SCANFIBRE

FOR SHOTCRETE

Scanfibre Reinforced Shotcrete Applications

Steel Fibre Reinforced Shotcrete (SFRS) has gained widespread use in applications such as:

- support of underground openings in tunnels, mines, drainage adits and exploratory adits;
- rock slope stabilisation and support of excavated foundations, often in conjunction with rock and soil anchor systems;
- channel linings, protection of bridge abutments and stabilisation of debris-flow prone creeks;
- rehabilitation of deteriorated marine structures such as bulkheads, piers, sea walls and dry dock;
- rehabilitation of reinforced concrete structures such as bridges, chemical processing and handling plants.

Benefits of Scanfibre SFRS

- Most economical fibre when judged on performance
- Can achieve performance levels unattainable with other fibres
- Replaces mesh to provide
  - *- Faster installation*
  - *- Reduced material cost*
  - *- Improved safety*
  - *- Lower establishment costs*
  - *- Better performance*
- Supported by experts in fibre technology, shotcrete, ground support

How SFRS Works

The principle of ground support is to provide a structural membrane that can accept large movements between rock bolts, particularly underground. this is necessary for the reinforced ground to take the load (fig 1&2). Key parameters are flexural strength, shear strength and bond strength.

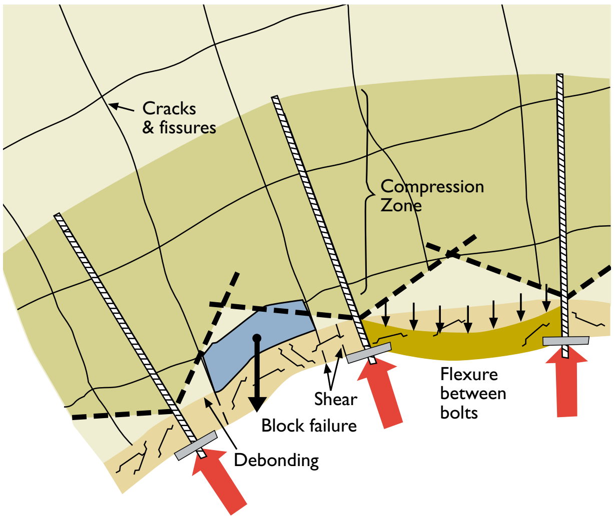


FIG 1.
For tunnel linings SFRS spans between bolts and keeps the ground from unravelling. The compression arch formed by the rock bolts is the primary structural member.

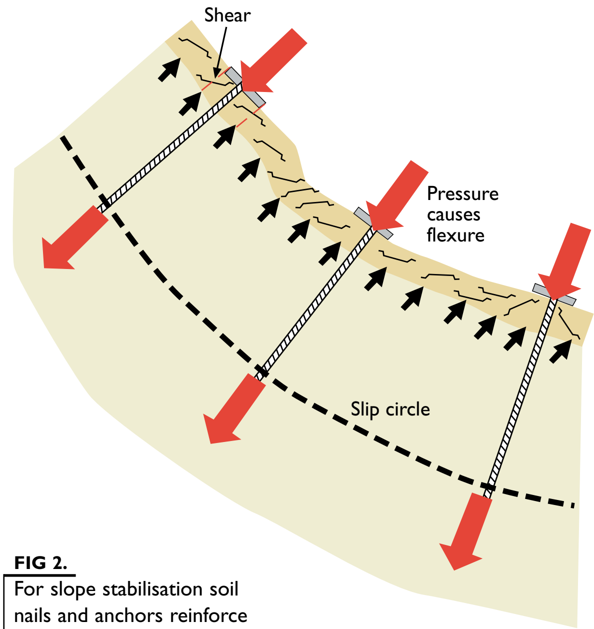
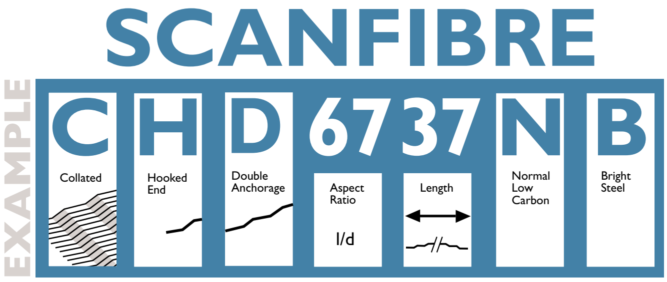


FIG 2.
For slope stabilisation soil nails and anchors reinforce slip planes while the SFRS spans between the anchors.

