

Effectiveness of fibres for structural elements

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Abstract

Present concrete technology requires fast execution and reliable material properties. Recent efforts concentrate on possible use of fibres for structural purposes. We discuss 3 examples for application of *polymeric fibers*: (1) The first example is the increasing of fire resistance thin webbed prestressed concrete roof girder. (2) The second example is the precast tunnel lining of the underground line in Budapest. We had the opportunity to take concrete core from the tunnel lining after 2-hours hydrocarbon fire for studies with CT. (3) The third example gives the application of polymeric fibres to reduce shear reinforcement in the prefabricated elements. Application of *steel fibres* in structural elements in 3 examples: (I) prestressed pretensioned beam in flexure with different amount of steel fibres, (II) non-presstressed beams in flexure with different amount of shear reinforcement and different amount of steel fibres, (III) precast joint element for reinforced concrete frame.

Keywords

FRC, fibre, spalling, failure mode, cracking.

1 Introduction

There is an increasing use of fibres for various structural concrete elements. Recent applications from Hungary are indicated in *Figure 1* for using polymeric fibres and in *Figure 2* for using steel fibres, respectively. Chapters 2 and 3 with give particular details to some of these and some other selected examples.

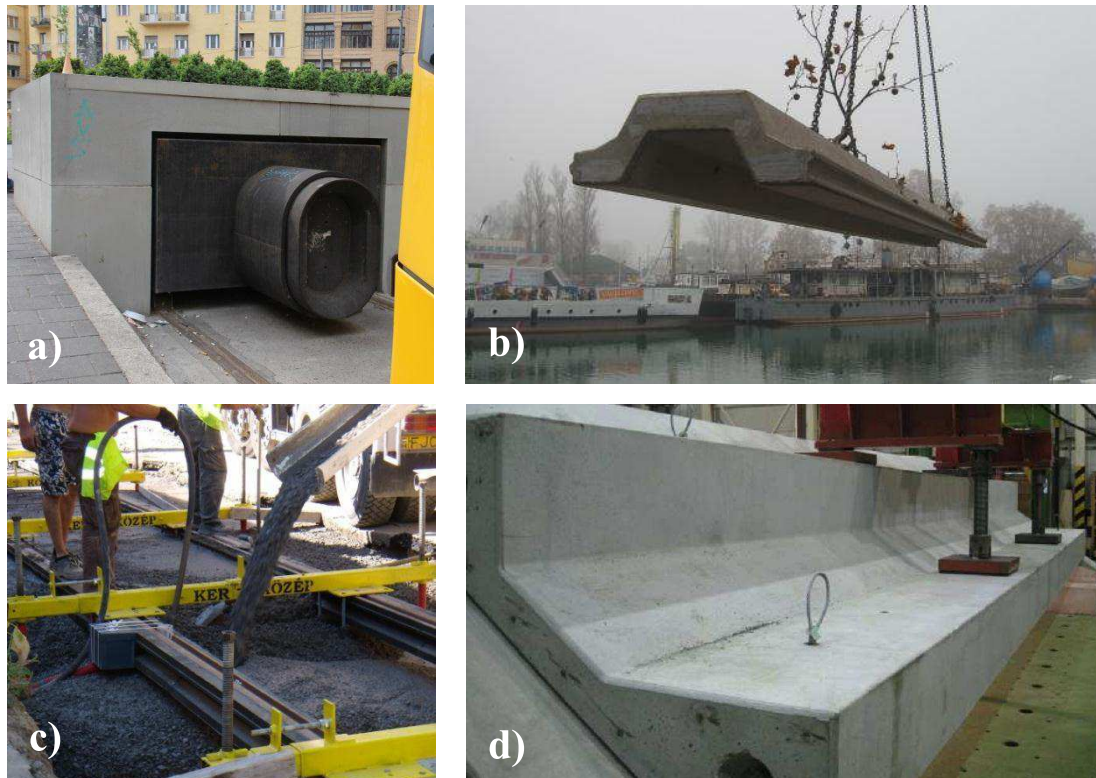


Figure 1: Recent applications of polymeric fibre reinforced concrete in Hungary
 a) End block (bumper) of tram line No. 6 in Budapest
 b) Prefabricated shore element at the Lake Balaton (fiberguru, 2014)
 c) Casting of tram runway in Szeged (fiberguru, 2014)
 d) Precast grandstand elements of new stadium, Debrecen (Dezső and Polgár, 2013)

