CHARACTERISTICS OF STEEL AND POLYMER BASED FIBRE CONCRETE

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Abstract

This paper discusses various material characteristics of steel and polymer fibres, with special regards to the long term performance.

Keywords: Macro synthetic fibre, steel fibre, creep, long term behaviour and performance

1 Introduction

Steel fibre reinforced concrete (SFRC) has been introduced in the European market in the second half of the 1970's. Neither standards nor recommendations were available at that time which was a major obstacle for the acceptance of this new technology. In the meantime, SFRC has been applied ever since in many different construction applications, such as in tunnel linings, mining, floors on grade, floors on piles, prefabricated elements.

In the beginning, steel fibres were used to substitute a secondary reinforcement or for crack control in less critical constructions parts. Nowadays, steel fibres are widely used as the main and unique reinforcement for industrial floor slabs and prefabricated concrete products. Steel fibres are also considered for structural purposes helping to guarantee the construction's ability and durability in:

- reinforcement of a slab on piles
- full replacement of the standard reinforcing cage for tunnel segments
- reinforcement of concrete walls and load bearing slab foundations
- steel fibres as shear reinforcement in pre-stressed construction elements
- combination with steel fibres and traditional reinforcement for crack control

This evolution into structural applications was mainly the result of the progress in the SFRC technology, as well as the research done at different universities and technical institutes in order to understand and quantify the material properties. In the early nineties, recommendations for design rules for steel fibre reinforced concrete started to be developed. Since October 2003, Rilem TC 162-TDF Recommendations for design rules are available for steel fibre reinforced concrete.

Around the millennium, suppliers of micro synthetic fibres started to offer macro synthetic fibres. Micro synthetic fibres are typically 6 to 12 mm long and have a diameter of 16 to 35 micron, and are widely used to reduce plastic shrinkage cracks, as well as to reduce concrete spalling during a fire. As the modulus of Young of a polyolefine is typi-

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cally around 3.000 to 5.000 MPa, it is generally understood that the reinforcing effect of these fibres is gone after a couple of hours of hardening of the concrete, as hardened concrete typically shows a modulus of Young of around 30.000 MPa. Macro synthetic fibres typically have dimensions equal to steel fibres, with length varying from 15 to 60 mm, and diameter from 0,4 to 1,5 mm. Macro synthetic fibres are to be considered as a relatively new construction material, but are often marketed as being equal to steel fibres.

But is this really true?

2 Material Properties of Steel and Polymer Fibres

2.1 The Modulus of Young of the fibres

The reinforcing ability of a fibre depends on the anchorage of the fibre into the concrete, the tensile strength and the modulus of Young.

The Young's modulus of concrete is typically 30.000 MPa, of steel fibre typically 210.000 MPa, and of polyolefine fibre typically 3.000 to 5.000 MPa. For well anchored fibres, and equal solicitation of the fibre, the elongation of the polymer fibre, and subsequently the corresponding crack width in concrete, might be considerably higher compared to steel fibres. This might have an impact on the durability of the concrete, especially in combination with traditional reinforcement.

2.2 Tensile strength of the fibres

The tensile strength of steel wire is typically 1.000-2.000 MPa, versus 300-600 MPa for most macro synthetic fibres.

2.3 Specific density of the fibres

The specific density of steel fibres is typically 7.850 kg/m³, versus 910 kg/m³ for polymer fibres, and 1.000 kg/m³ for water. Polymer fibres are light, which is favourable for health and safety, but they are lighter than water: the polymer fibres actually float on water, with potential risks for fibres at the surface in, for instance, flooring applications.

2.4 Fire resistance of the fibres

Polypropylene fibres typically melt at temperatures around 160°C. Therefore micro polypropylene fibres are proven to be suitable to improve the fire resistance. The exact reason is not yet fully understood, but it is generally accepted that the fine micro fibres start to melt in extreme fire conditions, thereby leaving small channels through which the pressurised vapour can escape. Consequently less damage, less spalling of the concrete is to be expected.

Macro synthetic fibres do melt at equal temperature, but are not fine enough to provide the concrete under fire with the necessary network of channels. Moreover, since the fibres melt, they are less suitable in those building constructions, where the reinforcing effect of the fibres is important.

2.5 Resistance against oxidation

Polymer fibres don’t rust, even if the fibres are sticking out at the surface. Bright steel fibres can show some staining if the fibres are at the surface, but never cause spalling of the concrete. If for aesthetical reasons, staining is not allowed, as in some prefabricated structures, galvanised steel fibres can be applied.

2.6 Mixability of the fibres

Some macro synthetic fibres tend to fibrillate during mixing. This fibrillation process goes on in the truck-mixer, until all fibres are completely destroyed. Quality degradation during mixing does not occur for steel fibres.

3 Properties of steel and macro synthetic fibre concrete

Fibre concrete is well known for its ductility. The effect of fibres is a combination of reinforcement and networking. Steel fibres in particular mainly change the behaviour of the concrete: steel fibres transform a brittle concrete into a ductile material which is able to withstand fairly large deformations without loosing its bearing capacity. Ductility means load redistribution and a higher bearing capacity of the structure with the mechanical properties of the basic concrete material unchanged.