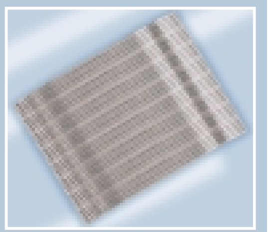
Front cover: Eastern Distributor Tunnel. 65kg/m³ of fibre required for desired performance in a beam test.

The Scanfibre Range

The Scanfibre range has been carefully tailored to provide the most appropriate fibre for each application and design. The Scanfibre nomenclature is described below.



C for Collated L for Loose



Collation is where wire from forty spools is fed to a glue line where a water dissolvable glue is applied. Collation of fibres was a major breakthrough in fibre technology. It is necessary in order to use high aspect ratios fibres (high aspect ratio is essential to obtain high toughness) without balling.
Where a low aspect ratio (<50) is used the fibres can be supplied loose.

H for Hooked End Primary Anchorage

The hooked end is designed to provide anchorage in a non rigid way. The fibre cross section remains unchanged so it can pull through the concrete at high loads to prevent brittle failure due to fibre breakage and to promote high energy absorption. The hook is designed to balance the fibre strength.

D for Double O for nil C for Continuous

For optimum performance fibre deformation has to increase as concrete stength decreases to maintain balance between the wire strength and its anchorage. Secondary anchorage, as described here, achieves this.

67 Aspect ratio

Aspect ratio (length/diameter) is a key characteristic in determining performance. High aspect ratios lead to high performance (toughness) but without collation fibres tend to ball at aspect ratios over 50. Scanfibre is supplied with aspect ratios of up to 80.

37 Length

Fibres can be supplied in any length but should be long enough to ensure aggregate overlap and short enough not to block equipment.

N Normal

Normal low carbon steel is pulled through a series of dyes to give a wire strength in excess of 1000MPa

B Bright

Bright steel is the norm for steel fibres in concrete. Corrosion is not generally an issue The fibres are not interconnected so there can be no corrosion current, hence galvanizing is not normally necessary.

Related Products and Technologies

Synthetic Fibres

For control of plastic cracking and to help reduce rebound and bleed.

Admixtures

A complete range of retarders/accelerators, plasticers and polymers. Our accelerators use cutting edge technology to provide a safe working environment and minimal concrete strength loss. Our plasticisers include melamine, naphthalene and polymer types. We also provide polymers for integral curing, improved bond and crack control.

Silica Fume

Apart from quality-controlled product we can supply software for design of waterproofing and durable concretes. We can also provide advice on the type of silica fume that should be used in your shotcrete application.

Injection Grouts

A range of injection grouting materials to control water inflows and to strengthen the ground.

Rock Bolts

A range of bolts including fibre reinforced plastic (FRP).

Equipment

Equipment for shotcreting and rock bolting either on purchase or hire terms.

Consultancy

Where extensive specialist technical support is required consultancy services are available from our international network.

Training

Training programmes combine theoretical and practical sessions.

FIG 3.
Related Products.

Benefits Compared to Mesh

The principal advantages of SFRS with Scanfibres are a reduction in material, greater speed, lower costs and greater safety. Scanfibre SFRS is also a technically superior solution to mesh or SFRS with lower performance fibre.

Technical Benefits

- The fibres reinforce the shotcrete homogeneously and gives a resistance to tensile stresses at any point in the shotcrete layer
- Increased load bearing capacity due to the redistribution of stresses
- The removal of mesh leads to an increased shotcrete bond to the substrate
- Excellent corrosion resistance. Scanfibre eliminates the problem of spalling due to rebar corrosion
- Excellent control of cracks giving less leakage
- Avoids "shadowing" or voids behind mesh.

