Concrete Basics – Guide To Steel Fibres

Comparison of slab on grade floor options from different suppliers

INTRODUCTION

Scancem Materials development of the use of steel fibres for slabs on grade over the last ten years has proven the performance, construction advantages and cost savings of high performance steel fibres. This has led to growth in demand and more recently a large range of fibres being promoted.

Whilst competition is good for the consumer it is a concern if the customer is not getting what he expects or needs. Scancem Materials have established their track record using high performance fibres and a toughness based design approach. Most of the new fibres on the market are low performance (hence low cost/kg) and suppliers are following less conservative design approaches in order to be competitive. This is leading to slab failures, which is reflecting poorly on the steel fibre industry.

The purpose of this note is to provide a simple guide to specifiers on how to:

- differentiate between low performance and high performance fibres
- compare the performance of different SFRC floor options provide by different manufacturers.

Fibres can vary in performance quite dramatically and so fibre dosage and slab thickness should reflect this. Fibre geometry, strength, deformations and their ability to be evenly distributed through the concrete all have a bearing on the load carrying capacity of Steel Fibre Reinforced Concrete (SFRC)

SPECIFICATION OF SFRC SLABS ON GRADE

There is no Australian standard covering the design of SFRC slabs on grade. The only guidance comes from Technical Report 34 (TR34) from the Concrete Society (UK). It requires that Re_3 values (% of flexural strength at 3mm deflection of a standard beam test) shall be such as to assure the stress in the slab is acceptable for the applied stress. This applied stress should combine temperature, shrinkage and applied load induced stresses. TR34 gives guidance on one load case but the designer is left to determine how to handle other load cases.

Scancem's design guide fully details how to handle each load case and can be used to calculate the stress and required Re_3.

CHARACTERISTICS OF STEEL FIBRES

There are four properties of steel fibre that are important.

1. Aspect Ratio (L/D)

All other things being equal performance increases as the aspect ratio (length/diameter) of a fibre increases. To increase the aspect ratio of a fibre you must increase the length while decreasing the diameter. By doing this you are increasing the number of fibres per kg.

All else being equal twice the dosage of a loose fibres with aspect ratio of 40 would be required to give the same performance as a fibre with an aspect ration of 80. This has particular relevance as loose fibres (most suppliers) have to have an aspect ratio of under 50 to avoid balling while Scancem commonly use a collated 80 aspect ratio fibre (see 4).

2. Fibre Anchorage Details

In order for the SFRC to continue to carry load and deform plastically after cracking has occurred, it is essential that

- the fibre is sufficiently anchored in the concrete matrix to enable the full tensile strength of the fibres to be harnessed
- fibres pull through as the ultimate fibre capacity is reached. This means the full capacity of the fibre is achieved over high deformations giving high energy absorption and the characteristic ductility required to prevent brittle failure. This is the basis for TR34's specification of Re_3 values.

In terms of fibre geometry the following is important:

- Small changes to the shape of a hooked end anchorage can mean the difference between high and low toughness
- Continuously deformed fibres, enlarged end fibres and mill cut fibre will bond over a short length of the fibre rather than pull through and a more brittle failure will result. Full scale tests show that this type of failure is not consistent with increased load carrying capacity even at high dosages. Manufacturers of these types of fibres typically do not quote Re_3 values as they are low. More typically they quote I_5, I_{10}, and I_{30} vales which correspond to the more brittle failure mode.

3. Physical Properties of Steel Fibres

To maintain the ductility of SFRC and ensure the reliability of the plastic deformation, it is imperative that the well-anchored fibres do not break. Breaking fibres equates to a brittle failure mode (this is the main problem with fibres continuously deformed). To prevent breakage steel fibres should be manufactured with sufficient tensile strength to ensure the ultimate failure mode is pullout rather than breakage. Fibres manufactured from hard drawn steel wire make available tensile strengths in excess of 1000MPa.

Sleet sheet steel fibres are available from some supplier are particularly cheap/kg but their Re_3 performance is generally very low.

4. FIBRE PACKAGING

High aspect ratio fibres are generally highly efficient in structural terms however, they tend to ball when mixed in concrete unless packaged correctly. Fibres can be glued together in strips of about 30-50 fibres with a water-soluble glue. High aspect ratio fibres when collated in this way can be added to the mix almost like an extra aggregate and no balling will occur. The aspect ratio of the bundle is less and the water-soluble glue guarantees that the fibres are uniformly distributed in the mix. Fibres are added into the truck in degradable bags for ease of handling. Low aspect ratio, loose fibres tend to be packaged in boxes. They can ball (even though low aspect ratio) and dispersion problems can occour if not handled and mixed with care.

SFRC SLAB ON GRADE DESIGN

Based on the fibre properties shown in table 1 (properties shown are from manufacturers information) we can do a comparative design. The design consist of checking the fibre dosage to achieve the required moment capacity and checking that the fibre dosage is adequate to achieve load transfer between fibres.