Application of fibres in concrete has been much faster than its codification. Publication of *fib* Model Code 2010 (fib, 2013) provides a complete proposal both for behaviour modeling as well as for design of steel fibre reinforced concrete members. This has been a very important step towards codification. There are also other important state-of-the-art reports, design guides, provisions available like: ACI 544 (2002), RILEM (2003), CNR (2007), Falkner and Grunert (2011), De Montaignac, Massicotte and Charron (2012), AFGC (2013).

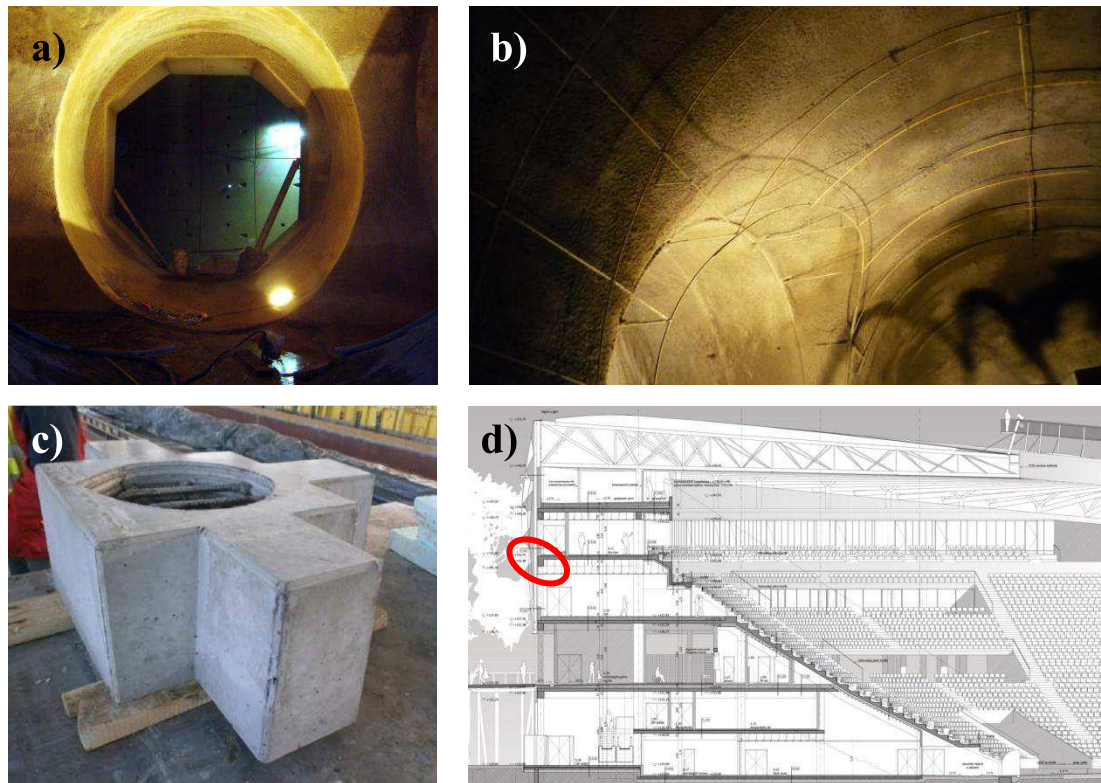


Figure 2: Recent applications of steel fibre reinforced concrete in Hungary
a) Shotcreted tunnel in the new underground line 4 in Budapest, view (Pethő, 2013)
b) Shotcreted tunnel in the new underground line 4 in Budapest, detail (Pethő, 2013)
c) Precast joint for the grandstand of new stadium in Debrecen (Dezső and Polgár, 2013)
d) View of the grandstand of new stadium in Debrecen (Dezső, Polgár and 2013)

2 Polymeric fibres

2.1 Thin webbed roof girder in fire

Previous research has been already indicated that thickness of web of a girder can be especially critical parameter for high temperatures (Di Prisco and Colombo, 2012). On the other hand, we also know that the concrete composition can highly influence the structural behaviour of reinforced concrete elements (Felicetti and Gambarova, 1998), (fib, 2008).

