Spraying the Surface or Just Scratching the Surface — What Are the Real Benefits of In-Cycle Fibrecrete

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ABSTRACT

Through the use of structural analysis programs such as Unwedge and considering the shear strength of applied fibrecrete it can be shown that fibrecrete can provide a higher factor of safety in a 'typical' underground development excavation than standard rock bolts.

This paper describes the progression of ground support from an 'as required' component of mining to the use of bolts and surface support as a mandatory requirement. With the mandatory requirement for surface support, fibrecrete has been considered and applied as a secondary feature but simple analysis and practical observations indicate that it may be considered as primary support. The key elements to its implementation are:

1. When is it safe to work under fresh fibrecrete and how do we practically determine this?
2. How much ground support does fibrecrete provide?
3. How can we reduce the cost of fibrecrete?

An examination of these questions indicates fibrecrete can be much safer, less expensive and quicker to install than normal ground support elements. This paper explores practical examples from sites where significant benefits have been achieved by mine operators.

CURRENT DEVELOPMENT CYCLES

Development cycles and ground support requirements have evolved over many years into today's current status of mandatory bolting and surface support. Increased levels of ground support have largely been driven by the requirement that any rockfall and possible injury resulting from such a rockfall, is unacceptable. In many Australian underground mines in the mid-late seventies, although the premise that any rockfall and possible injury was unacceptable, rock bolting was *not* the norm. Rockbolting standards slowly changed and by the early 1990s the Australian industry, by and large, adopted the operational premise that no one should work under non-supported ground. Non-supported ground was interpreted as ground that had not been rockbolted or cable bolted. Self-supporting ground with minimal structure, good rock quality and free from deleterious effects of stress were ignored under this 'blanket rock bolt' approach. That is to say, such ground was usually rockbolted whether it needed it or not.

A progression from the requirement to bolt all headings to the additional requirement to install surface support began in the mid to late 1990s in WA. At this time the WA regulating authorities made it mandatory to provide surface support for headings over 3.5 m in height, (MOSHAB, 1999), or to undertake a geotechnical risk assessment to prove such a support was not warranted.

At the outset, it would seem that there was an intention to force mine operators to undertake surface support, however, personal communication with various senior WA regulating staff, (Torlach, 2000), indicated that a geotechnical risk assessment was the mandatory element of the guideline. If mining companies were not prepared to undertake such a risk assessment then the surface support requirement was the 'fall back' requirement.

At present the WA code of practice, by and large, has been adopted throughout Australia. Mining organisations in many instances have found it simpler to add surface support for any new development rather than undertake the risk assessment approach that cannot be definitive. The risk assessment approach is open to interpretation whilst the provision of a surface support is a firm, undeniable barrier, although the installation of mesh using jumbos has it own inherent risks.

From the time the WA code of practice was adopted, the simplest approach was to provide surface support by way of some form of mesh. Meshing did not require the purchase of extra capital equipment or the employment of skilled operators separate to existing mine staff.

The installation of mesh has been occurring in addition to 'normal' rock bolts with the addition of shorter stubby bolts used to 'pin' mesh to the backs. The density of 'normal bolts' has in the majority of cases also increased to match the size of mesh sheets. The overall density of bolts has therefore risen dramatically. The author has witnessed up to twelve bolts per metre at some mines. In most cases, even with a lower bolting density, a large number of the bolts are required for mesh installation as opposed to supporting the rock.

DESIGN OF BOLTING PATTERNS

Much has been written about the ground support using rock bolts. The usual design methodology for a non stressed environment, ie where gravity alone is the expected driver for failure, is to consider rock quality or structural conditions.

Rock quality

This is described in Hoek, Kaiser and Bawden (1995). In summary, a designation of rock quality, Q, is determined by estimating a variety of factors, RQD, number of joints, joint roughness, etc. Using empirical charts similar to those developed by Barton and Grimstad, (1993), this quality factor is compared with span openings and once plotted onto the empirical charts an estimate of bolt spacing and length can be determined.

