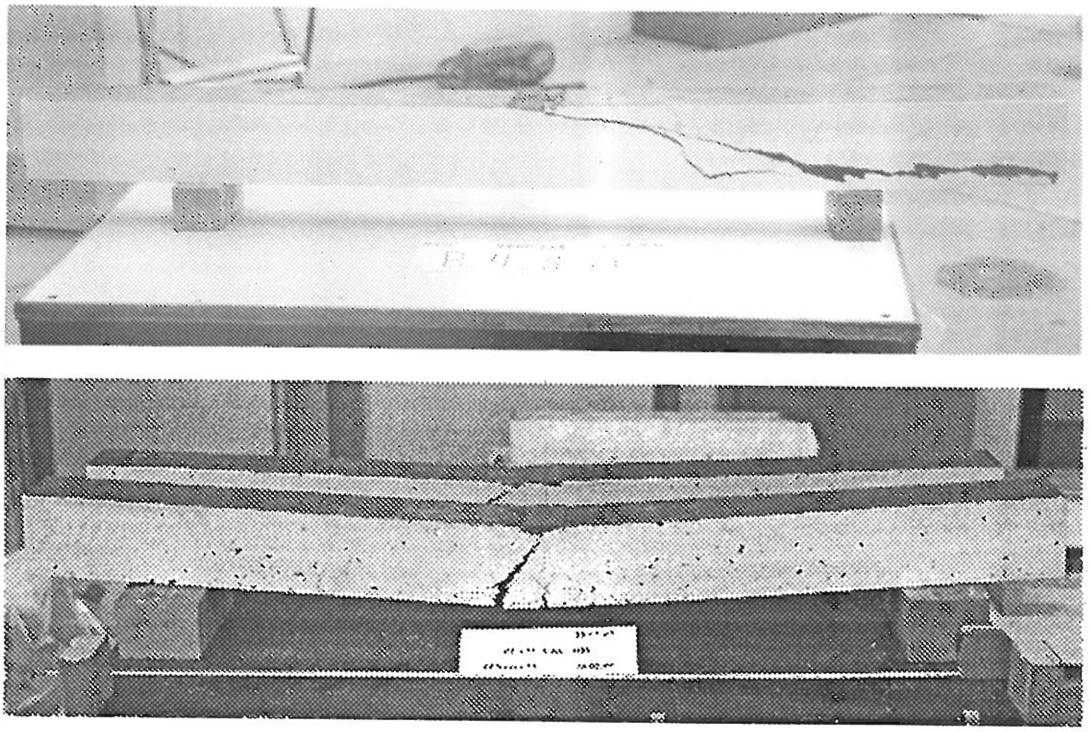

Figure 2. Photos of fractured beams. Upper photo: high strength concrete. Lower photo: steel fibre reinforced concrete.