Purpose of our study was to improve fire resistance of a thin webbed (60 mm thickness) prestressed, pretensioned concrete roof girder by optimization of the concrete composition instead of the modification of the geometry of the girder (Balázs, Lublóy and Mezei, 2010).

To understand the complex phenomenon due to high temperatures in concrete, a series of tests was carried out with various fillers and different fibre contents (polypropylene, $\ell=12$ mm, $\varnothing=0.032$ mm). The full scale girders have been subjected to fire tests in order to demonstrate the real behaviour of the structural element. Based on preliminary material tests, the beam tests were carried out with the following Mixes:

- Mix A: 460 kg/m³ cement, 165 kg/m³ water, 1679 kg/m³ siliceous aggregate, 130 kg/m³ siliceous sand and 3.8 kg/m³ superplasticizer; Parameters: *limestone filler*, no fibres (*Reference Mix which initiated the studies*),
- Mix B: 460 kg/m³ cement, 165 kg/m³ water, 1679 kg/m³ siliceous aggregate, 130 kg/m³ siliceous sand and 3.8 kg/m³ superplasticizer; Parameters: *limestone filler* and 1 kg/m³ polypropylene fibres,
- Mix C: 460 kg/m³ cement, 165 kg/m³ water, 1679 kg/m³ siliceous aggregate, 130 kg/m³ siliceous sand and 3.8 kg/m³ superplasticizer; Parameters: *slag filler* and 1 kg/m³ polypropylene fibres.

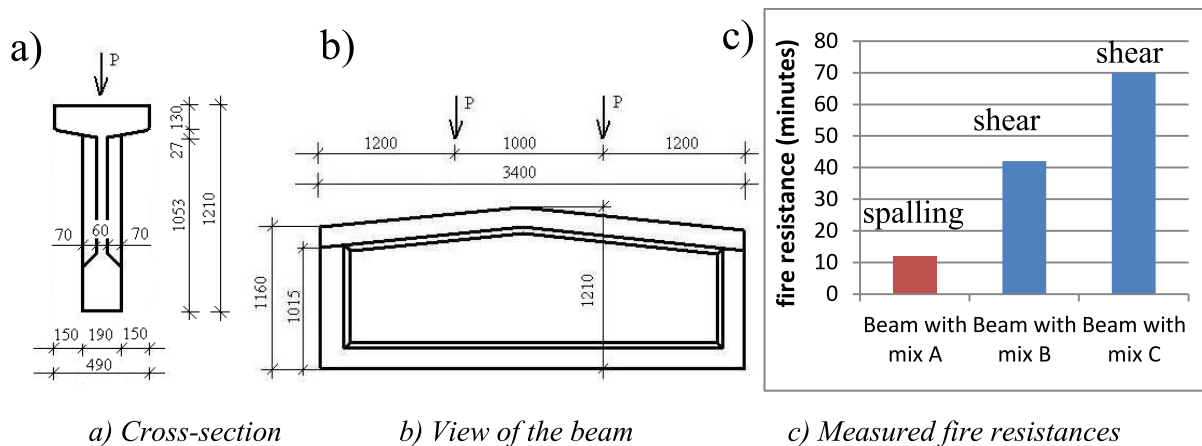


Figure 3: Prestressed, thin webbed roof girder for fire test (Balázs and Lublóy, Mezei, 2010)



Figure 4: Beam with the reference concrete (Mix A) after failure in 12 minutes



Figure 5: Beam with Mix C after failure in 71 minutes

The tested beams had 3.4 m length and real heights of 1.16 to 1.2 m, type of the concrete was: C40/50-XC2-16-F4, type of reinforcing bars: B500B and type of prestressing reinforcement: FP-100/1770-R2 (EN 10138) and the prestressing force: 130 kN. At the beginning of the test the beams were loaded with 2×350 kN concentrated loads that were kept constant during the fire tests (Figure 3).

