BOĞAZİÇİ UNIVERSITY

DEPT. OF CIVIL ENGINEERING

A Report on

FORTA FERRO FIBER REINFORCED CONCRETE PLATE TESTS

ADO DIŞ TİCARET LTD. ŞTİ.

Şemsettin Günaltay Cad., Tevfik Bey Sok. Altay Apt.

B-Blok, No:2/7, Kazasker- İSTANBUL

Presented to: Mr. Kürşat Hamzaoğlu

August 15, 2007

Introduction

Testing of concrete plates with different reinforcement and thickness was conducted on July 4, 2007 at the Structural Laboratory of Boğaziçi University. The objective of these tests is to investigate the behavior of Forta Ferro polypropylene fibers and wire mesh, used as secondary reinforcement in concrete, before cracking and at ultimate states. To accomplish this objective, tests of 16 plates were conducted with 4 tests in groups of 2 different thicknesses and 2 different secondary reinforcements in accordance with EFNARC (European Federation for Specialist Construction Chemicals and Concrete Systems) testing procedures.

The results were analyzed in terms of load-displacement and energy-displacement relationships. Observations from testing such as damage types and failure modes, and also load-displacement and energy-displacement relationships for cracking and ultimate stages were recorded.

Type and the Stiffness of the Test Machine

The test setup, as shown in Figure 1, consisted of 200-kN load capacity close loop rigid steel frame. The load applied to the specimen through a 200-kN load capacity hydraulic cylinder that was placed inside the test setup.

Displacement measurements were recorded along the axis of the applied load, at the center and underneath the specimens. At the same time, the magnitude of load was measured with a load cell. All these measurements were recorded with a data aquision system.

Appendix 1 includes the French Plate Test Method as per EFNARC's standard test recommendation.

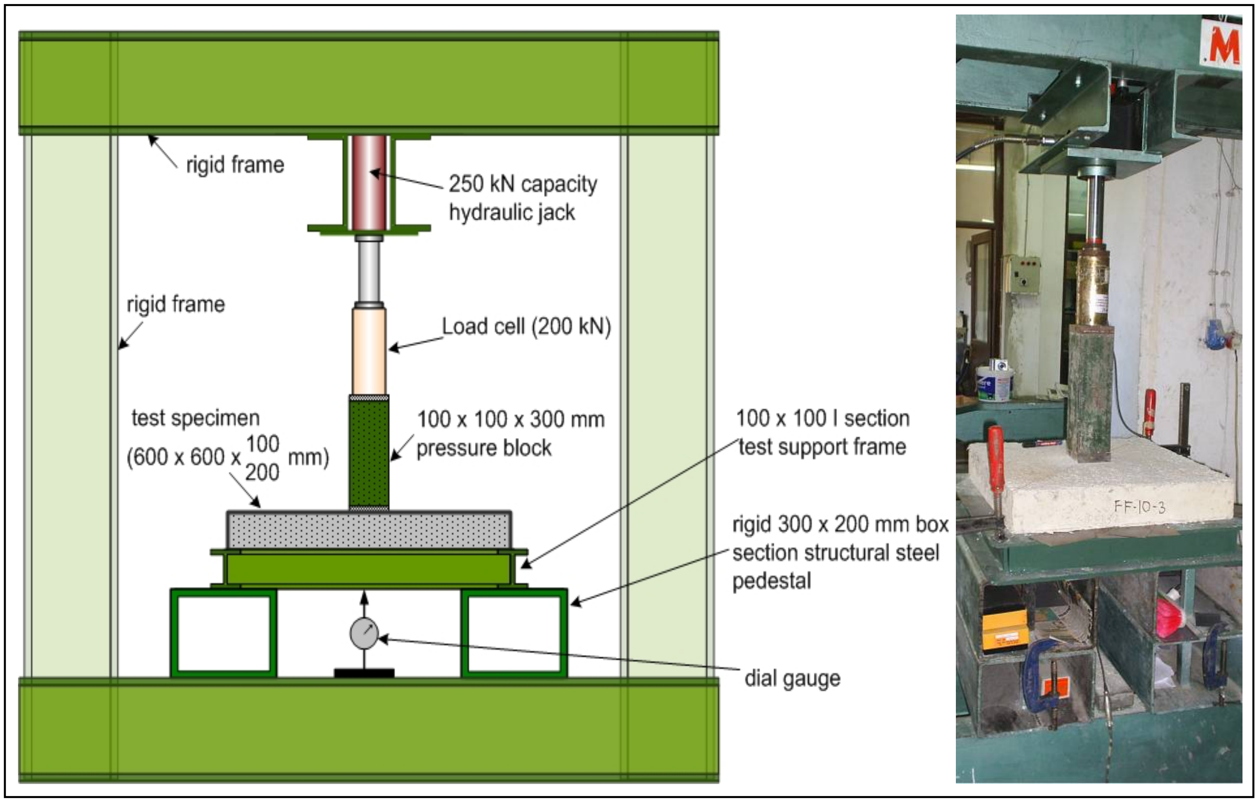


Figure 1: Test setup

Specimen Identification

The test specimens were produced, as shown in Figure 2, in forms of 600mm x 600mm dimensions with C20 (20 MPa) ready mix concrete grade. Total of 16 specimens of 100mm and 200mm thicknesses, and two different reinforcing details of fibers and wire mesh were prepared.

Figure 2: Production of concrete plate specimens

For each concrete cylinder specimen, slump tests were conducted at the site and compressive strength tests were carried out at the day of testing. These parameters are summarized in Table 1. Figure 3 illustrates the secondary reinforcement details used in concrete plates.