Economic Benefits

- Time - the use of Scanfibre SFRS can reduce tunnelling cycle time which cuts labour costs and also reduces non-productive time with tunnelling equipment. All up, Scanfibre SFRS shortens the total construction time.
- Safety - the safety of underground construction workers is of utmost importance. Scanfibre SFRS provides instant support. There is no need to install mesh in unsupported ground.

Materials

- Scanfibre SFRS follows the ground contours to give constant thickness and reduced consumption

Clean up

- Minimises rebound losses (up to 30% less material to spray), particularly in combination with Scancem Silica Fume, reducing volume to be cleaned up.

FIG 4.
Scanfibre SFRS is simple to apply in difficult locations as it eliminates difficult, inefficient costly and time consuming mesh installation.

The Problems of Mesh

a) The irregular positioning of the mesh does not ensure an efficient reinforcement (ie in the wrong place).

b) Overuse of concrete due to filling of pockets behind the mesh.

c) Bad filling of pockets resulting in voidage and water infiltration.

d) Additional SFRS consumption due to the requirement of steel cover (this is often not satisfactorily achieved).

e) Creations of shadows behind reinforcing reducing its effectiveness and durability.

f) Increases rebound as stone rebounds of mesh until covered.

The Advantages of Scanfibre

- Scanfibre concrete overcomes the problem of overspraying and filling of hollows so the ground contours can be followed when mesh is replaced with Scanfibres.
- Scanfibres give resistance to tensile stresses at any point in the shotcrete layer.
- Homogeneously reinforced concrete with excellent density and impermeability prevents the formation of water passages.
- The use of Scanfibre allows the shotcrete to better follow the contours of the ground.
- The inclusion of Scancem Silica Fume as an additive further reduces rebound and allows high first pass build.
- Scanfibre is delivered in the concrete illiminating one whole operation i.e. mesh installation.

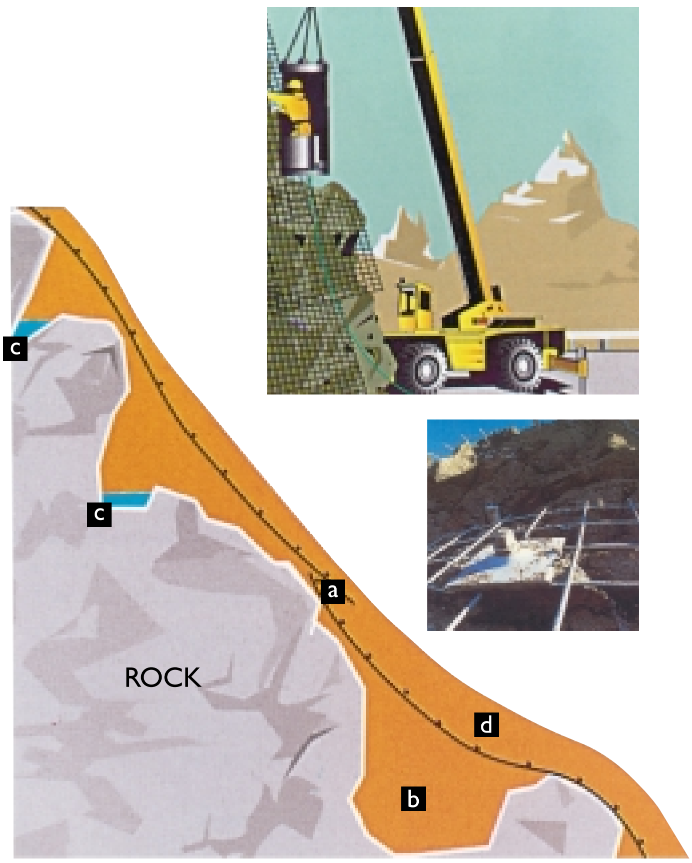


FIG 5.
Mesh installation is costly in terms of time, materials, special equipment and safety.