3.1 Reinforcing effect measured in beam tests

In general, most macro synthetic fibres perform rather moderately in a bending test. The pure reinforcing effect is rather poor due to the low modulus of Young, and the rather low tensile strength. As can be noticed from the curve on Figure 1 and 2, most macro synthetic fibres start working at much larger crack widths than steel fibres; steel fibres with anchorage, depending on fibre type, typically work optimally at crack widths 0.5 mm to 1 mm, whereas macro synthetic fibres work optimally after 3 mm of crack width.

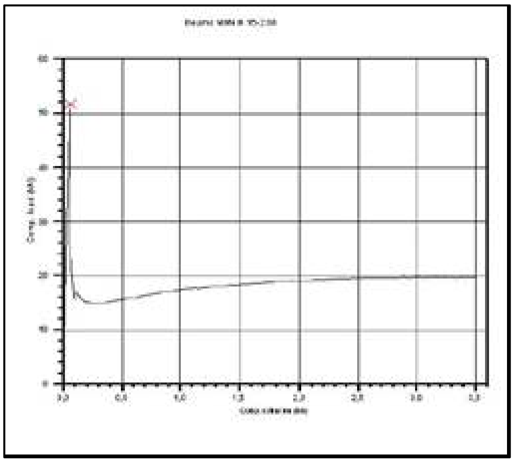

Fig. 1 typical load deflection curve for 1% vol. of macro synthetic fibres

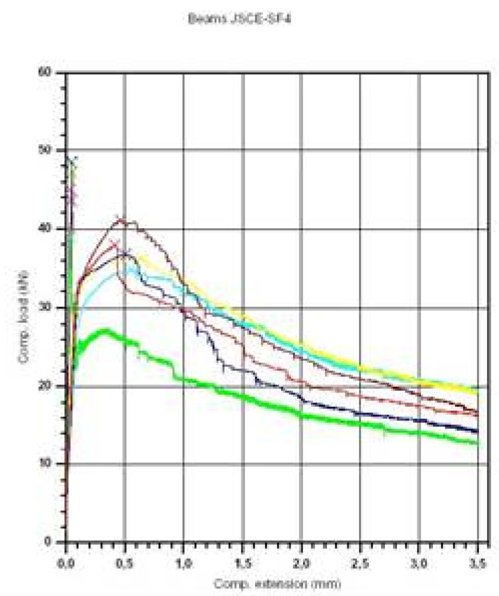

Fig. 2 Typical load deflection curve for 0,5% of steel fibres with hooked ends

4 Creep of steel fibre and macro synthetic fibre concrete

There is little information available as to the creep of concrete reinforced with macro synthetic fibres. The few papers [3, 4] that are available must be treated with care because the conclusions are sometimes based on a limited amount of test specimens, the creep tests are executed on different size test specimens, and different test procedures, as no standard test procedure is available, and some creep tests are executed only during three months time. The conclusion from those papers is that the creep coefficient is, depending on the type of the macro polymer fibres, of the order of 1 to 20 times the creep coefficient of steel fibre concrete.

In order to investigate the difference in creep behaviour between steel fibre and macro synthetic fibre reinforced concrete, N.V. Bekaert has set up a test program to compare the creep of both materials. Beams have been produced at the Bekaert laboratory with following mix design:

- 427 kg/m³ Cement CEM I 42.5R
- 854 kg/m³ Sand 0/5
- 854 kg/m³ Broken limestone 4/7
- w/c = 0,50
- Macro synthetic fibre type1 (48 mm long macro synthetic fibre with L/d of 48, embossed over the length, and tensile strength of 520 MPa) at a dosage of 4,55 kg/m³ (0,5 vol.%).
- Macro synthetic fibre type 2 (50 mm long macro synthetic fibre with L/d of 83, and tensile strength of 640 MPa) at a dosage of 4,55 kg/m³ (0,5 vol.%).
- Dramix® RC-65/35-BN steel fibres a dosage of 20 kg/m³ (0,5 vol.%).

The beams have been pre-cracked: the beams have been loaded in a displacement controlled way, as prescribed by most standards on steel fibre concrete. At a deflection of 5 mm, the load has been removed. This corresponds to a crack width of approximately 2mm as given by the dimension of the test specimen. The residual load at that moment can be read from the load deflection curve. (Figure 3)

The beams are now ready to be subjected to the creep test. Therefore 50% of the residual load is applied on the pre-cracked specimens. The load is applied in a four-point bending configuration. The deflection is measured, and shown on the Y-axis in 1/100 mm on Figure 4.

As can be noticed from Figure 4, the polypropylene fibres tend to creep 10 to 30 times more than the steel fibres after 2 years. Even a couple of beams with macro synthetic fibres couldn't carry the load anymore, and broke down in two pieces after 700 days. Moreover the creep of the macro synthetic fibre is not finished yet: the creep curve for the macro synthetic fibre is not yet stabilised. Therefore at present, the creep tests are still going on, as considerable higher creep can still be expected for the macro synthetic fibres. These deformations of course induce wider cracks.

