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To cite this article: A Kohoutková and I Broukalová 2017 IOP Conf. Ser.: Mater. Sci. Eng. 246 012001

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Abstract. The paper presents improvement of function and performance of the precast structural members by using fibre reinforced concrete (FRC) instead of ordinary reinforced concrete and attempts to transfer innovative technologies from laboratory in academic sphere into real industrial production which is cost-effective and brings about savings of labour and material. Three examples of successful technology transfer are shown – application of FRC in an element without common rebar reinforcement, in the element with steel rebar reinforcement and SFRC pre-tensioned structural element. Benefits of FRC utilization are discussed.

1. Introduction

For centuries, concrete has changed minimally. In recent decades, rapid development has taken place - new materials are invented, non-traditional materials and technologies are used in the production of concrete, or known materials are used in an unconventional way.

Various desired properties of the composite may be achieved by careful design of the concrete components and the structure of the composite material, so that the resulting component has completely different properties and potential applications compared to conventional concrete. The use and composition of concrete is currently being modified and adapted for different needs - from construction, architecture, concrete precast structural elements and products to everyday objects (e.g. furniture, applied arts).

Trends in the development of cement based composites can be seen in several major areas:

- Development and consolidation of the position of fibre reinforced concrete and other fibre-reinforced cement composites, use of special types of reinforcing – in addition to the fibres dispersed in the cement matrix, fibres arranged in unwoven or woven fabrics (TRC – Textile Reinforced Concrete) are used.
- A significant trend is the development of High Performance and Ultra High Performance cement composites (HPC, UHPC).
- One of the trends is the use of waste materials in the production of cement composites and the development of new technologies that will minimize the environmental burden.

The focus across all areas is on increasing durability and service life, and design and production according to the principles of sustainable construction.
Utilisation of fibre reinforced concretes is no longer exceptional. Fibres are used as a partial or full substitution of conventional concrete reinforcement. The fibres can be combined in such a way that each of the fibre types has its specific function - for example, short fibres eliminate shrinkage cracks and longer fibres have a structural function.

For industrial floors, the steel fibre reinforced concrete (SFRC) is now used more often than conventional reinforcement with weld mesh sheets. The steel fibre reinforced concrete was also used for slab structure. Experimental structures have confirmed that steel fibre reinforced concrete (SFRC) can be used as a ready-mix concrete, transported to the site and achieve the required quality and uniform distribution of the fibres in the mixture. The use of steel fibre reinforced concrete (SFRC) for tunnel lining is also a common application.

2. Advantageous application in precast elements

Very advantageous is application of fibre reinforced concrete (FRC) in precast elements. The technology of fibre reinforced concrete production is a bit more demanding than the production of traditional ordinary concrete; and a good control of production on the precast plant provides a high quality fibre reinforced concrete mixture with evenly dispersed fibres. Fibre reinforced concrete (FRC) in precast elements prevents shrinkage cracks and other types of cracking and thus helps to achieve better appearance and higher durability of the product.

Application of fibre reinforced concrete implies increased toughness and impact resistance, prevents spalling of the element’s edges during transport and handling. An advantage is improving the cohesion and anchoring of lifting and handling anchors. Another benefit is increased bond and anchoring of rebar reinforcement and lifting anchors. Fibre reinforced concrete, namely steel fibre reinforced concrete is used as a substitution of conventional reinforcement, which may result in reduction of thickness of the element, decrease of the total weight and consequent savings in transport and manipulation. In prestressed elements the steel fibre reinforced concrete substitutes shear reinforcement; the dispersed reinforcement enables reduction or omitting of conventional rebar shear reinforcement. Likewise, in compressed elements the conventional rebar reinforcement may be replaced by dispersed fibre reinforcement.

Several successful applications of fibre reinforced concrete elements have been developed in cooperation of the Department of Concrete and Masonry Structures of CTU with construction companies. In designing and preparing production of FRC element the following procedure was verified:

1. Choice of an element where the application of fibre reinforced concrete is profitable.
2. Preliminary structural design.
3. Selection, design and examining of fibre reinforced concrete parameters.
4. Detailed check of resistance and analysis of the structural member behaviour.
5. Full scale tests of the element in case of need.