Test beam with reference mix (Mix A) failed in only 12 minutes with spalling of the whole concrete cover of the web (Figure 4). Test beam with Mix B including 1 kg/m³ polypropylene

fibres failed in 44 minutes in shear (without spalling of concrete cover). Test beam with Mix C including 1 kg/m³ polypropylene fibres and slag as filling material instead of limestone failed in 71 minutes in shear (without spalling of concrete cover (*Figure 5*). The fire test results of roof girders with different concrete mixes are summarized in *Figure 3.c*.

2.2 Budapest M4 Underground tunnel lining subjected to fire test

Underground line M4 in Budapest has been opened on 28 March 2014. The prefabricated reinforced concrete tunnel linings had to be subjected to fire test. The tunnel lining included 2 kg/m³ polypropylene monofilament fibres ($\ell=12$ mm, $\varnothing=0.032$ mm). After the fire test (2-hours hydrocarbon fire) we drilled a concrete core from the tunnel lining and analyzed by CT (Computed Tomography) to study the internal structure of the concrete (*Figure 6*). Our CT measurements were carried out with Siemens Sensation CT with multislice technique. Computed Tomography (CT) measurements were originally used for medical analyses. During the time of data processing the quality of the picture depends on many factors. The displayed image is calculated from electrical signals by the imager, so it is not a real picture like a traditional photograph or a radiogram. The theoretical foundation was made by Hounsfield and Cormack in 1970s. (See requirements on tunnels in by Dehn (2008).)

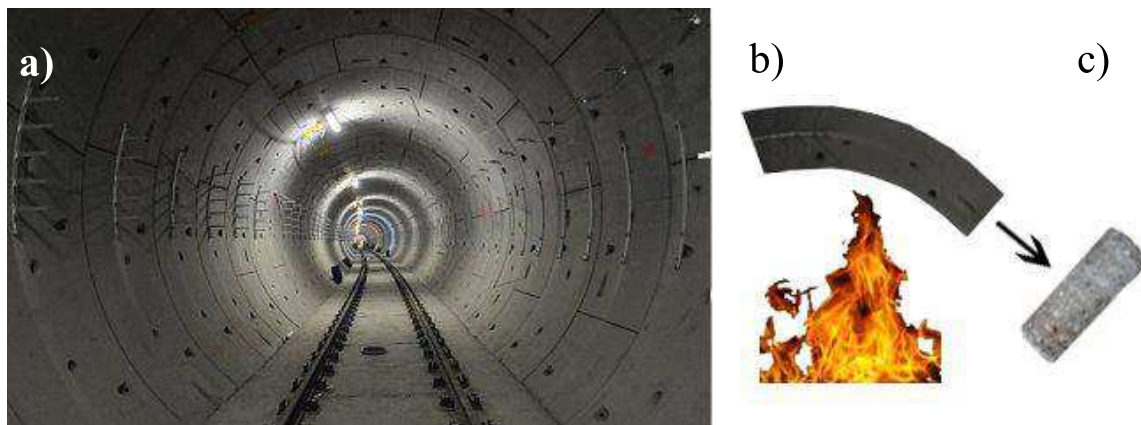


Figure 6: Underground Line 4 in Budapest and concrete core sample from tunnel lining
a) Underground (Photo: Kovács, 2014)
b) Fire test of the precast tunnel lining
c) Core

There is a relationship between CT relative density and gravity density of different minerals. The Hounsfield values of the cells are influenced by two factors. The first factor is the Hounsfield value of the mineral grains of the specified cell, while the other factor is the Hounsfield value of the pore space filled with liquid and/or gas (air) (Cnudde, Cwirzen, Masschaele and Jacobs, 2009).

Figure 7.a presents the photo of concrete core. *Figure 7.b* indicates the air void system in the concrete core as a CT image. An increased number of pores can be recognised towards the heated side. These measurements indicate that Computed Tomography (CT) can be efficiently used to study the internal structure of concrete in order to detect modifications by pore distribution or by cracking.