Table 1: Characteristics of specimens

Specimen Name	Type of Reinforcement	Concrete Plate Thickness (mm)	Concrete Slump Value Used (cm)	Average Concrete Compressive Strength Used (MPa)
WM-10-1	Wire mesh	100	24	20
WM-10-2	Wire mesh	100	24	
WM-10-3	Wire mesh	100	24	
WM-10-4	Wire mesh	100	24	
FF-10-1	Forte Ferro fiber	100	2	24
FF-10-2	Forte Ferro fiber	100	2	
FF-10-3	Forte Ferro fiber	100	2	
FF-10-4	Forte Ferro fiber	100	2	
WM-20-1	Wire mesh	200	24	20
WM-20-2	Wire mesh	200	24	
WM-20-3	Wire mesh	200	24	
WM-20-4	Wire mesh	200	24	
FF-20-1	Forte Ferro fiber	200	5	25
FF-20-2	Forte Ferro fiber	200	5	
FF-20-3	Forte Ferro fiber	200	5	
FF-20-4	Forte Ferro fiber	200	5	

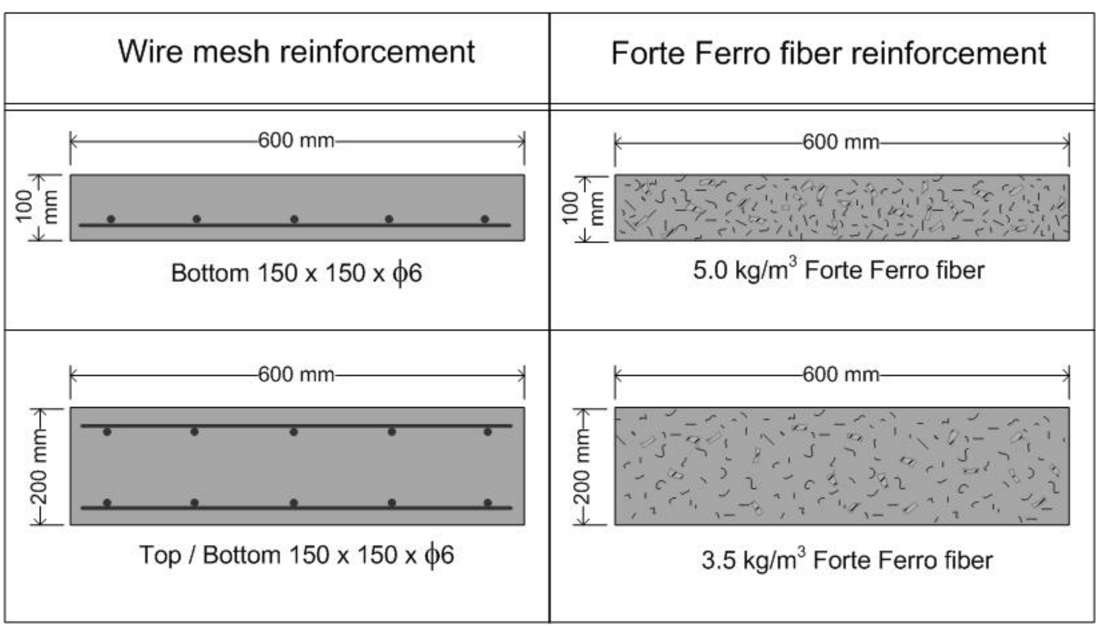


Figure 3: Specimen details

Test Specimen Dimensions

4 at 600mm x 600mm x 100mm concrete and 150mm x 150mm x 6mm wire mesh reinforcing
4 at 600mm x 600mm x 100mm concrete and 5.0 kg/m^3 FORTE FERRO polypropylene fiber

4 at 600mm x 600mm x 200mm concrete and 150mm x 150mm x 6mm wire mesh reinforcing
4 at 600mm x 600mm x 200mm concrete and 3.5 kg/m^3 FORTE FERRO polypropylene fiber

Curing Conditions and Age at Testing

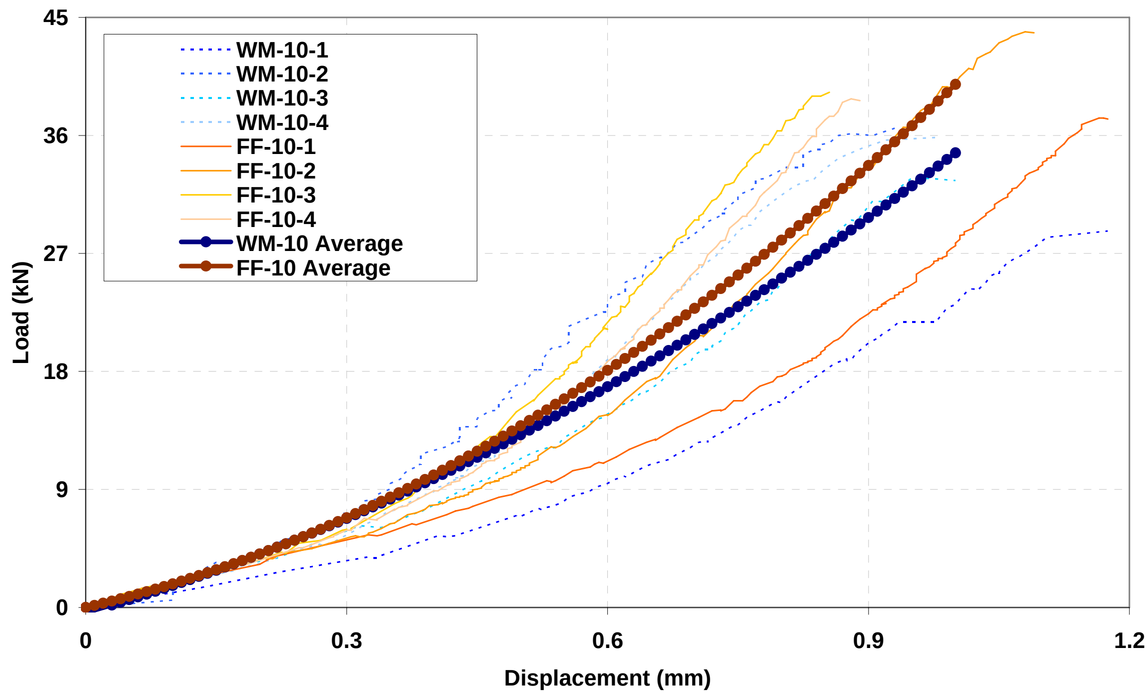
The test specimens were produced inside a factory building and they were cured with water-saturated burlap cover material placed over the specimens. Burlaps were kept moist at all times. This type of curing was performed for a period of 4 weeks. After 4 weeks of casting the concrete, the test specimens were transported to the Structural Laboratory at Boğaziçi University and testing started the day test specimens arrived to the Laboratory.