Application of fibre reinforced concrete shall not be the aim itself. The application of FRC in the element should lead to saving and/or enhancement of the element properties and behaviour. FRC is beneficial in elements with complex shape and thin elements subjected to tensile stresses.

The main features and advantages of FRC application in precast elements can be summarized as follows:

- FRC can become a partial substitution of steel rebar reinforcement or FRC can replace the rebar reinforcement.
- Thanks to FRC application the element may be thinner.
- The secondary cost reduction is due to decrease of the weight of the element – precast elements with lower weight are not so demanding as far as transport, manipulation and assembling concerns.
- Fibre reinforced concrete decreases labour demandingness.
- FRC reduces cracking, which implies high quality of the element.
• The reliability and durability of the element are enhanced.
• The damage of precast member during transport, manipulation and assembling is reduced or eliminated.
• The fire resistance is higher where FRC with synthetic fibres is applied.
• Utilization of FRC may reduce the cost of the product. The economic analysis is usually one of the decisive criteria for the acceptance and practical use of fibre concrete in the production of the precast element.

3. Transfer of technology

The team of the Department of Concrete and Masonry Structures of the CTU has conducted long-term investigations of fibre reinforced concrete (FRC) since the seventies; advantageous properties were observed, beneficial features were referred to. Knowledge of mix design and technology of FRC was gained and effect of various types of fibres on resulting properties of a particular fibre reinforced concrete.

A common problem of technology transfer of scientific and technology developments from laboratory to real applications retarded wider disseminating of FRC in structures and building products. Implementation of technological advances and new processes faces many obstacles – aversion of employees to new technologies, doubts of the firm management about profit from FRC use, fear of delays in production, needs to change the production process, demand to test a new technology on a company's existing production facilities and related interruption of the production.

Thanks to the open positive attitude of visionary management and their understanding of the potential benefits of FRC application we succeeded in tying cooperation with several firms, which led to practical application of FRC in construction industry. The following text presents examples of technology transfer and points to the benefits that use of FRC has brought.

3.1. Concrete sewage pipes

This application is a result of collaboration of the Department of Concrete and Masonry Structures of the Czech Technical University, firm Betotech, Ltd. and producers of fibres [1]. The firm produces sewage pipes of various sizes. Traditionally, the pipes are made from reinforced concrete. The reinforcement cage is formed from spiral wires welded to longitudinal rebars. The cage is made on spot welding machine and it is quite laborious.

Regarding required properties and behaviour of the underground pipe, the rebar reinforcement is not necessary because there are no tensile stresses in the element. The reinforcement is inserted to prevent damage of the pipes during transport and manipulation and because of the production technology; the pipes are made in vertical position and they are demoulded immediately after concreteing and vibration.

The development of the fibre reinforcement pipe accounted principle requirements on the pipes: The basic demand is water tightness of the pipes; so that the cracking must be avoided. The early demoulding was considered, too.

From several variants of tested fibre reinforced concretes, SFRC has proven the most efficient. The dosage was 40 kg/m$^3$ of steel fibres with length 50 mm, diameter 1 mm and strength ca 1 000 MPa. The composite mix is in the table 1.

Tests of material properties showed compressive strength 54 MPa (mean value) and mean tensile strength 5.2 MPa.

Making of pipe with actual sizes proved manufacturability of the elements. The resistance of pipes was measured in full scale tests of pipes with diameter 600 mm and 1 400 mm. The pipe was supported by two linear restraints at the bottom and loaded by linear load at the apex (figure 1).
Table 1. SFRC mixture composition

| Component           | Units  | Dosage |
|---------------------|--------|--------|
| Aggregate 0-16      | kg/m³  | 1800   |
| Cement CEM I 42,5 R | kg/m³  | 390    |
| Plasticizer         | kg/m³  | 1.5    |
| Water               | kg/m³  | 140    |
| Steel fibres        | kg/m³  | 40     |

Figure 1. Full scale test of the sewage pipe

The application of fibre reinforced concrete in the production of sewer pipes was motivated by efforts to streamline, simplify and reduce the cost of production. The investigations focused in substitution of classical rebar reinforcement by dispersed fibre reinforcement and determine suitable type and dosage of fibres. The modification of the technology brings profit; the production is more simple, less time consuming and cheaper. In general, it can be concluded that certain types of fibre reinforced concretes may substitute conventional rebar reinforcement; however, it is necessary to
choose the appropriate type of fibre and to design the appropriate composition of the mixture for the given application.

