Products For Concrete

SCANCEM MATERIALS

Fibre Reinforcement

Minimum Performance Levels and Dosage Rates

INTRODUCTION

Steel Fibres are added to plain concrete in order to turn an inherently brittle material into a tougher, more ductile composite.

The brittleness of plain concrete is characterised by the way in which once cracks are initiated they rapidly propagate right through the concrete section leaving it with no load carrying capacity whatsoever.

Adding steel fibres to the concrete matrix, to make Steel Fibre Reinforced Concrete (SFRC), initially inhibits the propagation of cracks, then maintains some measure of load carrying capacity even after a visible crack pattern is established.

Conventional reinforcement, in the form of bars or mesh, also provides load carrying capacity after cracking is established, but has a negligible effect in terms of slowing down or retarding crack development.

A very important aspect of SFRC is what dosage of any particular steel fibre is actually required to enhance the properties of a plain concrete. It is vital that this be known in order to avoid the situation of paying a premium for SFRC that effectively has the same performance characteristics as plain concrete.

Given the fact that the performance of a SFRC increases with increasing fibre dosage it is quite easy to understand the concept of a minimum dosage rate being required for a fibre to be effective. With the minimum dosage rate established, based on either the fibre properties or the performance of the SFRC, it is then possible to ensure that an ineffective dosage rate is not being allowed and ultimately paid for.

There are two methods of specifying minimum fibre dosage rates:-

Table 1. Minimum fibre Dosages to RTA QA Specification B82 for shotcrete

Aspect Ratio	40	45	50	55	60	65	70
Minimum Dosage (kg/m^3)	65	50	40	35	30	25	25

Figure 1. Load Transfer

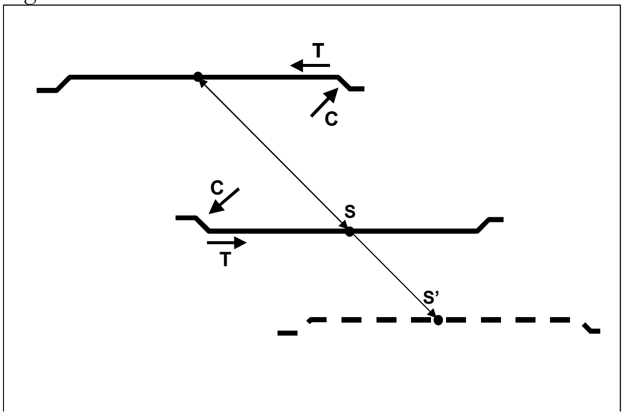
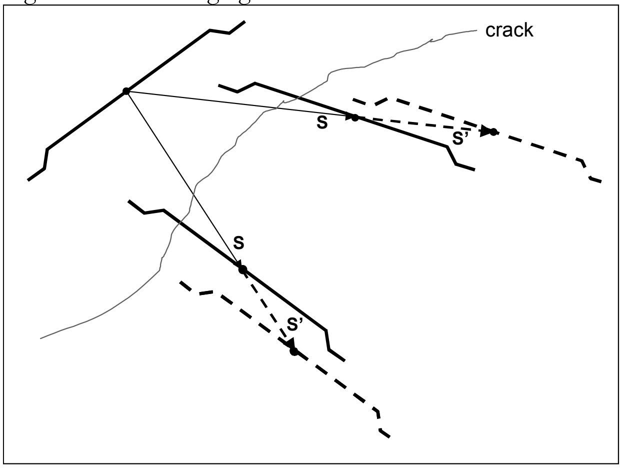


Figure 2 Crack Bridging



1. SPECIFYING FIBRE SPACING

The concept of requiring a maximum average 3D spacing between fibres can be explained in two ways:-

1. In order for tensile stress to be transmitted from fibre to fibre and hence through the composite the discreet fibres need to be close enough to permit a compressive strut to form in the concrete matrix between fibres (Figure 1).
2. Fibres must be close enough together so that they effectively intercept any cracks as they propagate through the composite (Figure 2).

The average spacing of fibres in three dimensions can be determined using the spacing theory of McKee(1) using the following formula:-

$$S = \sqrt[3]{(\pi d^2 l/4\sigma)}$$

Where:

S = average 3D fibre spacing
$\pi d^2 l/4$ = Volume of 1 fibre
σ = Fibre volume fraction (.01 = 78.5kg/m^3 for steel)

This formula can be manipulated to determine a minimum dosage for any steel fibre when using the recommendation that the maximum average spacing of fibres should be 0.45 times the typical fibre length.

