STEEL FIBRES AND MESH

– JUST HOW DO THEY COMPARE

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INTRODUCTION

The way in which fibres reinforce concrete can be compared directly to the way mesh reinforces concrete.

The aim of this technical note is to show how a fibre dosage can be selected and specified to provide the same ultimate capacity as a mesh reinforced concrete section.

1. MESH CAPACITY

Typically mesh has two applications in concrete as follows:-
1. To provide a post cracking bending moment capacity in flexural elements.
2. To limit shrinkage and temperature crack widths by providing a closing tensile force across the cracks.

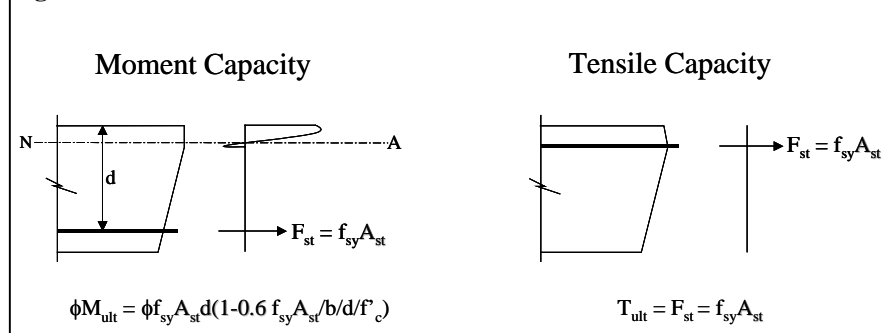The calculation of these two capacities for mesh is shown in Figure 1.

It is important to note the intrinsic assumptions in this analysis:-
1. The mesh wires and hence the tensile force they provide acts at a known depth in the concrete section.
2. The tensile force in the wires acts parallel to the longitudinal axis of the concrete section.
3. The crack width and wire anchorage are adequate to mobilise the full tensile strength of the wire ($f_{sy}A_s$).

2. FIBRE CAPACITY

Fibres are small discreet elements that are distributed throughout all three dimensions of the concrete matrix. The consequence of this is that the tensile capacity they provide when bridging a crack has the following properties:-

Figure 1 MESH REINFORCED CONCRETE

Moment Capacity

Tensile Capacity

$$\phi M_{ult} = \phi f_{sy}A_{st}d(1-0.6 f_{sy}A_{st}/b/d/f'_c)$$
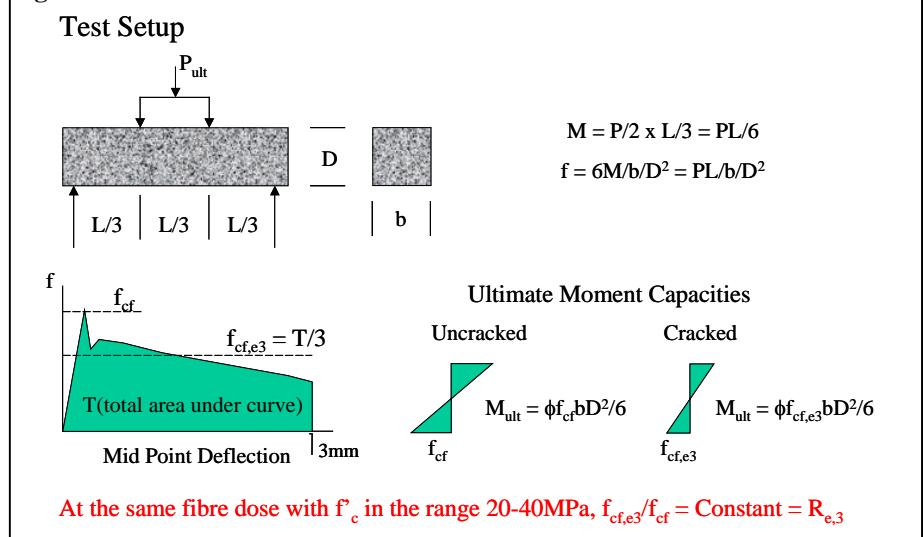
$$T_{ult} = F_{st} = f_{sy}A_{st}$$

1. The force generated in an individual fibre is a function not only of the fibre strength and anchorage capacity but also of the strength of the concrete matrix it is embedded in.
2. The 3-D distribution of the fibres means that only a component of the tensile force generated in each crack bridging fibre actually acts perpendicular to the crack.
3. The total tensile capacity generated perpendicular to a crack in fibre concrete is equal to the sum of the perpendicular components of tensile force generated by each individual fibre bridging the crack.

The differing stress level and orientation of each fibre as well as their distribution through the depth and width of the concrete section makes it impossible to simply model the tensile force provided by fibres in the same way as is done for mesh.

For this reason the ultimate moment and tensile capacities provided by fibre reinforced sections can only be effectively determined from the results of laboratory load tests. Fortunately the results of a great deal of such testing has provided a suitable design model for determining design capacities without the need to revert to testing for every new project.