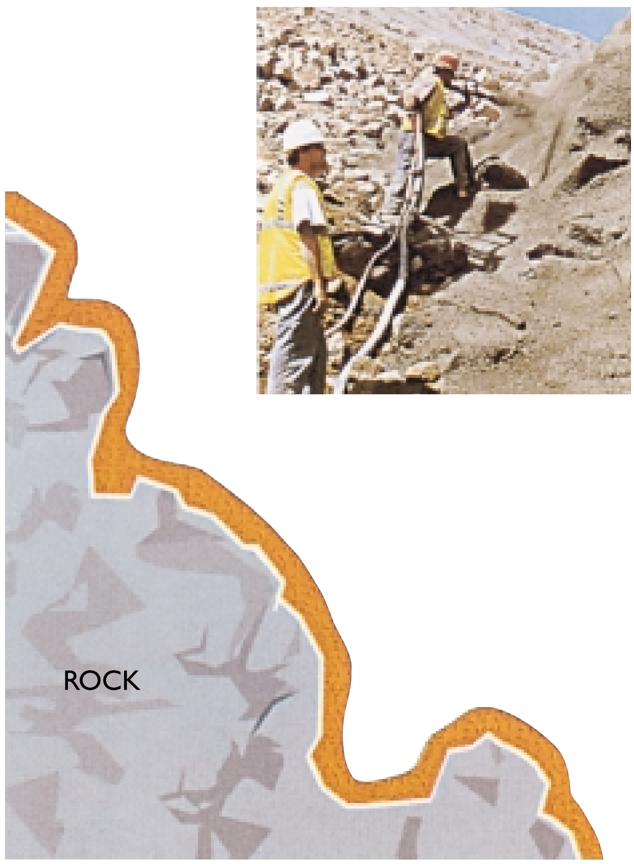


FIG 6.
Scanfibre SFRS is installed rapidly, safely and cost effectively.

Properties of Scanfibre SFRS

Shotcrete needs to behave in a ductile rather than a brittle manner (see design). Scanfibre SFRS has the ability to sustain load whilst undergoing significant deflections. The performance of fibre reinforced shotcrete varies with different fibre dosages and types and because of this, a standard performance test that simulates real conditions is required. There are several international standard test methods available to measure the ductility of fibre. The more commonly used term for ductility is "toughness". Beam tests (fig 7) are often used to give eqivalent flexural strength used for structural design but for shotcrete lining energy absorption is more critical. However, the most suitable single test is a punching / bending "panel" or "plate" test developed in Europe and now included in Norwegian, French and EFNARC guidelines. The test is now regularly used in tunnel specifications around the world.

Results from Japan and Australia (fig 9) show that Scanfibre can provide higher performance than mesh. Shotcrete with Scanfibre gives far higher performance than SFRS using other fibres most of which can not provide the same strength as mesh. The EFNARC test is used to verify that Scanfibre will provide the necessary flexural and punching strengths (fig 8).

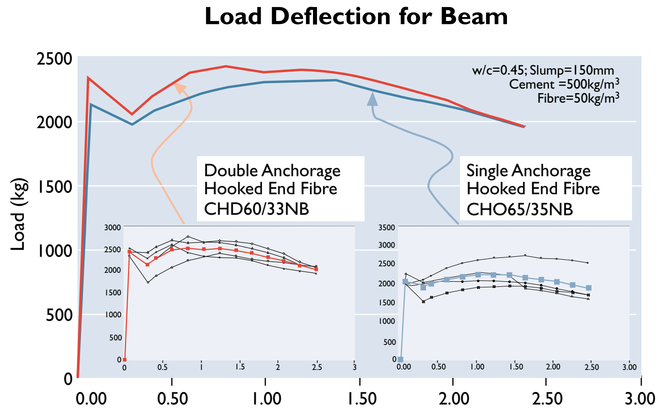


FIG 7(a).
Individual SFRC beam tests are variable (inset) hence, 5 samples are tested and the average result is used. This shows that double anchorage increase the performance of a 60 aspect ratio fibre to the same level as a 65 aspect ratio single anchorage fibre i.e. an 8% increase in performance.