This recommendation comes from a technical committee of learned professors brought together to formulate a design guideline(2) for SFRC for use with the European Code on concrete structures.

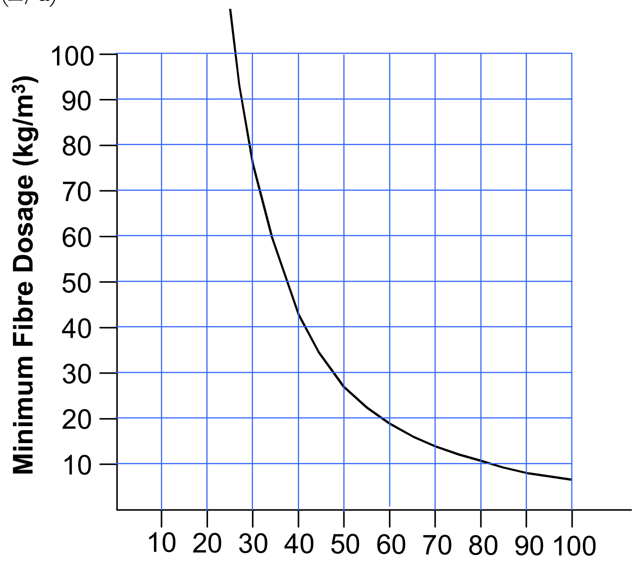
The result for steel fibres becomes:-

Minimum Fibre Dosage=$67658/(l/d)^2$

Where l/d is the fibre aspect ratio.

This relationship is plotted in Figure 3 for easy reference and forms the basis of the minimum fibre dosage recommendations found in RTA QA Specification B82 for shotcrete that is reproduced in Table 1.

Figure 3 Minimum Fibre dosage versus Fibre Aspect Ratio (L/d)



2. SPECIFYING PERFORMANCE

Performance Tests

There are several international standards that can be used to measure the performance of SFRC. All of these standards essentially rely on the use of third point loaded beams that measure the performance of SFRC both before and after cracking to determine "toughness".
For more information on the testing procedure refer to our technical data sheet titled "Design Of SFRC using Toughness"

In terms of the design of slabs on grade the only recommendation that actually addresses the use of the toughness properties of SFRC in the design process is Technical Report 34 (TR34) from the Concrete Society (UK), titled Concrete Industrial Ground Floors – A guide to their Design and Construction. This publication is available from the library of the Cement and Concrete Association of Australia in Sydney.

In order to design a SFRC ground slab in accordance with the recommendations given in appendix F of this publication it is necessary to have a value for $R_{e,3}$, defined as the ratio of the equivalent flexural tensile strength up to a deflection of 3mm ($f_{e,3}$), determined in accordance with Japanese standard test method JSCE-SF4, divided by the flexural tensile strength or modulus of rupture of the parent concrete (f_{ct}). $R_{e,3}$ is typically expressed as a percentage.

Any fibre manufacturer, even if not publishing $R_{e,3}$ values in their literature, should be able to advise suitable values based on fibre type and dosage.

Experimental data has shown that in order to use the design method outlined in TR34 it is necessary for the value of $R_{e,3}$ used to be greater than 30%. Under this critical value the slab will behave as an unreinforced or plain concrete slab that should be designed using the formulae of Westergard.

The Dutch, in their guideline for the design of SFRC, namely CUR 36 also recommend this same minimum value for $R_{e,3}$ is necessary to take advantage of the toughness characteristics of SFRC.

Conclusion

The minimum dosage of any particular fibre based on performance requirements should be such as to provide a value of not less than 30% for $R_{e,3}$.

References

1. McKee DC, 1969. *The properties of expansive cement mortar reinforced with random wire fibres*, PhD Thesis, University of Illinois, Urbana, 1969. Documented in ACI committee 544 report State of the art report on fibre reinforced concrete 1982.
2. *Design of concrete structures Steel wire fibre reinforced concrete structures with or without ordinary reinforcement.* Published by the Ministry of the Flemish Community Dept. for the Environment: *INFRASTRUCTUUR IN HET LEEFMILIEU* Nr. 4 - 1995.