Structural method

The structural analysis method is one by which an analysis of specific structures is undertaken. The use of modern analytical programs such as Rocscience's Unwedge, (1993 - 2004), provides a correlation between 'wedge' weight and support capacity. This correlation, or factor of safety (FoS), enables a variety of support scenarios to be considered. Typical input parameters are the dip and bearing of structures and the overall orientation of the mine excavation. Unwedge determines the largest 'wedge' than can form in the excavation and the user places patterned or individual support to support the postulated wedge.

In the current version of Unwedge (version 3.04), fibrecrete can be 'placed' on to the perimeter of the excavation covering the area where any apparent wedges may 'daylight' in the excavation. Unwedge calculates the FoS using the premise that a wedge or block, acting under the force of gravity alone, needs to shear through the fibrecrete around its perimeter to fail. Thus, to undertake a design, knowledge of fibrecrete's shear strength is fundamental and it is presumed that the fibrecrete is 'completely' bonded to the rock. Whilst the latter is not always the case, if an adhesive strength is known and the area over which a wedge can de-bond can be presumed, this data can be used to undertake an analysis of wedge support.

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This paper describes the use of fibre reinforced shotcrete, ie fibrecrete. This material is applied using a shotcreter. In the some of the quoted references the author has not specified the difference and in terms of application techniques the difference is immaterial.

Examples of such analyses

Example 1 – Bolts

In this case, a wedge of approximately 16 t in a 5 m wide drive is supported by 2.4 m friction stabilisers at a 1.0 m × 1.0 m pattern, as can be seen in Figure 1. The friction stabilisers are presumed to have a pull out strength of 6 t/m of embedment and a tensile strength of 18 t.

The FoS is a 1.6.

In this case there is a requirement to place a total of 10 bolts/m to accommodate any wall wedges. If the backs are analysed in isolation, 6 bolts/m are required to support this wedge.

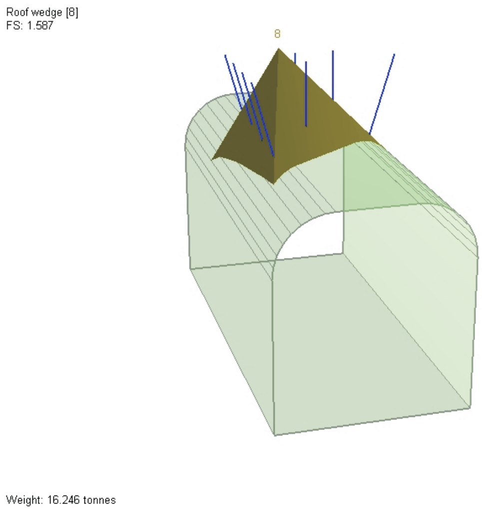

FIG 1 - Standard bolting pattern.

Example 2 – Fibrecrete

In this case the wedge that has been considered in the previous example is supported using fibrecrete in isolation. If 50 mm thick fibrecrete, with a shear strength of 1 MPa, is analysed as a replacement for the bolts in Example 1, the FoS is 3.6, ie an increase of over 100 per cent. To achieve the same FoS as Example 1, the shear strength of the fibrecrete need only be approximately 0.45 MPa. A graphical representation of this wedge and support can be seen in Figure 2.

Example 3 – Thicker fibrecrete

If a 75 mm thick application of fibrecrete is applied to the same wedge as discussed in the previous two examples, the shear strength need only be 0.3 MPa to achieve a FoS of 1.6.

Example 4 – Smaller back wedge

If a wedge with an apex height of approximately 0.35 m is considered with a layer of 50 mm thick, 0.3 MPa shear strength fibrecrete, the FoS is 73. This latter example, as shown in Figure 3, more closely resembles the conditions of friable rock where fibrecrete provides support for each individual particle.