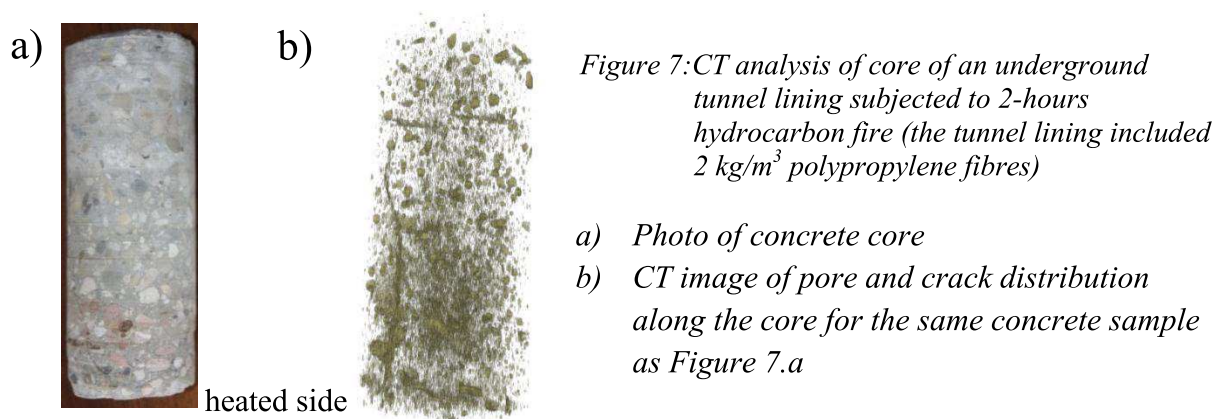


Figure 7: CT analysis of core of an underground tunnel lining subjected to 2-hours hydrocarbon fire (the tunnel lining included 2 kg/m^3 polypropylene fibres)

2.3 Grandstand of stadium in Debrecen

A stadium with a capacity of twentythousand people and with 28700 m^2 built-up area is constructed in Debrecen, Hungary in 2013-2014 (Dezső and Polgár, 2013).

Dezső and Polgár (2013) reported that each production line was suitable for the daily production of 10 pieces of the 7.50 m long L shaped grandstand elements in prestressing beds of 80 m length. A structural thickness of altogether 120 mm of the grandstand elements was possible by prestressing the elements. Prestressing increases the shear resistance, this has enabled the designers to use fibre reinforced concrete instead of traditional stirrups in the zone where $V_{Ed} < V_{Rd,c}$ which caused reduced manual labour during casting. For reasons of high aesthetic demand (see Figure. 1.d) polymer fibres are used instead of steel fibres, although in the very exposed parts of the stadium welded meshes were used to avoid protruding fibres. Further experimental results are available by Barragan et al. (2012) as well as Zhu, Mobasher, Vaidya and Rajan (2013).

Kovács and Juhász (2013) reported for the stadium in Debrecen that considering the representative state of the stadium and aiming for a high safety, they remained with the dosage of best performance during the preliminary test, namely 5 kg/m^3 of BarChip 48 polymeric (modified olefin) fibre, even if load tests showed that this quantity could have been somewhat reduced.

3 Steel fibres to improve shear and flexural behavior

3.1 Tests on prestressed concrete beams

Three prestressed pretensioned concrete beams of $80 \times 120 \text{ mm}$ cross-section and 2 m length were prestressed by a simple seven-wire strand ($\varnothing 12,9 \text{ mm}$, $f_{ptk} = 1770 \text{ N/mm}^2$, $f_{p,0.1} = 1550 \text{ N/mm}^2$, $A_p = 100 \text{ mm}^2$) at the core point of the section (Figure 8.a). Specimens were simultaneously prestressed along a single strand. Specimens did not contain any other non-prestressed reinforcement (not even stirrups) except the prestressing strand. Prestressing force was gradually released by hydraulic jacks. Dramix ZC 30/5 hooked-end fibres were applied in 0 V%, 0.5 V% and 1.0 V% fibre contents. Four-point bending tests were carried out on the prestressed pretensioned concrete beams. Failure loads and failure modes are

presented in *Figure 8.a*. The corresponding concrete cube strengths of these three beams were: 37.6 N/mm^2 , 39.6 N/mm^2 and 38.6 N/mm^2 , respectively.

These flexural tests on prestressed pretensioned beams clearly indicated that steel fibres influence the failure mode as well as the failure loads. Increasing fibre content yielded to higher failure loads in addition to the changing of the failure mode from shear through combined shear+bending to clear bending.