Rate of Deformation

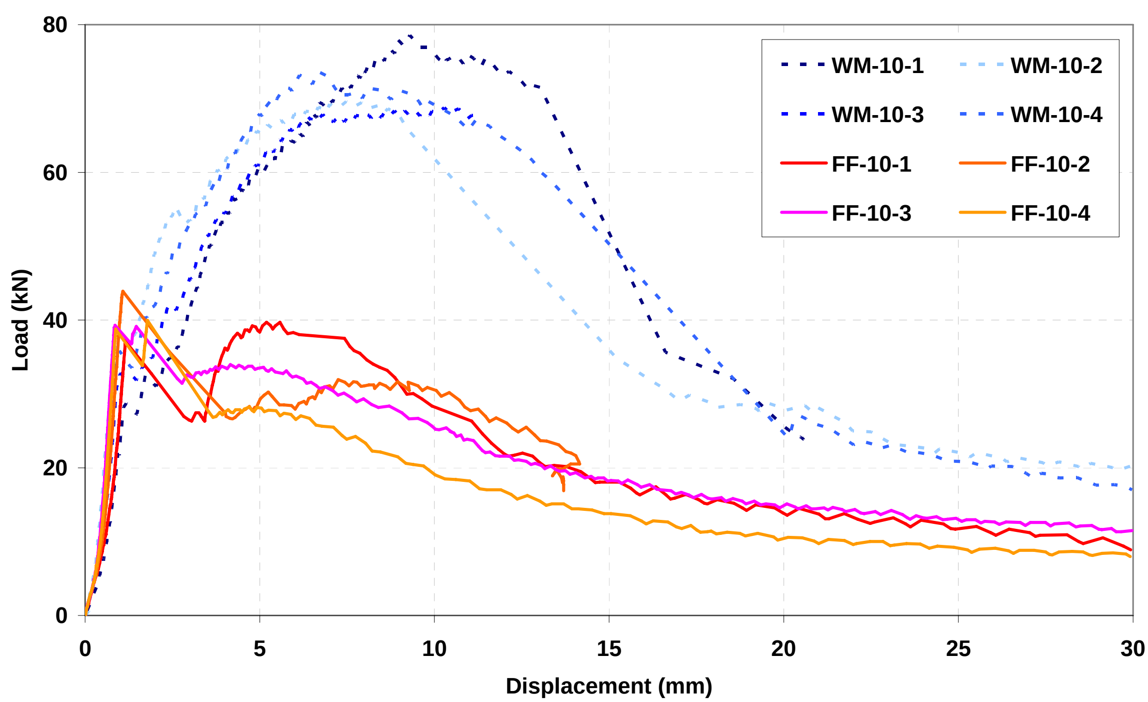
The applied load protocol was displacement-controlled loading type with a loading rate of 0.05 mm/sec.

Data Analysis and Failure Modes of Specimens

The values from the data acquisition system were transferred to the computer and the data was analyzed with Microsoft Excel program. The analyses were conducted on the determination of Load-Displacement and Energy-Displacement relationships before cracking and ultimate load levels. Figure 4 illustrates the Load-Displacement curves for each specimen, whereas Figure 5 shows the failure modes at ultimate loading.

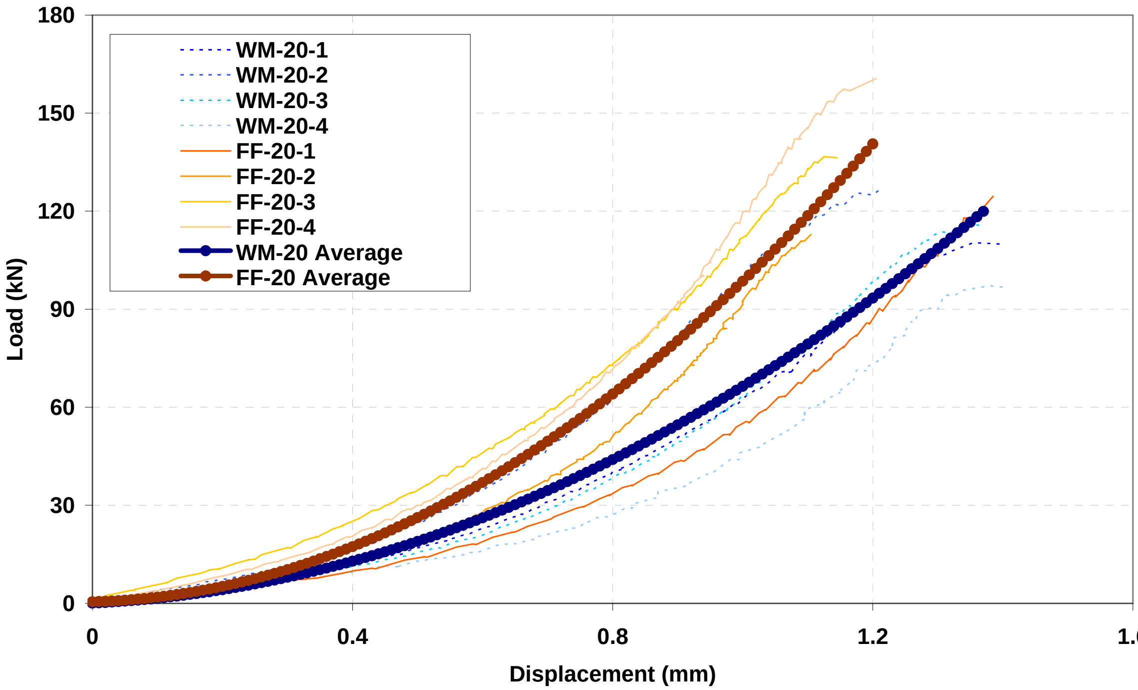


(a) Load-Displacement relationships until first crack (100mm concrete plates)