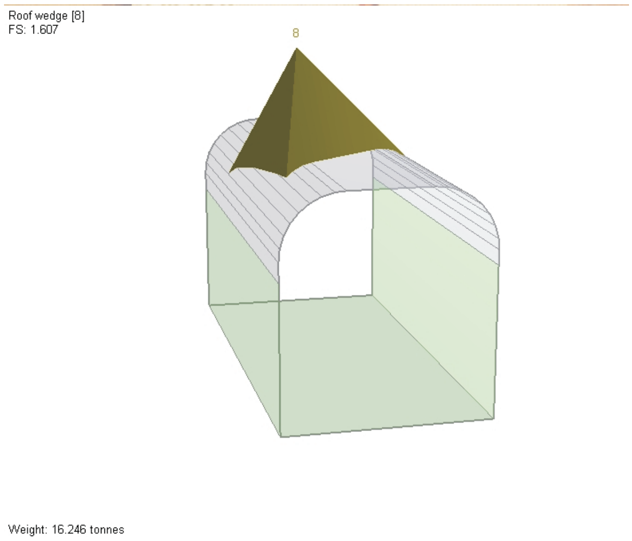

FIG 2 - Standard fibrecrete pattern.

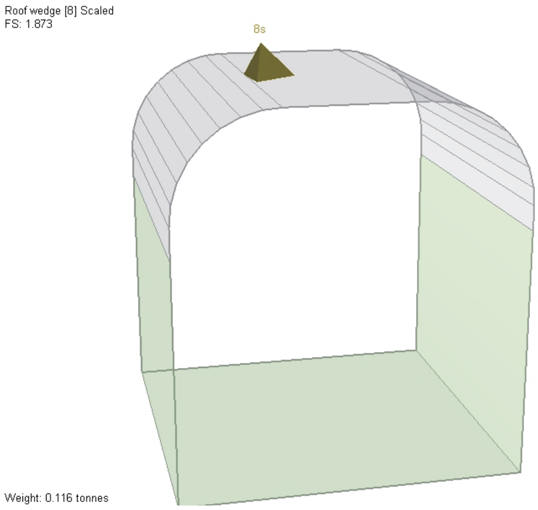

FIG 3 - Fibrecrete with small wedge.

In this example, rock bolts applied in a pattern may not hold the rock therefore some surface support is required. If similar particles can together create a large wedge then the analysis for the largest wedge may approximate the analysis undertaken in Example 1.

Note: All the above scenarios presume:

- that there is a natural cohesion factor of 10 t/m^2;
- stress does not deform the opening and the fibrecrete;
- the wedge does not rotate and overload the fibrecrete on any one of its perimeter edges; and
- that the fibrecrete is firmly fixed, or adheres, to the rock surface.

FIBRECRETE BENEFITS

In the previous examples, other support benefits of fibrecrete are important to note.

- The fibrecrete shear strength increases with time. The preceding discussions relate to fibrecrete with relatively low shear strength; however, if a shear strength of 2 MPa is used, in the case in Example 2, the FoS is 7. This matches the author's field observations in unstressed ground where fibrecrete support performs well.

- Generally, any failure of fibrecrete is slow and obvious. This benefit is often underestimated but is extremely important for mine operators. The ability to differentiate minor ground movement from the surrounding rock mass is practically impossible with other forms of ground support. Whilst it may be the case that on occasion there are some indications of rock movement, it is often the case that operators have difficulty in poor ground determining where the most, or specifically most significant, movement occurs. The inherent danger of unpredicted rock falls is obvious and a mechanism that provides an early warning system is extremely valuable.
- Fibrecrete is in contact with every rock in friable ground situations thus providing a support that gives the greatest protection against ground relaxation.

What does this mean for mine operators?

The calculations shown above replicate examples where the use of fibrecrete can enable a reduction in rock bolt density.

Using the Unwedge analyses above, fibrecrete can support the rock mass without rockbolts; however, most mine operators are naturally cautious of this and therefore will need strong practical evidence to prove that this is the case.

Boltless shotcrete is not new and Espley, Malek and O'Donnell (2001), reported on its use at Inco's Stobie mine in Canada in the mid 1990s. They report success with this method in a variety of developments and stoping applications. They nominate a re-entry time of 12 hours but do not discuss as to how this was arrived. Dimmock, Rispin and Knight (2003) report a re-entry time of four and eventually two hours for re-entry in North America. They also discuss a continuous mining process, ie no waiting between blasting shotcreting and mucking at the following sites:

- Tara, Ireland,
- Galmay, Ireland,
- Lisheen, Ireland, and
- Daw Mill Coal Colliery, England.