Observed load versus mid-span deflection relationships are presented in *Figure 8b*. Fibre application provided a considerable increase in the ultimate deflection. Ultimate deflection was almost the double for the beam with 1.0 V% fibre content than that of the beam without fibres. See further experimental results by Taheri, Barros and Salehian (2012).

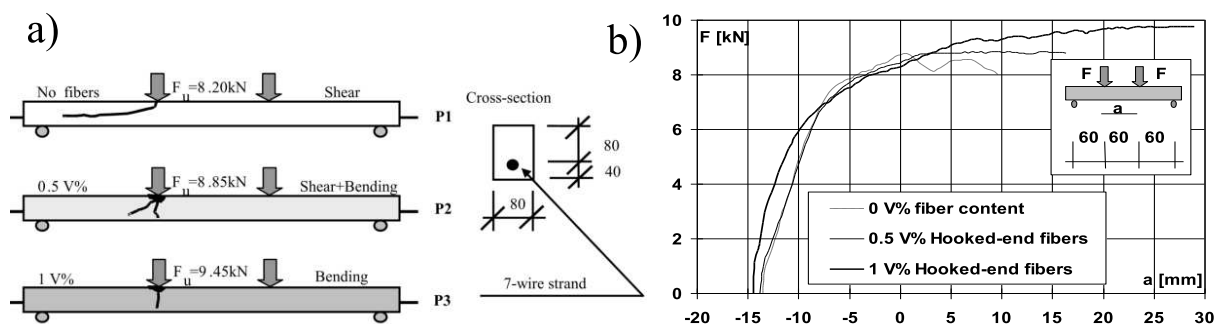


Figure 8: Failure modes of prestressed pretensioned fibre reinforced concrete beams (fibre reinforcement: Dramix ZC 30/5) (Kovács and Balázs, 2004)
a) Crack pattern and Failure loads b) Load-deflection diagrams

3.2 Tests on steel fibre reinforced concrete beams

Significant influence of the fibre reinforcement was detected on the shear resistance of fibre reinforced concrete beams (*Figure 9*). Due to the increasing fibre content, considerable improvement of the failure load was observed in case of beams without stirrup reinforcement (B1...B3). On the other hand, the failure mode changed from shear (B1 and B2) to simultaneous shear+bending failure for the beam containing 1.0 V% crimped fibres and no stirrup (B3). Considering stirrup reinforcement $\varnothing 4/240 \text{ mm}$, the shear capacity improved applying crimped fibres (B4...B6). *The higher fibre content led to changing of the failure mode, from shear failure to clear bending failure.* Longitudinal reinforcement was the same for each beam, i.e. $2\varnothing 16$ bars in the tension zone and $2\varnothing 6$ bars in the compressed zone. The beams were 2 m long (span 1.8 m) having $100 \times 150 \text{ mm}$ of cross-section.

Full crack mapping was carried out in each load step. Figure 10 indicates the crack distribution of the beam at the service load level of $F = 20 \text{ kN}$. Heights of column in *Figure 10* indicate the widths of the cracks and positions of the columns indicate the place of the cracks along the beam. Below the crack width diagrams of *Figure 10*, tables summarise the number of cracks, the sum and the average widths of the cracks, as well as the mean crack spacing. Presented test result indicate that in case of application of steel fibres: (i) maximum crack width decreased, (ii) average crack width decreased from 0.066 mm (0 V%) to 0.034 mm (1.0 V%) and (iii) the average crack spacing decreased from 82 mm (0 V%) to

60 mm (1.0 V%). Fibres were more effective in the middle portion of the beam where (B) the bending moment is constant than over the shear span (S) for crack control