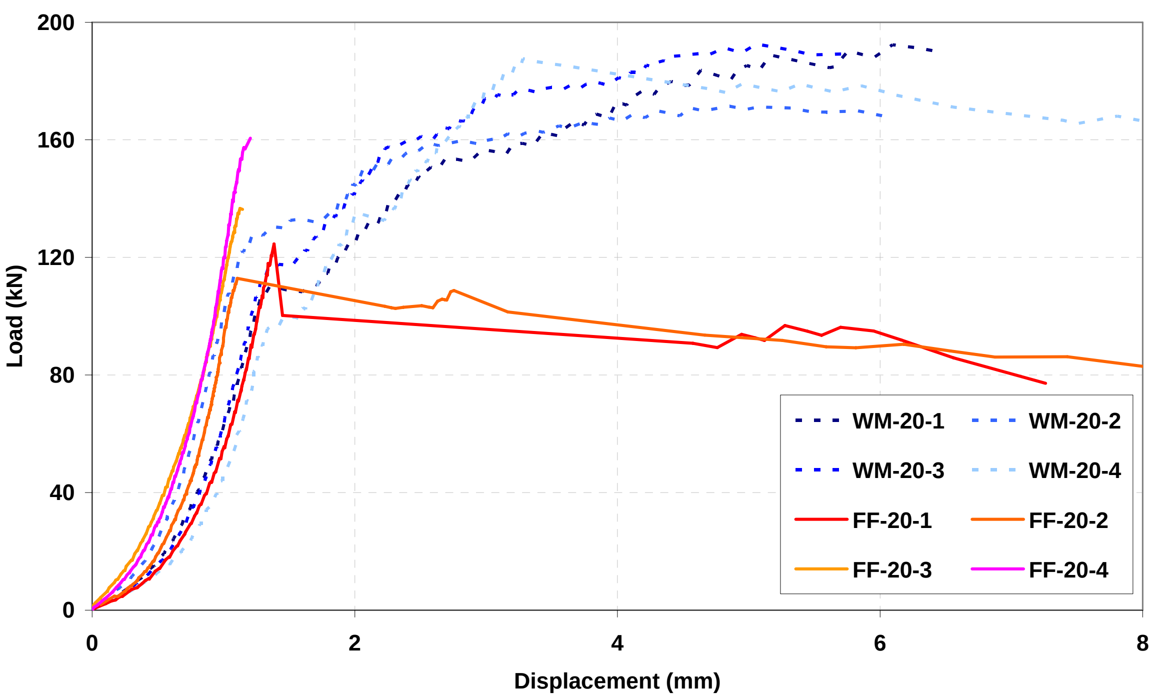


(b) Load-Displacement relationships at ultimate loading (100mm concrete plates)

Figure 4: Load-Displacement curves of test specimens

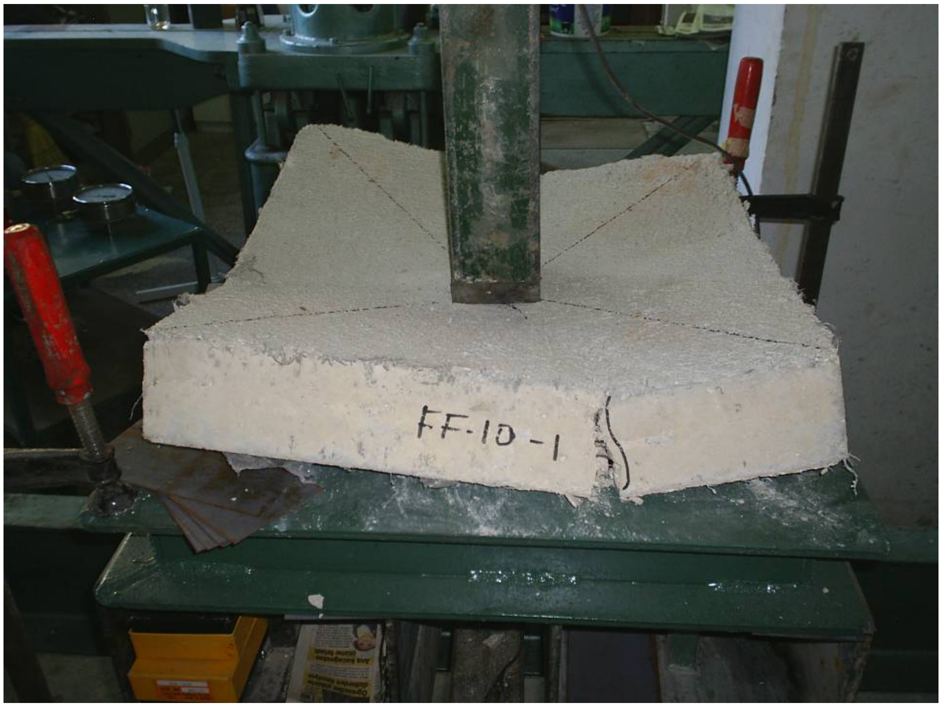


(c) Load-Displacement relationships until first crack (200mm concrete plates)



(d) Load-Displacement relationships at ultimate loading (200mm concrete plates)

Figure 4: Load-Displacement curves of test specimens (Continued)



(a) FF-10-1

(b) FF-10-2

Figure 5: Failure modes

(c) FF-10-3

(d) FF-10-4

Figure 5: Failure modes (Continued)