Figure 2 ESTABLISHING PROPERTIES FOR FIBRE REINFORCEMENT

Test Setup

$$M = P/2 \times L/3 = PL/6$$

$$f = 6M/b/D^2 = PL/b/D^2$$

Ultimate Moment Capacities

Uncracked

$$M_{ult} = \phi f_{cf}bD^2/6$$

Cracked

$$M_{ult} = \phi f_{cf,e3}bD^2/6$$

$$f_{cf,e3} = T/3$$

T(total area under curve)

Mid Point Deflection

At the same fibre dose with f'_c in the range 20-40MPa, $f_{cf,e3}/f_{cf} = $ Constant $= R_{e,3}$

The testing procedure for fibre reinforced concrete is described in numerous international testing methods using third point loaded beams (for example ASTM C1018, JSCE-SF4) and is shown diagrammatically in Fig. 2.

Given manufacturer's published values of R_{e3} for a selected fibre type and dosage, along with the flexural tensile strength or modulus of rupture of the concrete, it is possible therefore to calculate both the ultimate moment capacity and ultimate tensile capacity of a fibre reinforced concrete section as shown in Figure 3.

WORKED EXAMPLE:
Determine the fibre dosage required to provide the same ultimate tensile and moment capacities as a sheet of F72 mesh in a 125mm thick slab/panel of N32 concrete.

1. For the F72 mesh located in the top of a 125 thick slab on ground to provide shrinkage and temperature crack control:-
Ultimate tensile strength of F72
$= A_{st} \times f_{sy} = 198\text{mm}^2/\text{m} \times 450\text{N/mm}^2$
$= 89.1\text{kN/m} = 0.37R_{e3}f_{cf}\,bD$.
To determine the fibre dosage required determine the performance level required in terms of R_{e3}.
i.e. $R_{e3} = 89.1/0.37/125/f_{cf}$

If the mean flexural tensile strength is not known it can be calculated from the 28day compressive strength of the concrete using the Eurocode 2 formula:-
$f_{cf} = 0.5(f'_c)^{2/3} = 0.5 \times 32^{2/3}$
$= 5.0\text{N/mm}^2$
Using this value the required value for $R_{e,3} = 89.1/0.37/125/5.0 = 0.39$

2. For the F72 mesh located centrally in a wall panel:-
Ultimate design moment capacity (ϕM) for F72 mesh $= 0.8 \times 198 \times 450 \times 62.5(1-0.6 \times 198 \times 450/62.5/1000/32)$
$= 4.3\text{kNm/m} = 0.7R_{e3}f_{cf}bD^2/6$

and using the calculated value of f_{cf} above the required value for R_{e3}
$= 4.3 \times 6000/0.7/5.0/125^2 = 0.48$.
From the above calculation it is possible to achieve the same design ultimate moment capacity as the mesh using any selected fibre at a dosage required to achieve an R_{e3} value of 0.48.

Two possible solutions are the Dramix RC 80/60 BN fibres at a dosage of 20kg/m³ (Re3= 0.52) or the Dramix RL 45/50 BN fibres at a dosage of 30kg/m³ (R_{e3}=0.49).

3. MINIMUM DOSAGES
When using fibre reinforcement it is important to ensure that the dosage used is adequate to provide the following minimum performance criteria:-
1. A minimum level of ductility (toughness) i.e. $R_{e3} \geq 0.30$.
2. A minimum number of fibres to provide crack control.

In regards to point 2 it is necessary that the fibres, on average, are close enough together in the hardened concrete to effectively lock off any cracks that start to propagate through the matrix. Essentially, the fibres need a minimum level of overlap.

This is considered to be achieved if the average spacing between the fibres is not greater than 0.45 times the fibre length.

The average fibre spacing can be calculated using the spacing theory

of McKee:-

Average fibre spacing "S"
=[(vol. of 1 fibre)/(fibre volume fraction)]$^{1/3}$.

For steel fibres with a density of 7850kg/m³ this translates to:-
$S = [\pi d^2 l/4/(\text{fibre dosage}/7850)]^{1/3}$

Substituting the minimum allowable fibre spacing of 0.45l into this equation and rearranging gives the minimum allowable fibre dosage as:-
67658/(l/d)²
where l/d is the fibre aspect ratio.

Checking the two fibres proposed above against this formula gives a minimum dosage of 10.6kg/m³ for the 80 aspect ratio Dramix RC 80/60 NB fibres and 30kg/m³ for the 48 aspect ratio Dramix RL 45/50 BN fibres.

4. IMPORTANT NOTE
Unlike mesh, fibres are dependent on the strength of the concrete matrix in order to provide their design capacities, so that the tensile capacity of a fibre reinforced concrete varies with the strength of the concrete matrix the fibres are reinforcing. For this reason the
capacity provided can be low in early age concrete, a potentially critical time for crack control.

Figure 3 FIBRE REINFORCED CONCRETE

Stress Distribution Model for Fibre Concrete

Cracked $M_{ult} = f_{cf,e3} \cdot bD^2/6 = f_{ft} \cdot 0.9bD \cdot 0.5D$

$\Rightarrow f_{ft} = 0.37\,f_{cf,e3} = 0.37R_{e3}\,f_{cf}$

Moment Capacity

Tensile Capacity

$\phi M_{ult} = \phi 0.37f_{cf,e3} \cdot 0.9bD \cdot 0.5D = 0.7R_{e3}f_{cf} \cdot bD^2/6$

$T_{ult} = 0.37\,f_{cf,e3}\,bD = 0.37R_{e3}f_{cf} \cdot bD$