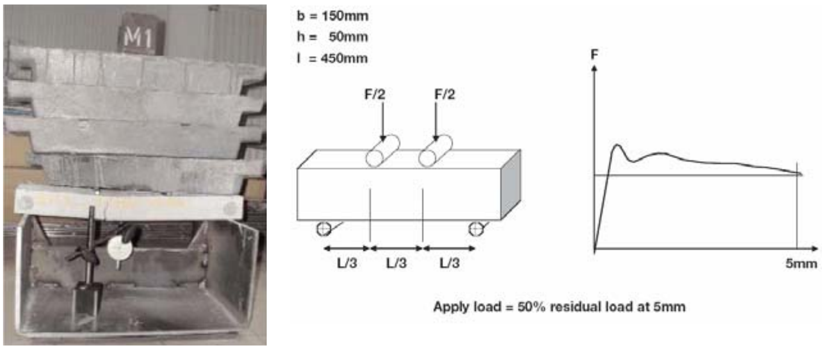

Fig. 3 Test setup

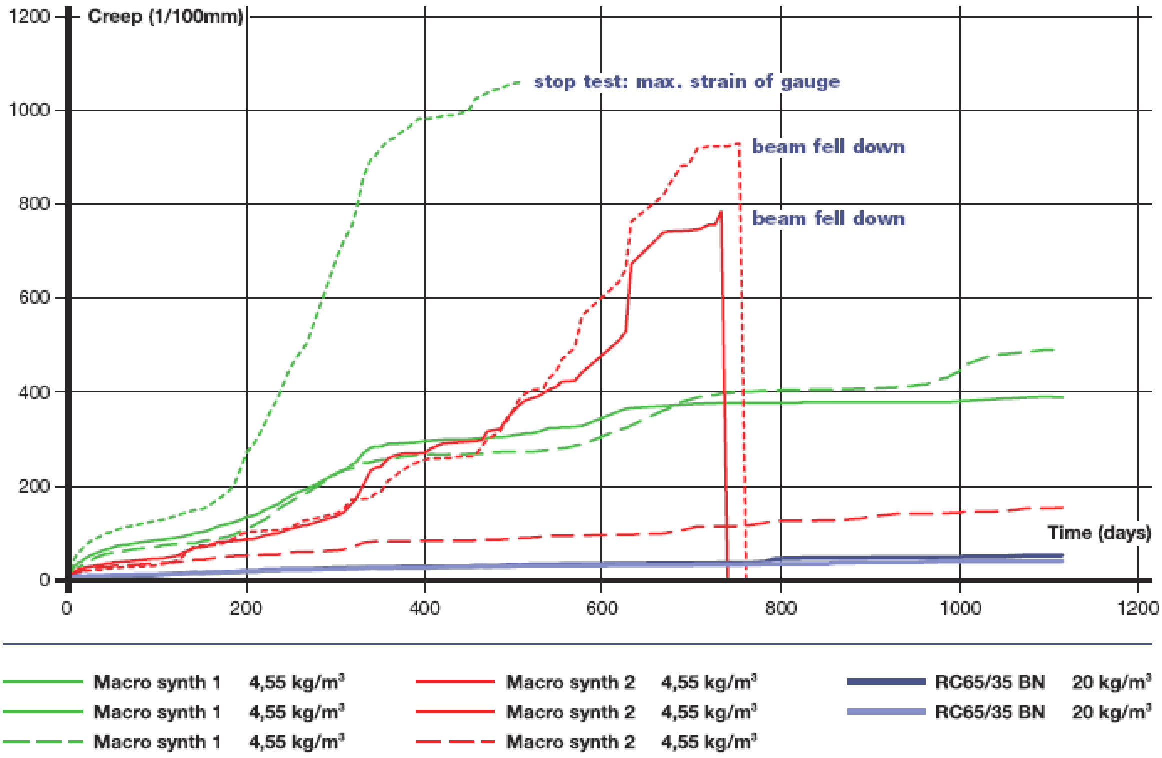

Fig. 4 Long term load-deflection curves

Currently the Austrian Society for Concrete and Construction Technology (ÖVBB) is running a long term test on the performance of three different macro-synthetic fibres and one steel wire fibre with hooked ends. The tests are still ongoing, but preliminary results are very similar to those described above [5].

4.1 Design rules for steel and macro synthetic fibres

Since October, 2003, Rilem TC 162-TDF design guidelines [1] are available for steel fibre concrete. No such guideline is available yet for macro synthetic fibre concrete.

4.2 Quality control of steel versus macro synthetic fibre concrete

As part of the quality production control, wash-out tests are quite common in order to check the dosage of fibres in fresh concrete. This is always time consuming, but a lot easier when the fibres can be removed by a magnet, as is the case for steel fibres.

5 Conclusions

Steel fibre concrete/shotcrete has proven over the years to be a reliable construction material. After 30 years of experience, the first Rilem design guidelines for steel fibre concrete were edited in October 2003 [1]. New fibre concretes, such as macro synthetic fibre concrete, are not yet fully understood, but gain attention. Creep data, shear resistance, crack control, durability, design methods… are lacking at the moment for macro synthetic fibre concrete, but the experience will learn.

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