(e) FF-20-1

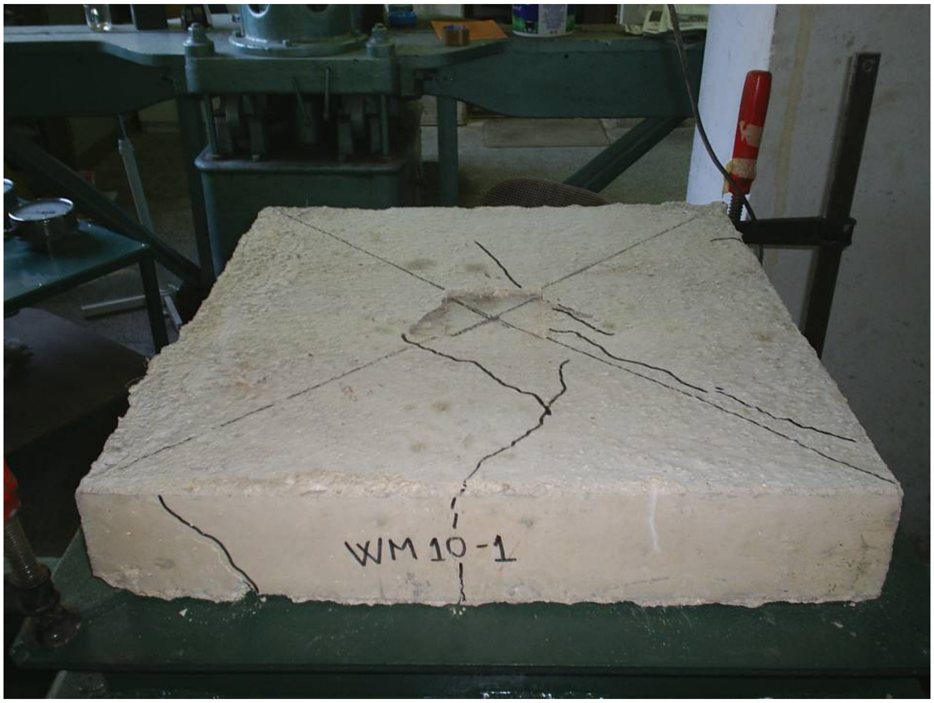
(f) FF-20-2

Figure 5: Failure modes (Continued)

(g) FF-20-3

(h) FF-20-4

Figure 5: Failure modes (Continued)



(i) WM-10-1

(j) WM-10-2

Figure 5: Failure modes (Continued)

(k) WM-10-3

(l) WM-10-4

Figure 5: Failure modes (Continued)

(m)WM-20-1

(n) WM-20-2

Figure 5: Failure modes (Continued)

(o) WM-20-3

(p) WM-20-4

Figure 5: Failure modes (Continued)

First Crack Load and Maximum Load

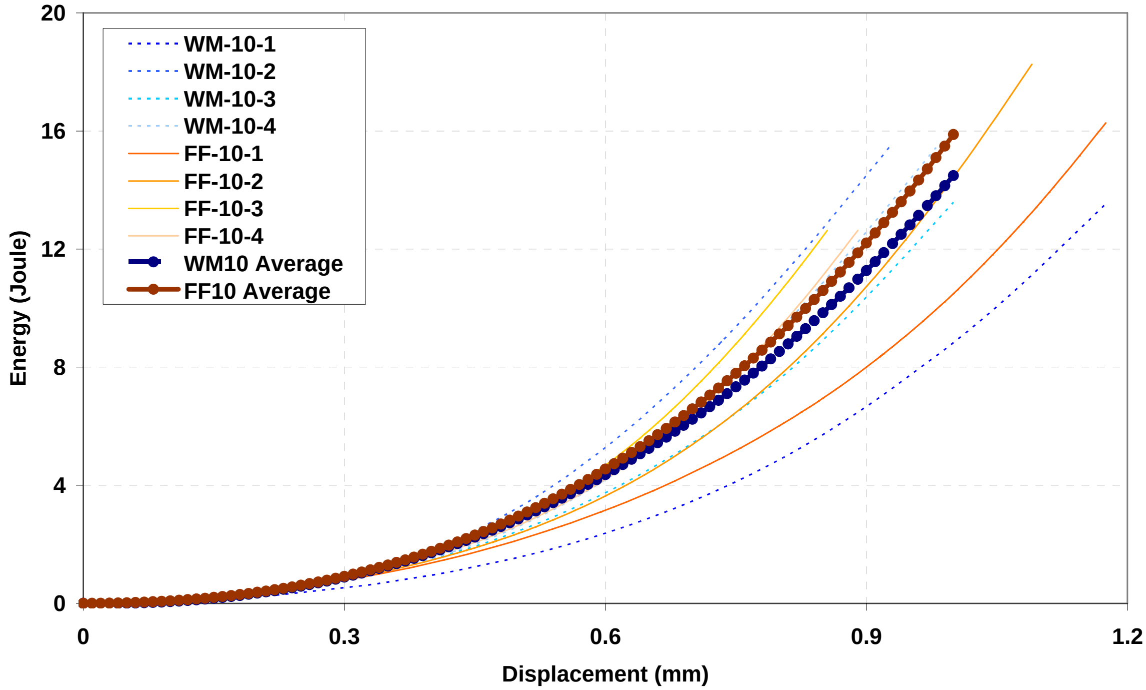
For each specimen, the values of displacements corresponding to first crack load and ultimate load is given in Table 2.

