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Development and Application of Hybrid Fibre Reinforced Concrete

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ABSTRACT

Hybrid fibre-reinforced concrete is a type of fibre-reinforced concrete characterised by its composition. It contains at least two or more types of fibres of different sizes, shapes or origins. Considering that fibres of different types have different effects on the properties of fresh and hardened concrete, the use of hybrid fibres allows optimisation of the properties of fibre-reinforced concrete at all levels. In this paper are given some basic results of investigation before application of hybrid fibre reinforced concrete with steel and polypropylene fibres. Case studies of application of hybrid fibre reinforced concrete for construction of concrete pavement and repair of bridge deck overlay are also shown. Some particular material properties and technology aspects of hybrid fibre reinforced concrete in practice are analyzed.

INTRODUCTION

Fibre reinforced concrete (FRC) is a type of concrete that contains, including usual components, fibres having high tensile strength. Depending on the amount of fibres added to the concrete mixture, fibre-reinforced concretes can be categorized into two groups: the FRCs containing a small amount (< 2 vol. %) of fibres and the FRCs with a large amount (≥ 2 vol. %) of fibres. [Skazlić 2003; Skazlić et al, 2008]

Fibre reinforced concretes most often used in practical applications are those incorporating a small amount of fibres, i.e. up to 50 kg/m^3. The addition of fibres to concrete in the said amounts has a significant influence on hardened concrete properties; thus toughness and energy absorption are improved; higher resistance to dynamic loads achieved; and crack spacing and width reduced. [Johnston 2001; Skazlić et al, 2008]

Research into hybrid fibre-reinforced concretes (HFRC) has recently been fairly frequent. A characteristic feature of these concretes is that they contain less than 1 vol. % of fibres of varying shape, length and origin. By using hybrid fibres in a concrete mixture the same properties of concrete can be obtained as those exhibited by conventional fibre reinforced concrete but with the addition of a smaller amount of fibres. [Banthia et al, 2000; Qian and Stroeven 2000; Qian et al, 2000; Banthia and Nandakumar 2003; Skazlić 2003]

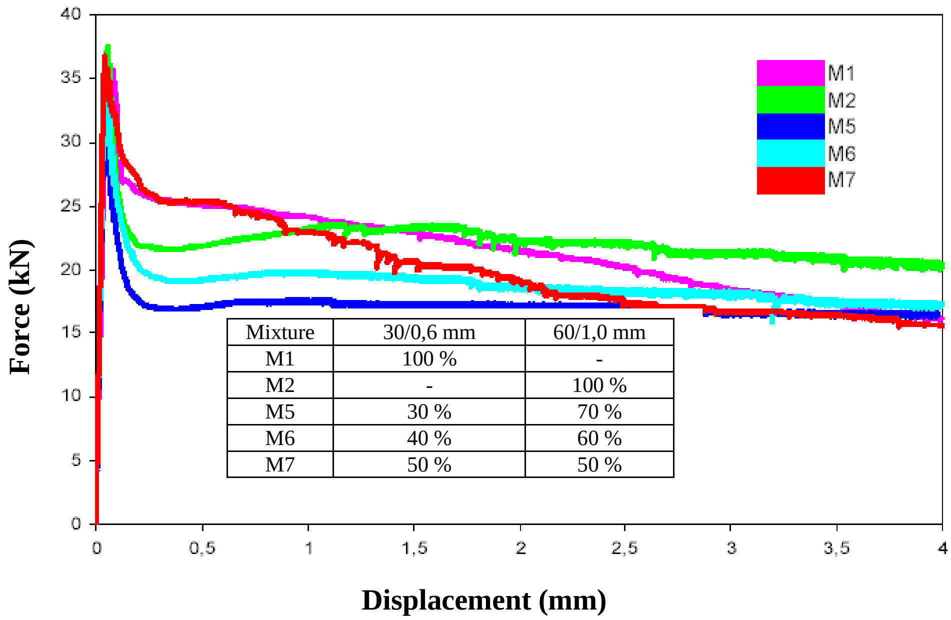
In this paper a presentation is given of investigations into hybrid fibre-reinforced concretes with steel and polypropylene fibres. In addition, a brief description is provided of typical applications of HFRC in new structures and repair and rehabilitation of the existing ones.