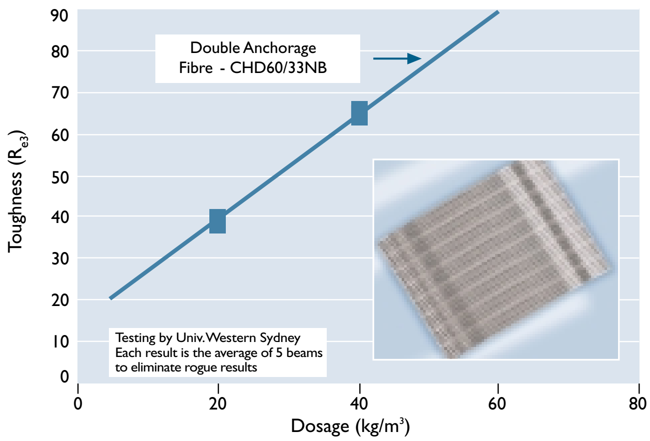


FIG 7(b).
From the same beam tests R_{e3} values are calculated and the results are used to show the performance vs dosage.

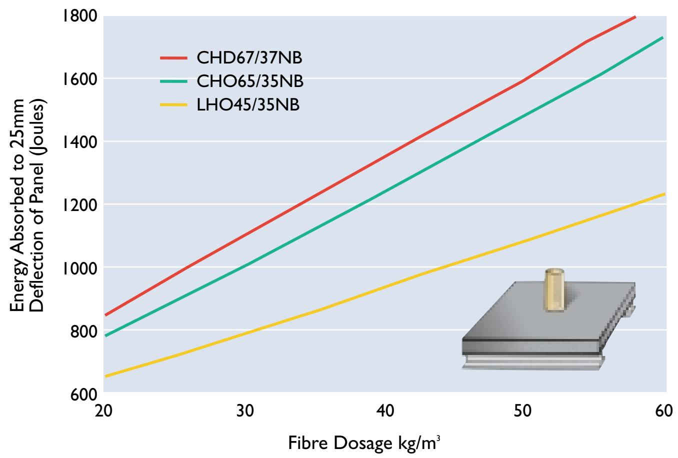


FIG 8.
The EFNARC punching/bending test was developed to simulate "in place" shotcrete. This graph gives approximate performance levels of various Scanfibres for 30-60MPa shotcrete. These values are a guide only. Data sheets on each fibre provide more detailed information but shotcrete panels should be made from the proposed project mix using the contract equipment and personnel to finally establish the toughness of the in place shotcrete.

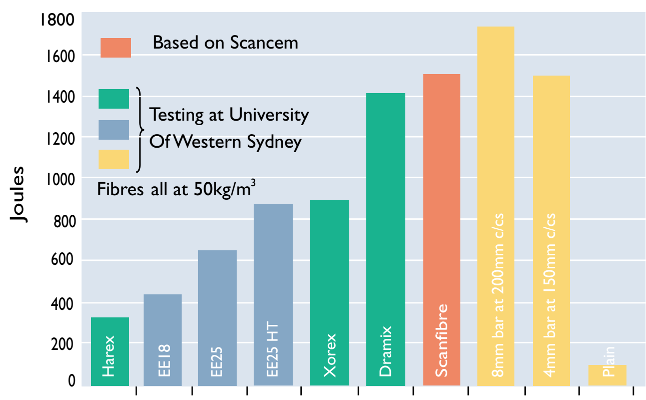


FIG 9.
Independent tests overseas and in Australia show that high performance fibres can out perform mesh and that low performance fibres, even at maximum dosage can't achieve the performance that is required in certain ground conditions (also see figure 10). Scanfibres often provide the necessary high performance to achieve the maximum toughness requirement of 1400 Joules at 50kg/m³.