Table 2: Load-Deformation curves of specimens

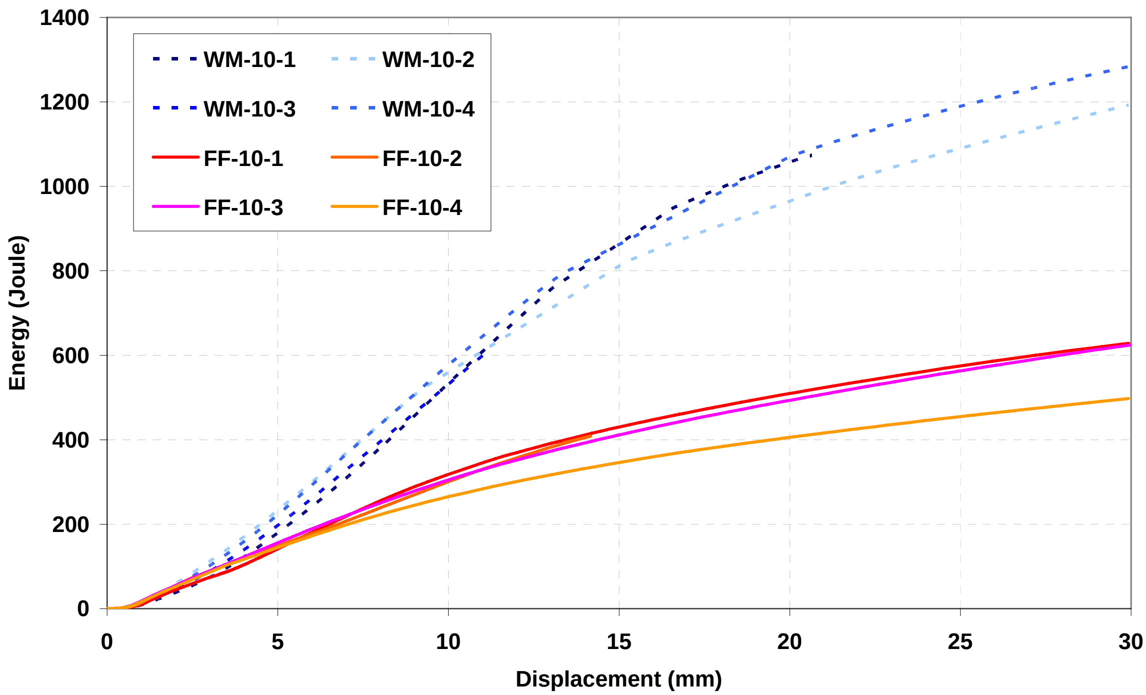
Specimen Name	First Crack Load		Ultimate Load	
	Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)
WM10-1	28	1,1	78	9,4
WM10-2	36	0,9	70	7,5
WM10-3	33	1,0	68	10,4
WM10-4	36	0,9	74	6,7
FF10-1	37	1,2	40	5,6
FF10-2	44	1,1	44	1,1
FF10-3	39	0,8	39	0,8
FF10-4	39	0,9	39	0,9
WM20-1	110	1,4	192	6,1
WM20-2	125	1,2	171	5,1
WM20-3	118	1,4	193	5,1
WM20-4	97	1,4	187	3,3
FF20-1	125	1,4	125	1,4
FF20-2	113	1,1	113	1,1
FF20-3	137	1,1	137	1,1
FF20-4	161	1,2	161	1,2

Calculated Energy-Deformation Curves

The area under the Load-Deformation curve gives the energy absorption amount or capacity. Figure 6 shows the energy amounts of all the specimens for specific displacements.

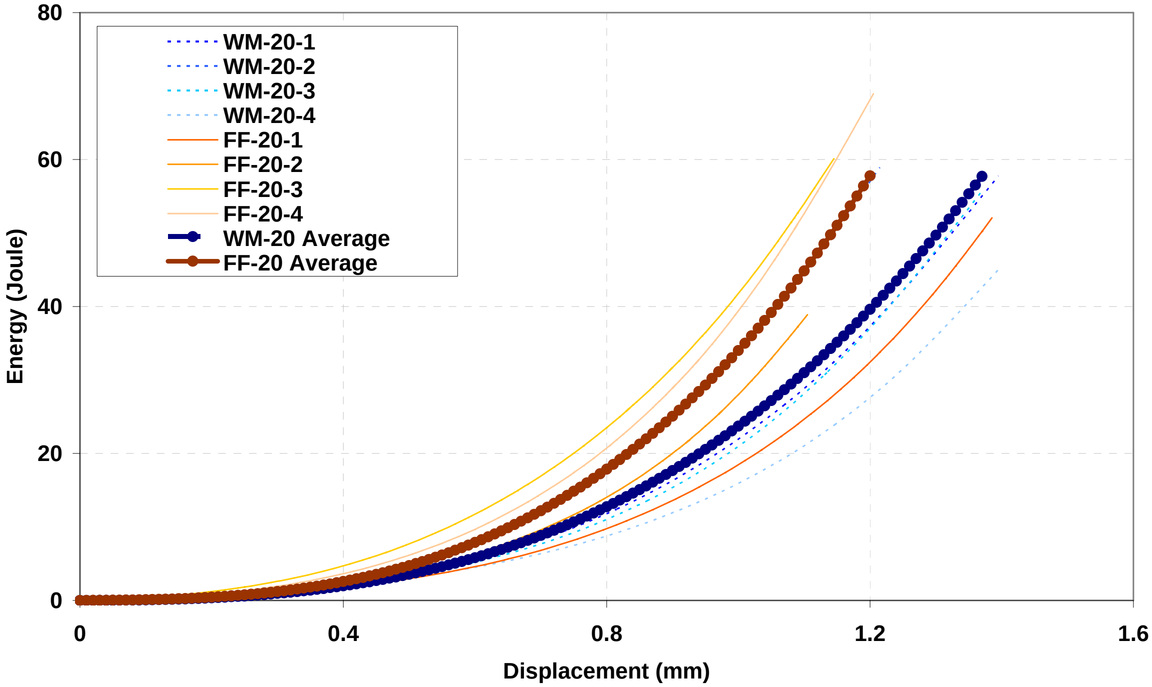


(a) Energy-Displacement relationships until first crack (100mm concrete plates)