Re3 Requirement

Re_3 is a toughness coefficient defined in section 3.2.6 of Technical Report 34 (TR34) from the Concrete Society (UK) and is used in Appendix F of the same publication to determine the moment carrying capacity of a SFRC slab on grade.

Re_3 is calculated as the average load carrying capacity offered after cracking (due to the presence of fibre reinforcement) divided by the flexural tensile strength of the uncracked concrete matrix – the ratio is typically expressed as a percentage. TR34 states the Re_3 value used should be greater than 30%. Under this critical value the slab will behave as an unreinforced or plain concrete slab and should be designed using the Westergard formulae.

Example

If we want to calculate the fibre dosage for a 150mm thick slab, 32MPa concrete with a moment capacity (M_u) of 7.80 kN/m we know:

$M_u = R_{e3} f_t \times bd^2/6$ of a SFRC section

Therefore Re_3 (ductility required from fibres and is different for different fibres)

$= M_u \times 6/bd^2 f_t$

$= 7.8 \times 6 \times 10^6/150 \times 150 \times 10^3 \times 4.73$
$= 0.44$ (ie ductility factor required)

Comparative Design

17kg/m³ Scanfibre CHO80/60NB (high tensile wire, hooked end fibre with 80 aspect ratio)

20kg/m³ of Scanfibre CHO65/60NB (high tensile wire, hooked end fibre with 65 aspect ratio)

30kg/m³ of Qubix UW10/50 fibre (50 aspect ratio wire fibre with continuous deformations. Estimate based on aspect ratio and design. Manufacturers only quote I_5, I_{10}, and I_{30})

40kg/m³ of Qubix CR50 fibre (slit sheet fibre. Estimate based on type of fibre. No performance values quoted by manufacturer)

40kg/m³ of BHP EE25HT fibre (enlarged end high tensile fibre)

75 kg/m³ of BHP EE18mm fibre (enlarged end fibre)

Minimum Reinforcement

European publications also recommendation that, irrespective of the Re_3 requirements the minimum steel fibre dosage permitted shall be that required to give a maximum avaerage spacing factor of 0.45 times the nominal fibre length calculated using the spacing theory of McKee. This is to ensure adequate overlap between fibres to transfer load. The McKee formula can be broken down to min. dosage = 67,658 / (Aspect ratio)²

This has been used to calculate the minimum fibre dosage for load transfer in table2.

Final Dosage Requirements for various fibres.

Table 2 – Fibre Dosages For Structural Design Of Slab On Grade using Toughness Design Method.

Fibre Type	For Moment Capacity	For Load Transfer	Final Dosage
Scanfibre CHO80/60NB	17kg/m³	11kg/m³	17kg/m³
Scanfibre CHO65/60NB	20kg/m³	16kg/m³	20kg/m³
Qubix UW10/50	30kg/m³	27kg	30kg/m³
BHP EE18mm	75kg/m³	67kg	75kg/m³
BHP EE25HT	40kg/m³	34kg/m³	40kg/m³
Qubix CR50	40kg/m³	?kg/m³	40kg/m³

The final dosages required for the various options is found from the maximum of moment capacity or load transfer requirements and are given in table 2

CONCLUSIONS

Fibre dosage varies according to the performance of the particular fibre chosen. Merely specifying a dosage will not take into account the individual performance of the fibre. At a low dosage a particular fibre may meet the ductility requirements as determined via a beam test, however the dosage may not be enough to provide the continuous reinforcement required for load transfer as determined by McKee.

It is therefore important for designers to agree the toughness design (even when undertaken by suppliers) and to specify that the SFRC slabs shall:

1. **achieve a performance requirement for load carrying by stating the required Re_3 value**
2. **comply with minimum dosage requirements of McKee**

In this way the design requirements of load capacity and load transfer will be equal for all fibre suppliers and the most cost competitive supplier will win the project.

Table 1: Fibre Properties

Fibre Properties	Scanfibre CHD80/60NB	Scanfibre CHO65/60NB	BHPEE25HT	QUBIX CR50
Length	60mm	60mm	25mm	50mm
Diameter	0.75mm	0.92mm	0.55mm??mm	
Aspect Ratio	80	65	45	??
Tensile strength	1200Mpa	1200Mpa	800Mpa	750MPa
Anchorage	Hooked ends + indent	Hooked ends	Enlarged ends	Undulating
Collation	Collate	Collate	Loose fibres	Loose fibres
Fibre type	Drawn wire	Drawn wire	Cut sheet	Shit Sleet
Packaging	Degradable bags	Degradable bags	Boxes	Boxes
Re_3 value	44% at 15kgs	44% at 20kgs	38% at 35kgs	??
Min. Dose	11kg/m³	16kg/m³	35kg/m³	??kg/m³

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