3.2. Bridge cornice

The application of fibre reinforced concrete in precast bridge cornice was designed in cooperation of the Department and firm SMP CZ from Vinci Group [2]. The primary aim of the investigations was verification of possibilities of production of the fibre reinforced element with an existing production facility without the need for demanding changes of production technology or needs for additional equipment of production machines. The economic indicators were naturally carefully monitored; analysis from a range of angles showed that the introduction of fibre reinforced precast member into the production, in addition to the increased lifetime of the element, also generates immediate profits.

The precast bridge cornice is a common part of equipment of some bridges. The cornice is not a load-bearing part of the bridge; nevertheless it can be subjected to substantial strain, salts treatment and atmospheric effects. Because of aesthetic requirements on cornice, to provide bond of anchors and prevent corrosion and pull-out of anchoring elements it is desirable to avoid excessive cracking. The main reasons of cracking of cornice are principally volume changes. Fibre reinforced concrete with synthetic fibres is usually an effective solution to this kind of cracks. Knowing the stress state and considering demands on durability of the cornice, fibre reinforced concrete mixture composition was proposed. After testing the workability of the FRC mixture in the precast-plant devices the mixture was modified a bit. The final composition shows the table 2.

| Aggregate                  | extracted aggregate fraction 0-4 and 4-8 |
|----------------------------|------------------------------------------|
|                            | crushed aggregate fraction 0-16          |
| Cement                     | CEM I 52,5 R                             |
| Filler                     | ground limestone                         |
| Plasticizer                | two types of carboxylate based plasticizers |
| Water                      |                                          |
| Additives                  | air entrainment additive                 |
|                            | stabilizing additive                     |
|                            | microsilica                              |
| Synthetic fibres           | polypropylene fibre of length 54 mm; dosage 3,5 kg/m³ |

Measured in standard tests, the mean compressive strength was determined 52 MPa with a standard deviation of 2.99 MPa.

The manufacturability of the cornice has been verified in a pilot plant (figure 2) and the elaborated cornice was used in a bridge construction.

The innovation of the element consists of substitution of part of the steel rebar reinforcement of the original element with polypropylene fibres dispersed in concrete matrix. The changed properties and behaviour of the FRC element enabled reduction of conventional rebar reinforcement by 42% and decrease of thickness of the element. The consumption of concrete was reduced by 27%. The total weight of the cornice is 25% lower. The lower material consumption led to decrease of cost; the price is 10% lower.

Fibre reinforced concrete shall be a contribution to better service, behaviour and durability of the element. Other problem that may be solved by use of FRC is cracking and failure during transport and resulting fall of the element and injure of pedestrians and damage of passing vehicles. Use of
Polypropylene fibres changed behaviour of the element, which is more tough and more impact resistant and has higher deformation capacity. Indirect savings consist in reduced transport costs, factory handling and assembly. Small cargo is transported, thus more elements are transported at once and handling and manipulation is easier, and storage space requirements are lower. Fibres tribute to higher durability and longer life cycle, what decreases maintenance cost. Tougher material better resist impact load and so there is no risk of spalling of corners during transport and manipulation, what decreased number of complaints.

Figure 2. Bridge cornice manufactured in the pilot plant

Research and development, laboratory and field tests of fibre reinforced concrete with synthetic fibres proved possibility of industrial production of precast fibre reinforced elements without the need to modify the existing production equipment even without necessity to change the production quality management system. At the same time, some limiting features of fibre reinforced concrete, such as the influence of fibres on fresh concrete rheology and relatively higher costs per cubic meter have been successfully eliminated.