Design

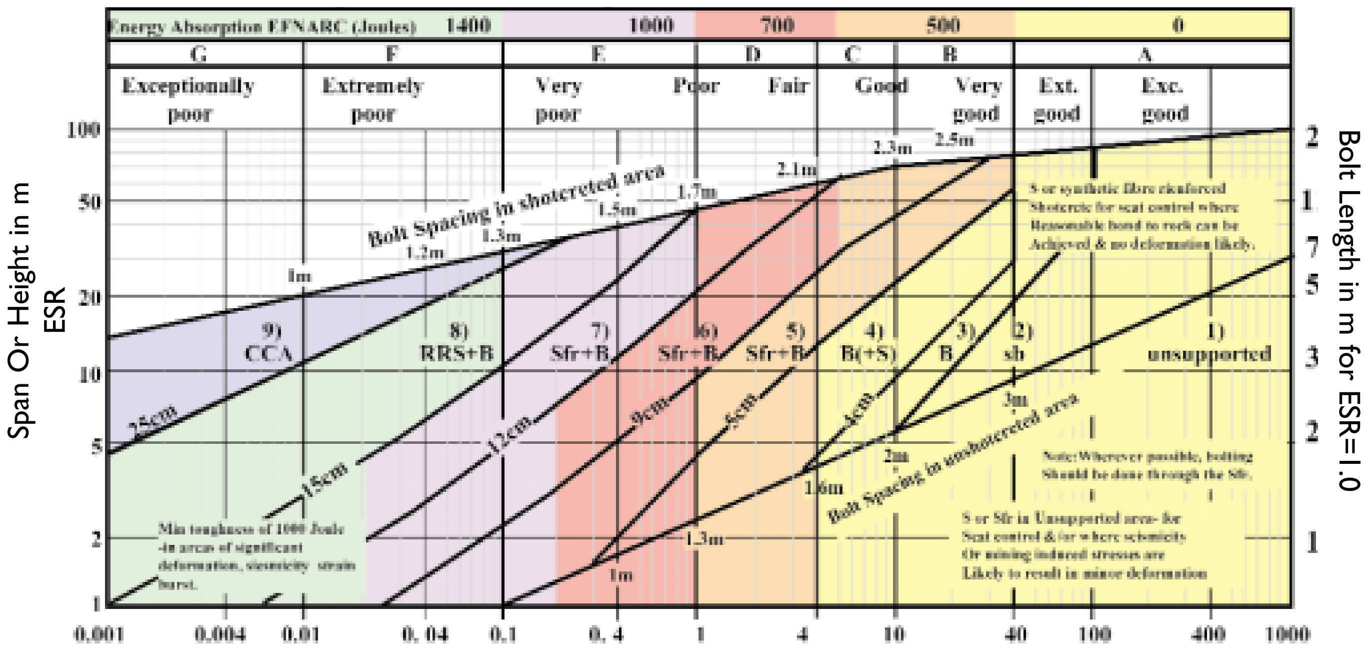
A major part of the Scanfibre guidelines for ground support selection (civil engineering and mining tunnels) is shown in fig 10 below. The overall method draws on:

- the NMT (Norwegian Method of Tunnelling)
- the NGI (Norwegian Geotechnical Institute) Q-System of rock mass classification and support
- published comment from Dr D. R. Morgan of Agra Earth & Environment Limited, Canada
- analysis of rock mass conditions and experiences with the use of SFRS from numerous underground projects.

The NMT design approach is based on allocating the ground a "Q" factor, which is then related to the required ground support. The problem with this is that there is no toughness (ie fibre performance) requirement indicated. The overriding recommendation is that there is a sufficient level of toughness in the SFRS to ensure a ductile failure mode rather than a brittle failure mode. By considering Morgan's guidelines for SFRS requirements which indicate the toughness applicable to different rock classes a performance based system is developed.

Rock Mass Classiffication

Ammended to provide for SFRS performance classification - (Scancem July 1999)



Rock mass quality $Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SFRF}$

Reinforcement Categories

1. Unsupported
2. Spot bolting, Sb
3. Systematic bolting, B
4. Systematic bolting (and unreinforced shotcrete, 4-10cm), B(+S)
5. Fibre reinforced shotcrete & bolting, 5-9cm, Sfr+B
6. Fibre reinforced shotcrete and bolting 9-12cm, Sfr+B
7. Fibre reinforced shotcrete and bolting 12-15cm, Sfr+B
8. Fibre reinforced shotcrete >15cm, Sfr, RRs+B (reinforced ribs of shotcrete & bolting, Sfr, RRs+B)
9. Cast concrete lining, CCA

FIG 10.
Design guideline for mining and civil engineering tunnels using modified Barton's Rock Mass Classification chart.