They also state that mines in Finland follow the same approach, ie no waiting between construction sequences and they provide typical shotcrete mixes used in Irish mines.

Espley (2003) provides further information in relation to re-entry times stating re-entry times used in the Inco examples were based on time-strength data.

The dilemma for Australian mine operators using fibrecrete is: when is it safe to work under fibrecrete?

There are numerous studies that deal with the strength and toughness of fibrecrete; however, if in an analysis, shear is used as the controlling failure mode, as is the case in Unwedge and Espley, Malek and O'Donnell (2001), information about the shear, and adhesive strength of 'green' fibrecrete should be sought.

The author has undertaken investigations into the information available on the shear strength of 'green' fibrecrete but has not found any practical information on this subject. The information that has been discovered is based on the shear strength of fully cured fibrecrete and concrete. Bernard and Nyström (2000) and Bernard and Curnow (1999) undertook punching tests on cured fibrecrete. Their papers describe a testing frame that could be used to determine shear strength of 'green' fibrecrete. The testing frame pulls a fibrecreted plate away from a rock wall. Adhesive strengths are reasonably well documented however if the fibrecrete adheres to the rock then the next 'weakest link' in relation to a rockfall is obviously the ability of the fibrecrete to prevent a rock punching through it, ie the shear strength of fibrecrete. Ideally research using such a frame or something similar, to enable some correlation to a point index test should be undertaken. The desired end result would be a simple test undertaken on site that provides an index value referenced against shear strengths. This in turn could be used in conjunction with the Unwedge program to determine the safe time at which personnel could work under the fibrecrete.

Unwedge can be used to some degree, to evaluate fibrecrete adhesive strength. If an adhesive strength is known and the width of the area over which the fibrecrete is expected to de-bond, then this can used to analyse wedge failure. The difficulty in this type of analysis is how an estimate of the de-bonded area is derived and the author is only aware of experience as a guide.

There is an obvious unique characteristic of fibrecrete that is sometimes overlooked when undertaking a fibrecrete support design. Once it has been determined that the strength of the fibrecrete is acceptable for personnel access then, because fibrecrete shear strength increases with time, the probability of safe access in most cases, only increases.

It is worth noting that the correct curing of fibrecrete is fundamentally important in improving its unconfined compressive strength (UCS) and shear strength. Correct curing can be enhanced by chemical additives however, simple methods exist to assist the curing process. Melbye and Dimmock (2001) describe the use of curing agents in some detail however, the 'wetting' and re-wetting of fibrecrete after spraying assists the curing process. The removal of ventilation also assists but this may only be possible if multiple development headings are available and attention is paid to any build up of ammonia gas due to the use of ANFO as a blasting agent. Regular wetting of fibrecrete however will go a long way to achieving optimised strength and shear properties.

COSTS

Mesh and bolts

Standard

An example has been taken from a WA mine where bolting and meshing is conducted. In this example meshing is conducted as close to the face as possible and approximately 2 m down each wall. To connect the mesh from one round to the next, 0.9 m long, 39 mm diameter, 'stubby', bolts are used. A plan view and section view can be seen in Figures 4 and 5 respectively.

The cost for this mesh/bolt support can be seen in Table 1.

The excessive number of bolts and plates are used to tie the mesh together. The determining factor in relation to the number of bolts is the size and shape of the mesh sheets, ie how they overlap and how they are pinned together. If mesh was not required in the above example the number of bolts would be greatly reduced. The author has witnessed many examples where good ground has been bolted simply so that mesh can be installed.

The cost of various ground support options vary with type of support and opening size and importantly the time it takes to perform the task, ie total jumbo and operator time. For a nominal 5 m × 5 m drive with meshing 2 m down each wall and moderate rockbolting, an approximate cost of \$495/m of advance is expected. Given the area of backs and walls are 5 m + 2 m +2 m = 9 m, per metre advance, this is approximately \$55/m^2.