3.3. Prestressed precast girder
The last example of practical application of the fibre reinforced member presents utilization of the steel fibre reinforced concrete in the prestressed girder. The girder was designed as a load-bearing element for the prestressed foot bridge with the span 13.6 m. It has a solid cross-section in the shape of irregular hexagon with dimensions ca 400 mm x 1000 mm and embodies only pre-stressed reinforcement without any mild rebar reinforcement [3].

The dispersed reinforcement are steel fibres of diameter 0.8 mm and 60 mm long, with strength 1 200 MPa. Composition of the SFRC is in the table 3.
Table 3. SFRC mixture composition

| Component           | Units  | Dosage |
|---------------------|--------|--------|
| Fine aggregate 0-4  | kg/m³  | 700    |
| Aggregate fraction 4-8| kg/m³ | 290    |
| Coarse aggregate 8-16| kg/m³| 750    |
| Cement CEM I 52,5   | kg/m³  | 400    |
| Plasticizer         | kg/m³  | 1,5    |
| Water               | kg/m³  | 167    |
| Steel fibres        | kg/m³  | 40     |
| Ground limestone    |        |        |
| Microsilica         |        |        |
| Plasticizer         |        |        |

The tests of SFRC proved parameters required for the concrete class C 55/67. The concreting procedure was recommended in the direction from end of girders to the centre. The SFRC flew in below the strands and the fibres are evenly distributed.

The load-bearing capacity of the beam was controlled by full-scale tests, where the deflections were measured and cracking was monitored. Naked eye observing before, during and after test did not discover any cracking, damage and other abnormalities in the girder behaviour.

Figure 3. Load test of the prestressed SFRC girder

Additional tests were conducted for verification of the railing anchors. The pull-out tests showed that SFRC has much better anchoring capacity than ordinary concrete without dispersed fibre
reinforcement. The failures occurred at loads 7.5 times higher than guaranteed load-bearing capacity of the anchors. The confinement of fibres prevents cracking in concrete and changes the failure mode from pull-out to rupture of the steel anchor.

The application of SFRC in pre-tensioned girder demonstrated ability of dispersed steel fibres to substitute shear reinforcement and enhance the anchoring. Minimizing of conventional rebar reinforcement diminishes workability and time consumption in the manufacturing of the element and thus the manufacturing becomes cheaper.

4. Conclusions
The potential of fibre reinforced concrete is undeniable. FRC is used as partial or total substitution of conventional reinforcement, what is economically profitable since higher cost of FRC material is compensated by reduction in labour cost of manipulation and storage of conventional reinforcement. Moreover, there are a lot of small or thin concrete elements that are not subjected to significant loads, where rebar reinforcement is required to prevent a brittle failure due to accidental actions and shrinkage cracking. In these cases fibres are very suitable, because production process of elements without rebars is easier and quicker and placing of rebar reinforcement in such tiny element is very demanding and labour-consuming. The dispersed reinforcement is able to enhance parameters of concrete in a number of ways; FRC have higher mechanical properties, higher impact resistance, better control of cracking, favourable behaviour in fire, etc. Utilization of fibre reinforced concrete increases durability and life cycle of the structure or structural element, thus it is favourable also regarding sustainable building and environmental assessment.

The FRC is usable either in a form of plain FRC, or with rebar reinforcement, or in a prestressed member. The most efficient is utilisation of FRC in precast members, thanks to better control of manufacturing the composite mixture. The paper introduces three examples of application of fibre reinforced composites in precast structural members, presents composites employed in particular application, mentions benefits of each application.

Each application of fibre reinforced concrete must be carefully planned and prepared. The realization of the fibre reinforced concrete element should be successful not only because of the immediate success and profit of the producer, but also because the eventual failure of the fibre reinforced concrete can cause distrust and inhibit or stop the development of the use of fibre reinforced concrete as a structural material.

Acknowledgement
This outcome has been achieved with the support of the Czech Science Foundation, project: GA15-19073S and project „The durability of concrete with recycled composites materials“, SGS17/123/OHK1/2T/11 supported by the Ministry of Education, Youth and Sports.

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