Compared to beam tests sprayed panel tests have demonstrated

- much greater repeatability and reliability,
- simple and representative construction
- two way spanning enabling moment redistribution (ie similar to shotcrete linings)

The toughness performance recommendations in fig 10 are interpreted for EFNARC panels based on Morgan's performance recommendations for beam tests and SFRS practices.

Appropriate Scanfibre dosage rates to achieve these plate test performance criteria can be determined from each fibres data sheet.

Modifications to this design approach are necessary in:-

- ground experiencing excessive movement
- areas of anticipated seismicity
- areas where strain burst may occour

In such areas a minimum energy absorption capacity of 1000 Joule should be used, preferably 1400 Joule.

Scanfibre SFRS

In order to reflect the known variability in fibre types and their performance it becomes mandatory that SFRS is specified in terms of a performance requirement. SFRS should never be specified by fibre dosage rate unless applied to a specific fibre type.

In addition to the general requirement for Scanfibre SFRS as detailed in the general Scanfibre brochure the specification shall include the following:

- The concrete shall include ... Kg/m^3 of Scanfibre type ... consistant with the dosage to achieve an absorbed energy not less than the requirement set out in Scancem's modified Rock Mass Classification guide, as determined by the energy absorption class (plate test) in accordance with EFNARC (1996) "European Specification for Sprayed Concrete".

Technical Support

Technical support related to most aspects of the use of shotcrete in construction is available. This support takes the form of:-

1 Liaison with the owner, consultant, engineer and or contractor to develop a cost effective and technically appropriate High Performance shotcrete solution that invariably offers advantages to all parties, 'the win, win, win approach'

2 Presentation to interested parties on shotcrete performance evaluation and mix options, report preparation that details the latest methods and assumptions used for any analysis. Published papers and output from computer models are also available.

3 Guidance on the placing of Scanfibre shotcrete to provide optimum performance and economy.

Suggested Reading

1 Papworth F "Design of Steel Fibre Reinforced Concrete Slabs on Ground and Shotcrete Linings" The New Zealand Concrete Society, Making Innovations Happen n Conference, October 1996 Taupo, New Zealand.

2 R.Ratcliffe; "The important properties of steel fibre reinforced shotcrete (SFRS) used in mining" Rock support and reinforcement pratice in mining conference. Kalgoorlie. March 1999.

3 Zeptner M "Concrete and Mining in the Eastern Goldfields" March 1996, Kalgoorlie.

4 "European Specification for Sprayed Concrete" EFNARC, 1996.

5 An Introduction to Shotcrete Technology, Shotcrete Seminar, Wood D, March 1997, Sydney.

6 "Toughness Testing of Fibre Reinforced Shotcrete", Sintef Structures and Concrete. Skjolsvold O, Hammer TA. Norway.

7 "Toughness of Fibre Reinforced Shotcrete" Morgan D, Chen L, Beaupre D.

8 Banthia N "Influence of Fibre Geometry in Steel Fibre Reinforced Wet-Mix Shotcrete" Concrete International. American Concrete Institute. June 94.

9 Struther, M and Keogh, J., Performance of Mesh and Fibre Reinforced Shotcrete Under High Ground Pressures, Shotcrete, Techniques, Procedures and Mining Applications, Kalgoorlie, Western Australia, October, 1996, pp.10.

10 Ripley, B.D., Rapp, P.A. and Morgan, D.R., Shotcrete Design, Construction and Quality Assurance for the Stave Falls Tunnels, Canadian Tunnelling, 1998, pp 141 - 156.

11 Morgan, D.R. and Parker, P.L., Applications of Fibre Reinforced Shotcrete in North America, Fibre Reinforced Concrete, Present and Future, Editors, N. Banthia, A.Bentur and A. Mufti. Published by the Canadian Society for Civil Engineering, October, 1998, pp.109-127.