EXPERIMENTAL INVESTIGATIONS

The idea of using steel fibres of different lengths in fibre-reinforced concrete is similar to that of using aggregate of different grain sizes because fibres having different sizes have a positive effect on an improvement in various properties of fresh and hardened fibre-reinforced concrete. In the case of aggregate grain-size distribution, the proportion of particular aggregate grains of different sizes is also optimized in the total aggregate grain-size distribution. [Qian et al, 2000; Skazlić 2003]

The main aim of the investigations was to determine the optimum composition in terms of flexural behaviour of fibre-reinforced concrete containing 30 kg/m^3 steel fibres; namely, this is the amount of steel fibres most often used in fibre-reinforced concrete. The research was conducted on 12 fibre-reinforced concrete mixtures. The designed concrete had exposure class XD3, compressive strength class C30/37, and consistence classes S4 and F4. The maximum aggregate grain size was 16 mm. The steel fibres used in the research were of five different types: (1) hooked-end fibres of: 30-mm length (aspect ratio 50), 50-mm length (50) and 60-mm length (60); (2) sickle-shaped fibres of 32-mm length; and (3) wave-shaped fibres of 50-mm length (50). On the basis of the investigations it was established that an optimum fibre-reinforced concrete mixture with 30 kg/m^3 of steel fibres contains a combination of 50 % each of hooked-end steel fibres of 30-mm length and 60-mm length. A synergetic effect of hybrid steel fibres was observed on the behaviour of hardened fibre-reinforced concrete under flexural load (see Figure 1). This means that the incorporation of steel fibres having different lengths results in better concrete properties than those achieved with one length fibres, although the amounts added are the same. It was established that hybrid steel fibres have higher average orientation coefficient than only one type of steel fibres. [Skazlić et al, 2008]

In similar research, investigations were carried out into the following: (1) fibrillated polypropylene fibres of 12 mm and 20 mm in length; (2) hooked-end steel fibres of 35 mm in length (aspect ratio 64) and 25 mm in length (45); and (3) straight steel fibres of 6 mm in length (40). For these purposes, ten different concrete mixtures were prepared with various combinations of polypropylene and steel fibres. All the mixtures had the same water/cement ratio of 0.41, and the same workability in fresh state. The volume percentages of the steel and polypropylene fibres used were from 0.75 to 1.15 vol. %. On the basis of the research conducted, it was determined that hybrid fibre-reinforced concretes have significantly higher values of compressive and flexural strengths, and splitting strength in comparison with fibre-reinforced concretes containing only one type of steel fibres and the same amount of fibres. Durability properties (gas permeability and capillary absorption) of hybrid fibre-reinforced concretes with steel and polypropylene fibres are better than those of fibre-reinforced concretes containing one type of fibres. An analysis of the test results showed that polypropylene fibres are effective in crack reduction in young concrete due to their lower modulus of elasticity, while steel fibres serve the useful purpose for the behaviour of the hardened concrete (see Figure 2). [Skazlić 2003]



Mixture	30/0,6 mm	60/1,0 mm
M1	100 %	-
M2	-	100 %
M5	30 %	70 %
M6	40 %	60 %
M7	50 %	50 %

Fig. 1. Flexural strength diagram obtained from tests carried out on 150x150x600-mm prisms

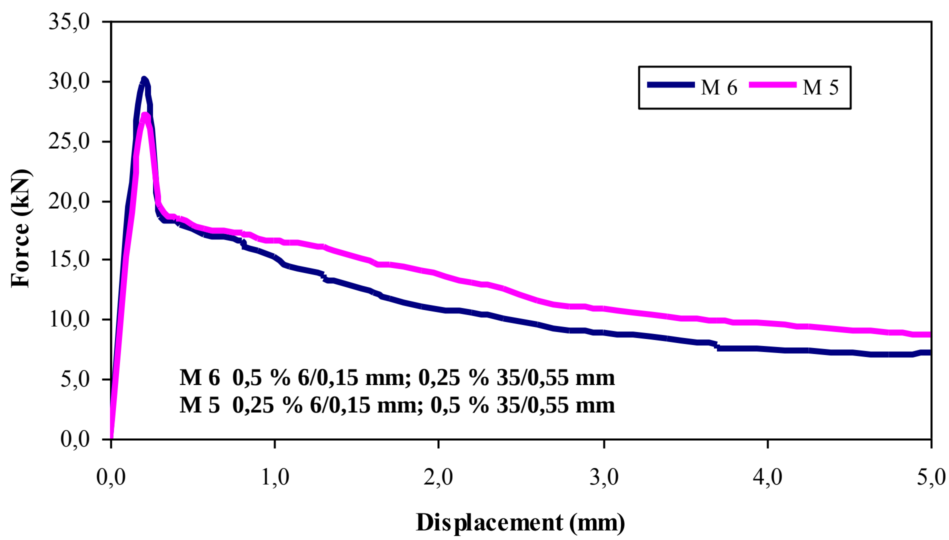


Fig. 2. Flexural toughness diagrams obtained for hybrid fibre-reinforced concrete containing different steel fibres

APPLICATION OF HFRC IN CONSTRUCTION OF CONCRETE PAVEMENT

Hybrid fibre-reinforced concrete was applied in construction of concrete pavement for warehouses located in the surrounding area of Zagreb, Croatia. The concrete pavement slab was 22 cm thick; the fields of 5x5 m were placed and reinforced with shear connector at joints. The concrete was delivered to the construction site in a concrete mixer, placed by concrete finishers, and surface finished (See Figure 3).