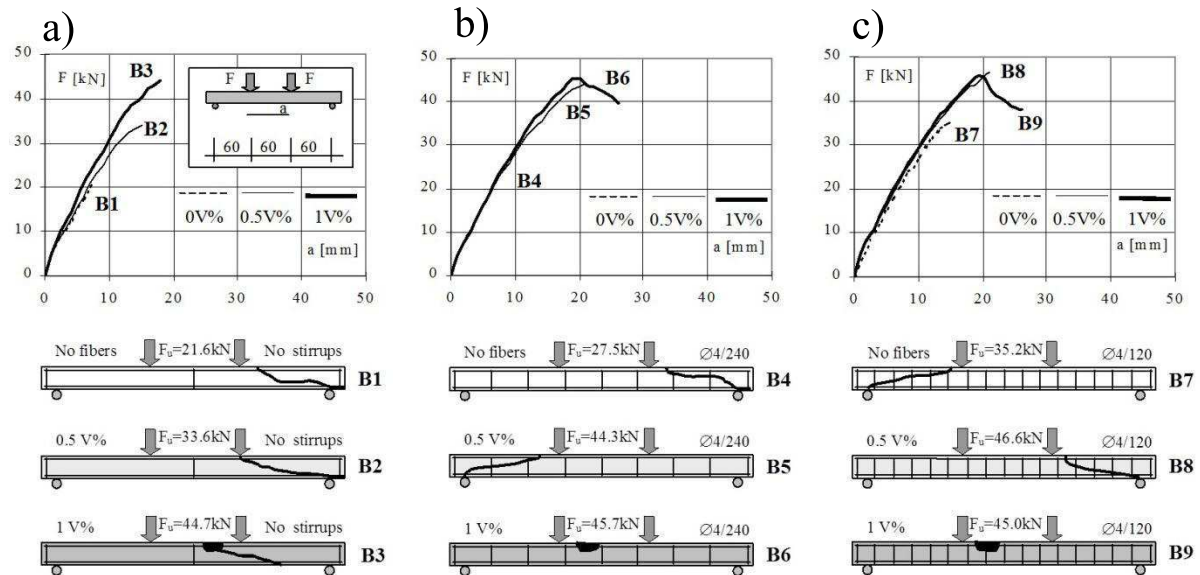


Figure 9: SFRC beam tests; Crimped fibres, $D \& D \sim 30/.5$ (Kovács and Balázs, 2004)
a) No stirrups b) Stirrups: $\varnothing 4/240$ mm b) Stirrups: $\varnothing 4/120$ mm

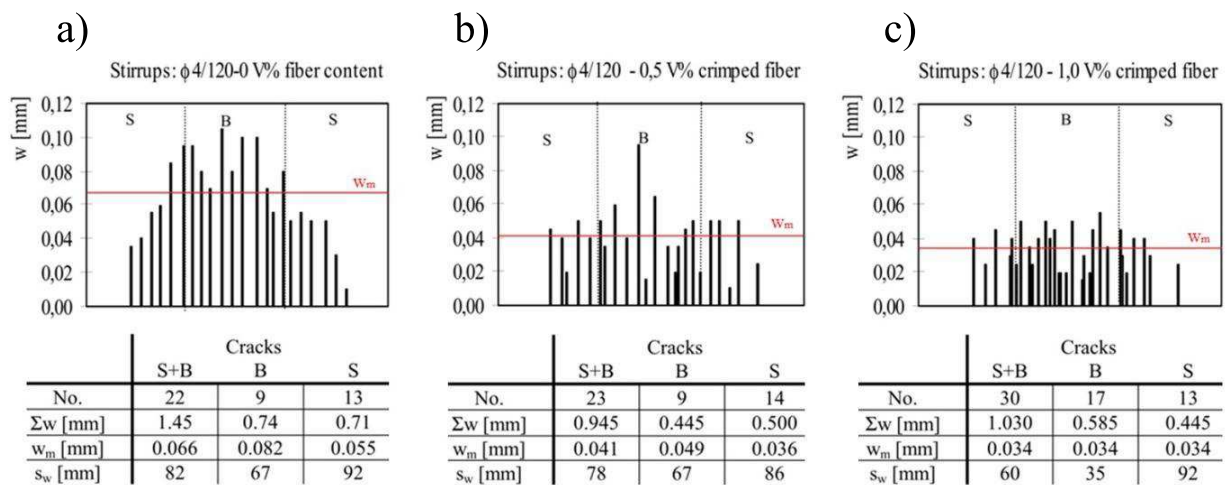


Figure 10: Crack distribution in beams having crimped fibres and $\varnothing 4/120$ shear reinforcement measured at $F=20$ kN jacking force (S+B: shear and bending region = whole beam, B: bending (middle) portion, S: shear (outer) portion). The horizontal axis of the diagrams give the position of the crack (Kovács and Balázs, 2004)

3.3 Precast joint elements of steel fibre reinforced concrete

The example of Debrecen stadium in Figure 2.c and 2.d indicates the application of high strength steel fibre reinforced concrete for prefabricated joints which form the support of prefabricated elements and are finally integrated into them (Dezső and Polgár, 2013).