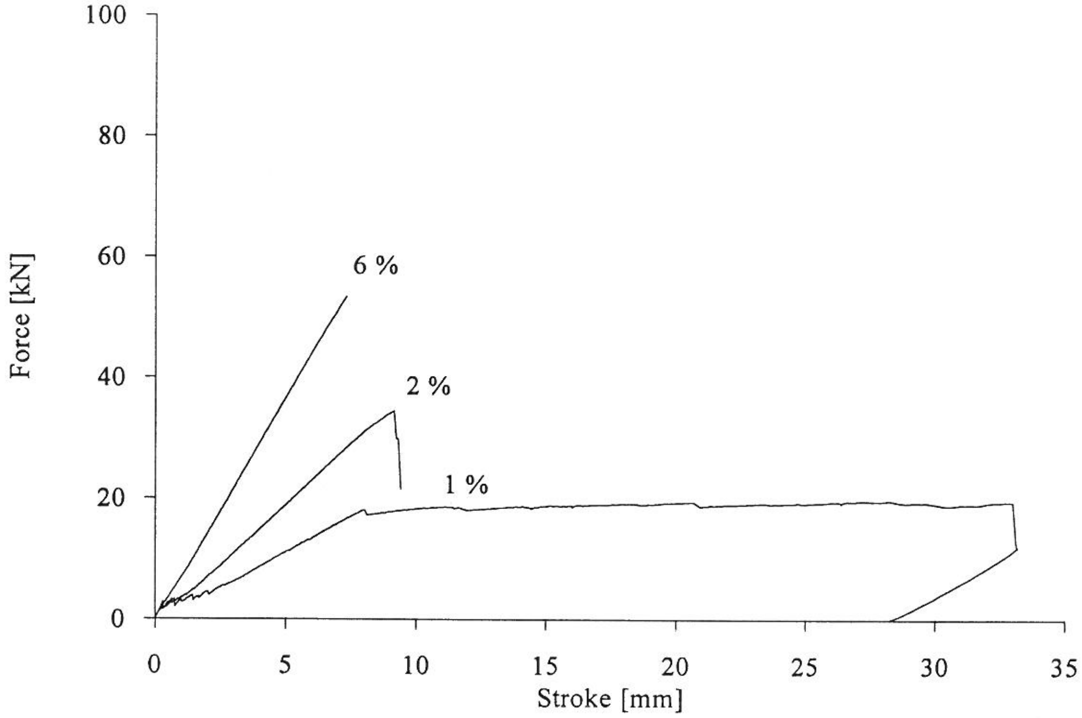

Figure 3. Load displacement curves for the ultra high strength concrete.

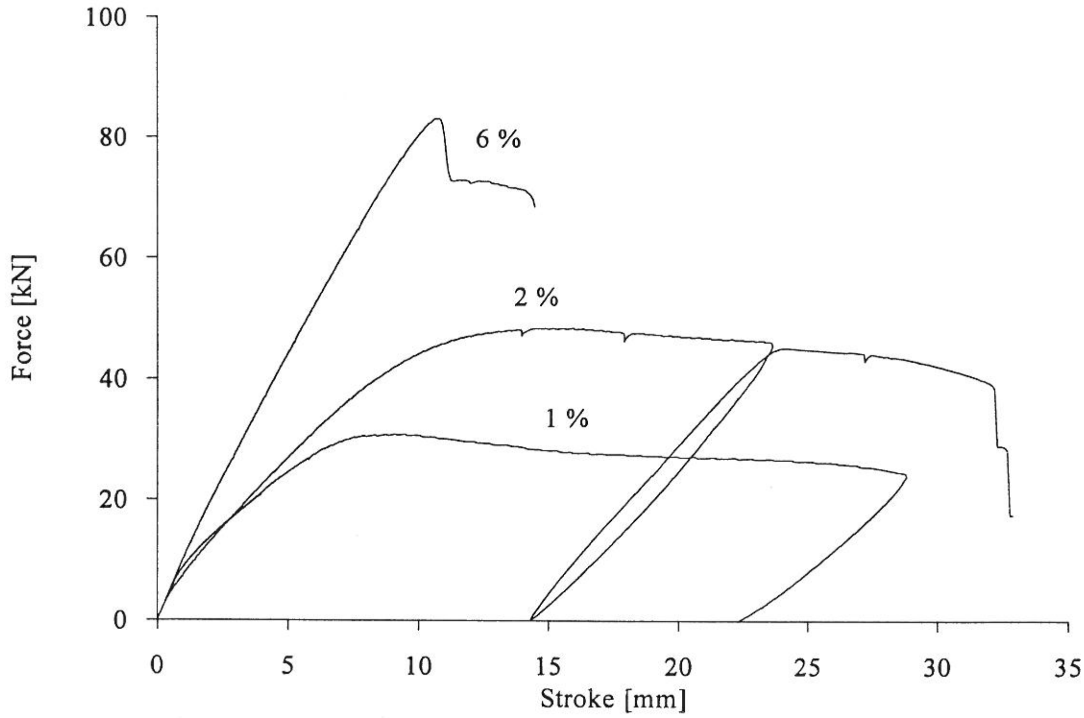

Figure 4. Load displacement curves for the steel fibre reinforced concrete.

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