Fig. 3. Concrete placement in the pavement by concrete finisher (left) and surface finishing (right)

The used hybrid fibre-reinforced concrete had 30 kg/m^3 of steel and 1 kg/m^3 of polypropylene fibres. The hybrid fibre-reinforced concrete was prepared with 420 kg/m^3 of cement and water/cement ratio of 0.38. Concrete compressive strength class was C35/45, and exposure classes were XF4, XC4, XD3 and XM3.

In addition to compressive strength, further requirements for hybrid fibre-reinforced concrete were related to flexural strength (≥ 6 MPa), water impermeability (≤ 3 cm), Bohme's resistance to wearing (≤ 18 $cm^3/50\ cm^2$), and resistance to freezing with de-icing salts for the duration of 50 cycles. In Table 1 average values of the properties of hybrid fibre-reinforced concrete are listed. [University of Zagreb 2007]

During the construction of the concrete pavement, the application of hybrid fibre-reinforced concrete proved to be useful. The addition of fibres did not affect the aesthetic quality of the external surface after the surface finishing was completed (see Figure 4). In spite of unfavourable thermo-hygrometric conditions that prevailed in the course of concrete placing and high traffic loads during the use of concrete pavement, owing to the addition of polypropylene and steel fibres no cracks occurred in the concrete pavement slab.

Table 1. Properties of hybrid fibre-reinforced concrete used for concrete pavement construction

Property	Testing method	Unit	Result
Slump	HRN EN 12350-2	cm	25
Entrapped air	HRN EN 12350-7	%	4
Temperature	-	°C	16
Compressive strength (28 days)	HRN EN 12390-3	N/mm^2	55.4
Flexural strength (28 days)	HRN EN 12390-5	N/mm^2	7.2
Water permeability	HRN EN 12390-8	mm	14
Bohme's resistance to wearing	HRN EN 1340	$cm^3/50\ cm^2$	7.5
Frezing and thawing with deicing salts	HRN U.M1.055	50 cycles	passed

Fig. 4. Final appearance of the concrete pavement without being swept (left) and after being swept (right)

BRIDGE DECK REHABILITATION USING HYBRID FIBRE-REINFORCED CONCRETE

Hybrid fibre-reinforced concrete was used to repair the bridge deck overlay of Rogotin Bridge over the Neretva River on D8 in Croatia. Thickness of the overlay of bridge deck was only 8 cm. The concrete properties are given in Table 2. [Geoexpert IGM 2008]

The hybrid fibre-reinforced concrete was prepared in the site concrete batching plant located in the near vicinity of the bridge. The concrete contained 400 kg/m^{3}of cement with water/cement ratio of 0.38. The concrete mixture included polypropylene fibres with the lengths of 30 mm (2 kg/m^3) and 12 mm (1 kg/m^3). Before concrete was placed, the worn-out bridge deck was removed using a hydro-demolition technology. In addition, the testing carried out prior to concrete placement indicated that the tensile strength of the old concrete according to the pull-off method exceeded 1.5 MPa. The concrete was placed in unfavourable conditions in an extremely windy period of the year. Beside that, since during the repair the bridge was open to alternating one-way traffic, due to traffic vibrations the concrete could not be cured properly. In spite of this, the application of adequate concrete placement technology and use of hybrid fibre-reinforced concrete made the successful completion of the works possible (see Figure 5 and 6). The hybrid fibres in the concrete mixture prevented the occurrence of cracks either in the young concrete or in hardened concrete.

Table 2. The properties of hybrid fibre-reinforced concrete used to repair the bridge deck

Property	Testing method	Unit	Result
Slump	HRN EN 12350-2	cm	10
Entrapped air	HRN EN 12350-7	%	5
Temperature	-	°C	18
Compressive strength (1 day)	HRN EN 12390-3	N/mm^2	29.1
Compressive strength (7 days)		N/mm^2	47.4
Compressive strength (28 days)		N/mm^2	64.3
Water permeability	HRN EN 12390-8	mm	11
Freezing and thawing with de-icing salts	HRN U.M1.055	25 cyles	passed

CONCLUSIONS

This paper presents main results of the research carried out into hybrid fibre reinforced concretes. The research indicated that a combination of steel and polypropylene fibres can be effectively used to optimize the behaviour of concrete in fresh and hardened states. A description is given of an optimum combination of hybrid steel and polypropylene fibres in concrete. On the basis of the investigations conducted, applications are illustrated of hybrid fibre-reinforced concretes in the construction of a concrete pavement and repair of a bridge deck overlay. As the concrete installed into the said structures contained hybrid fibres, and based on its properties in hardened state, this concrete type can also be defined as high-performance concrete.

It is safe to say that the properties of hybrid fibre-reinforced concrete can be used in the cases when concrete is placed under unfavourable thermo-hygrometric conditions.

Fig. 5. Concrete placement during the bridge deck repair work


Fig. 6. Surface finishing of bridge deck (left) and curing of the concrete placed (right)

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