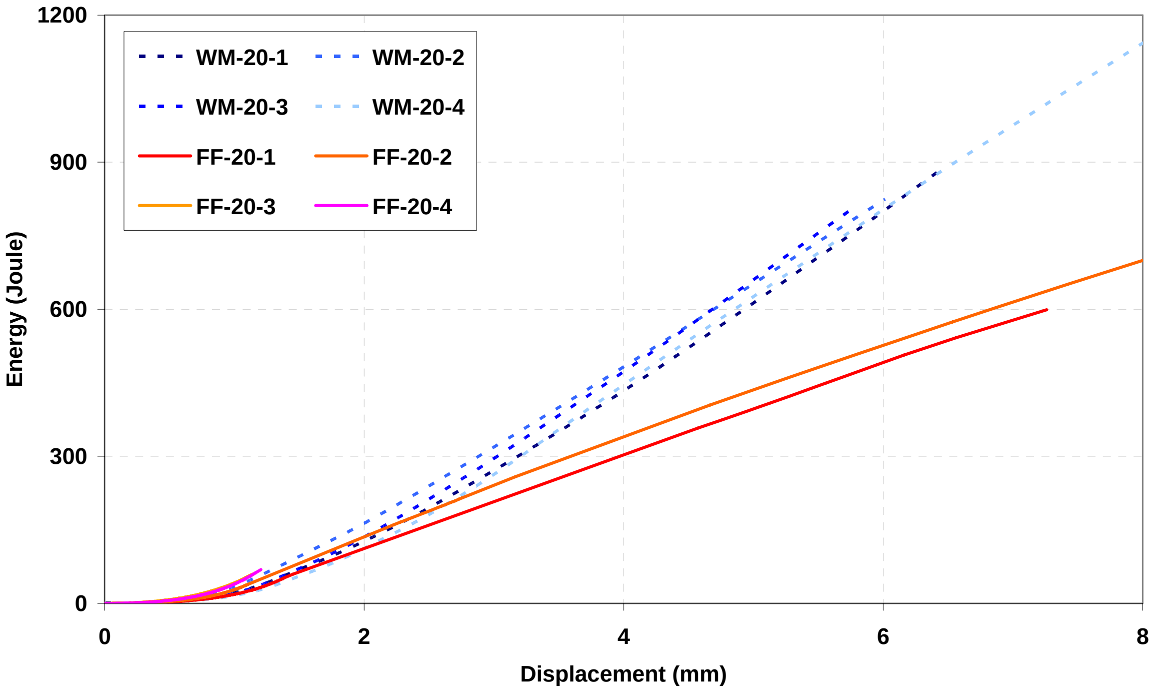


(b) Energy-Displacement relationships at ultimate loading (100mm concrete plates)

Figure 6: Energy-Displacement curves of test specimens



(c) Energy-Displacement relationships until first crack (200mm concrete plates)



(d) Energy-Displacement relationships at ultimate loading (200mm concrete plates)

Figure 6: Energy-Displacement curves of test specimens (Continued)

Energy Absorption in Joule at First Crack

The area under the Load-Displacement curve corresponding to a displacement at first crack load represents the absorption capacity at first crack. These values for each specimen are given in Table 3.

Table 3: Energy absorption capacity of specimens first crack load

Specimen Name	Energy Absorption Capacity (Joule)	Average Energy Absorption Values (Joule)
WM-10-1	13,5	14,5
WM-10-2	15,6	
WM-10-3	13,6	
WM-10-4	15,4	
FF-10-1	16,3	15,0
FF-10-2	18,3	
FF-10-3	12,6	
FF-10-4	12,6	
WM-20-1	57,8	54,5
WM-20-2	58,9	
WM-20-3	55,7	
WM-20-4	45,5	
FF-20-1	52,1	55,0
FF-20-2	38,9	
FF-20-3	68,9	
FF-20-4	60,1	

Energy Absorption in Joule for a Deflection of 25mm

The energy absorption capacities of 100mm-thick specimens with respect to the area under Load-Deformation curve at 25mm deformation are shown in Table 4.

In calculations, 1 Newton·meter = 1 Joule relationship was used.

Table 4: Energy absorption capacity of specimens at 25mm displacement

Specimen Name	Energy Absorption Capacity (Joule)	Average Energy Absorption Values (Joule)
WM-10-1	1075	
WM-10-2	1095	995
WM-10-3	615	
WM-10-4	1195	
FF-10-1	575	
FF-10-2	400	500
FF-10-3	565	
FF-10-4	460	

Conclusions

After conducting the aforementioned tests the following results are established:

The analysis of Load-Displacement relationships of wire mesh and Forta Ferro fiber reinforced specimens shows that they display similar behavior until the first concrete crack for 100mm specimens. Furthermore, the analysis of average load levels that correspond at the time of concrete cracking with a displacement of 1.0mm on average, the fiber-reinforced plates carry 15% more load than wire mesh-reinforced plates. As a result, when the energy levels are compared, the fiber-reinforced plates, on average, absorb 10% more energy compared to wire mesh-reinforced plates.

On the other hand, similar results, as mentioned above, are achieved for 200 mm plate specimens. Average load value corresponding to first crack displacement of 1.2 mm on average, carry 50% more load for fiber-reinforced plates compared to wire mesh-reinforced ones. In addition to that, comparison of the absorbed energy amounts shows that until the concrete reach its cracking displacement, fiber-reinforced plates absorb 40% more energy.

Ultimate load is the same with first cracking load for the fiber-reinforced plates.

At the ultimate load level, load bearing capacities of the fiber and steel mesh-reinforced plates differs; steel mesh-reinforced plates carry 80% more load for 100 mm-thick plates, and 30% more load for 200 mm-thick plates. The reason behind this is the fact that wire mesh carries the tensile stresses until its rapture strength. In this case, the diameter and the spacing of wire mesh are the deciding parameters for the ultimate load bearing capacity of the specimen, after the concrete cracks. As a direct result of this, the average absorbed energy level for 25 mm of displacement is approximately 2 times higher in wire mesh-reinforced plates. The reduction in wire mesh parameters will reduce the ultimate load bearing capacity and consequently lower the difference in energy absorbing levels.

At Annex 1, the French Plate Test standard recommended by EFNARC is given. This standard provides Load-Displacement, and Energy-Displacement curves for steel fiber-reinforced (such as Dramix) specimens. The tests conducted in the Structures Laboratory of Boğaziçi University also have the same trends for Load-Displacement relationships and the equivalent relation for Energy-Displacement for the polypropylene fiber-reinforced specimens. In the figures that are given in EFNARC standard, a wire mesh comparison has been given and it is shown that this relationship is lower in values than for steel fibers. Since there is no explanation, we assume that an equivalent rebar diameter (or volume) for wire mesh has been used in lieu of steel fibers.

It is observed that the polypropylene fiber-reinforced specimens, generally, have more ductile failure behavior while wire mesh-reinforced specimens have failure behavior in the form of sudden rapture of rebars or punching.

The test results showed that in the case of an elastic design of a concrete member, polypropylene fiber reinforcement is more advantageous than wire mesh reinforcement in terms of load bearing capacity and energy.