Considerable advantage of this solution was that the joints could have higher strength (C70/85) than the connected elements. The joints included Dramix 3D steel fibres and the reinforcing bars in the cantilevers had a specific form with heads.

4 Conclusions

It is already widely recognized that fibres may influence fresh concrete properties or hardened concrete properties (like toughness, energy absorption etc.). Intension was here to demonstrate that not only material but also structural properties can be improved by fibres in concrete.

Polymeric fibres

Fire tests indicated delayed spalling (hence increased fire resistance) in thin webbed prestressed concrete roof girder with polymeric fibres.

In grandstand elements of a new stadium in Debrecen polymeric fibres were used in order to provide minimum shear resistance in the zone where $V_{Ed} < V_{Rd,c}$ instead of stirrups.

Steel fibres

Beam test with prestressed or with non-prestressed reinforcements indicated improved shear resistance and improved cracking behaviour with increasing amount of steel fibres.

An example has been also shown for a precast joint element for reinforced concrete frame including steel fibre.

All these examples intend to demonstrate contribution of fibres for structural purposes.

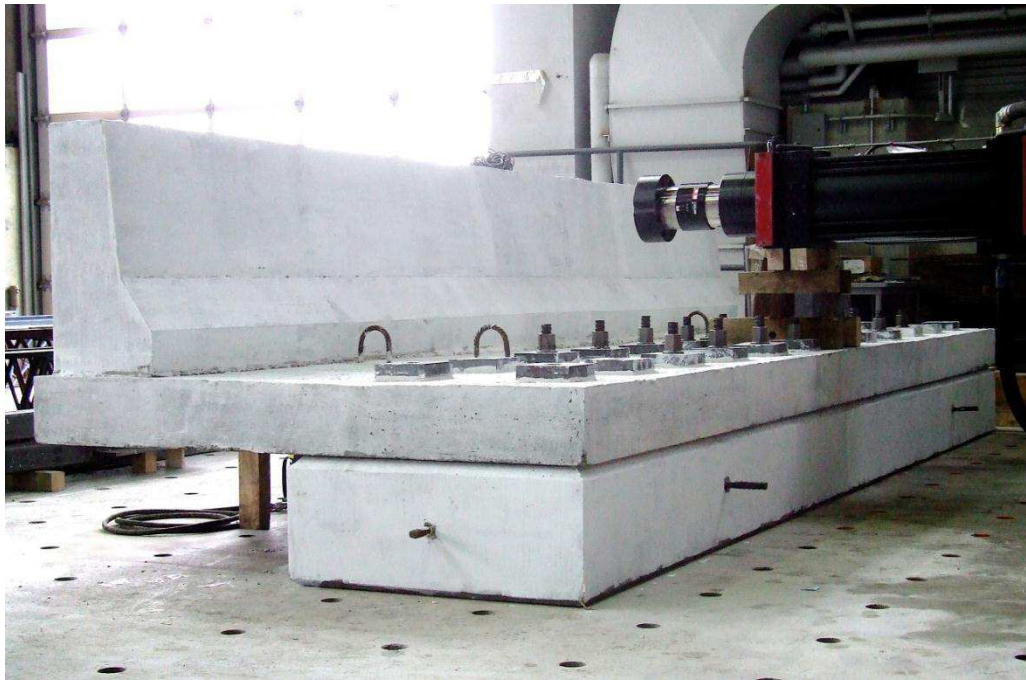
5 Acknowledgements

Contribution of Mr. Sándor Mezei (ÉMI Non-profit Ltd.) for the full scale fire tests of prestressed roof girders is gratefully acknowledged.

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