Acknowledgement

Tests were conducted by the staff and graduate students at the Structural Laboratory of Boğaziçi University. Our project manager was Mr. Mehmet Ülkücü, MS, and tests were conducted by PhD students, Mr. Osman Kaya, MS, and Mr. Selçuk Altay, MS. The technicians, Mr. Hasan Şenel and Mr. Hamdi Ayar, helped the construction of specimens and setting up the testing facility.

Sincerely,

Assistant Prof. Cem Yalçın
Civil Engineering Department, Boğaziçi University

Encl. Appendix-1: EFNARC Standard for French Plate Test Method

Appendix-1: EFNARC Standard for French Plate Test Method

EUROPEAN SPECIFICATION
for
SPRAYED CONCRETE

Association House, 99 West Street, Farnham, Surrey, GU9 7EN, UK
tel: +44(0)1252 739147 fax: +44(0)1252 739140
www.efnarc.org

EFNARC was founded in March 1989 by five national trade associations representing producers and applicators of specialist building products. Membership has since been widened to include major European companies who have no national body or institution to represent their interests. EFNARC provides a common voice for the industry to make known its comments and views to the European Commission, CEN Technical Committees and other groups dealing with European Harmonisation of Specifications and Standards in sprayed concrete, flooring and protection and repair of concrete structures. EFNARC has specialist Technical Committees dealing with sprayed concrete and flooring.

The Sprayed Concrete Technical Committee was formed in early 1991 and subsequently produced a Final Draft of this document in 1993. Over 1,000 copies have been circulated and it has been widely used as a reference document by specifiers, contractors and material suppliers in many European countries and beyond such as USA, Australia, the Far East, the Middle East and South Africa. It was also adopted by the European Working Group CEN/TC104/WG10 as one of its main documents to produce European Standard on Sprayed Concrete in 1994; and CEN/TC104/SC3 used Appendix 1 on Admixtures as the basis for the production of the European Standard for Sprayed Concrete Admixtures. This new edition takes account of comments made by users of the document during this time.

Bayhass El-Jazairi
President

Acknowledgements

EFNARC wishes to gratefully acknowledge all the contributions and comments made by the users to the 1993 Final draft and to the extensive work undertaken by the members of its Technical Committee. EFNARC wishes to acknowledge with thanks the work undertaken by Simon Austin, Loughborough University in the preparation of this Edition of the Specification.

ISBN 0 9522483 1 X

The report shall contain:

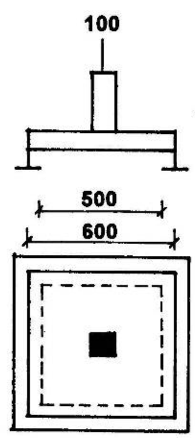
- type of the testing machine
- specimen identification
- test specimen dimensions
- curing conditions and age at testing
- rate of deformation
- load-deformation curve including flexural stress values for the specified deformation class deflections
- deformation class and residual strength class

10.4 Energy absorption class (plate test)

A test plate of 600 x 600 x 100mm shall be supported on its 4 edges and a centre point load applied through a contact surface of 100 x 100mm (Figure 10.4.1). The rough side shall be on the bottom during the test, i.e. the load is applied opposite to the spraying direction.

The rate of deformation of the midpoint shall be 1.5mm per minute.

Figure 10.4.1: Set-Up for plate test



The plate shall be produced from a sprayed panel by levelling the panel at a thickness of 100mm -0/+10mm, immediately after spraying. The sloped edges of the panel shall be sawn off when the plate is prepared in the laboratory. The prepared plate shall be stored in water for a minimum of 3 days immediately before testing and kept moist during testing.

The load-deformation curve (Figure 10.4.2) shall be recorded and the test shall continue until a deflection of 25mm is achieved at the centre point of the slab.

From the load-deformation curve a second curve shall be drawn giving the absorbed energy as a function of the slab deformation (Figure 10.4.3).

The toughness requirements are given as a specified energy absorption at a certain deflection.

Figure 10.4.2: Example of load-deformation curves

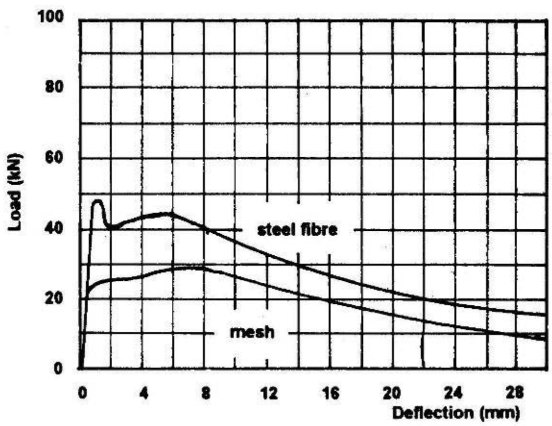
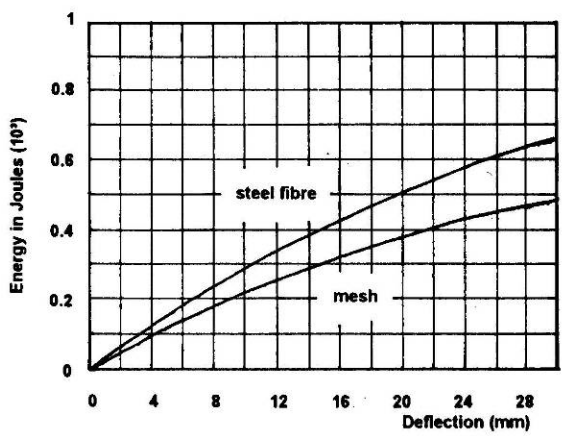


Figure 10.4.3: Example of energy-deformation curves



The report shall contain:

- type and stiffness of the testing machine
- specimen identification
- test specimen dimensions
- curing conditions and age at testing
- rate of deformation
- calculated energy-deformation curves
- first crack load and maximum load
- calculated energy-deformation curves
- energy absorption in Joule for a deflection until 25mm

10.5 Modulus of elasticity

The testing shall be done in accordance with EN 6784.

The report shall contain:

- specimen identification