Bolt only

If only bolting was required in the example shown in Table 1, Table 2 indicates the costs involved. Note: The bolt spacing has not been increased compared to Table 1, the bolts required to pin the mesh have been removed.

Given the area of backs and walls are 5 m + 2 m +2 m = 9 m, per metre advance, this is approximately $26/m^2. Therefore the meshing component is approximately: $55 - 26/m^2 = $29/m^2.

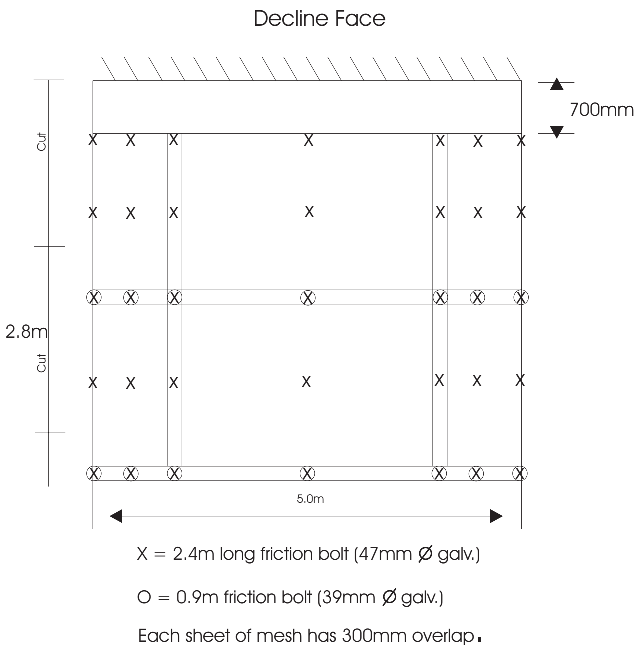

FIG 4 - Standard rockbolting and meshing pattern (plan view).

Reduced bolting

A scenario whereby bolting is further reduced is shown in Table 3. In this case the surface support is not considered in the costing exercise; however, it is assumed that fibrecrete is the preferred support option and bolting of backs and walls can therefore be reduced appropriately; ie three bolts in the backs and none in the walls:

- Given the area of backs and walls are 5 m + 2 m +2 m = 9 m, per metre advance, this is approximately $11/m^2.

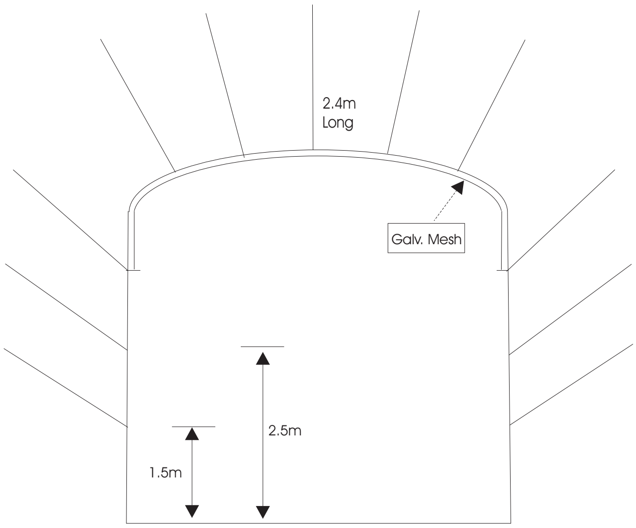

FIG 5 - Standard rockbolting and meshing pattern (section view).

TABLE 1

Ground support costs, bolt and mesh/2.8 m round.

Item	Specification	Unit cost estimates	No.	No. incl wastage	Cost $
Mesh	4 × 2.4 m × 3.0 sheets + 10% wastage	42	3	3.3	138
Back bolts	2.4 m long, 47 m dia, friction stabilisers. Gal + 10% wastage	13	10	11	143
Wall bolts	2.4 m long, 47 mm dia, friction stabilisers. Gal + 10% wastage	13	8	8.8	114
Stubby bolts	0.9 m long, 39 mm dia, friction stabilisers. Gal + 10% wastage	5	9	9.9	50
Washer and plates	Butterfly plate and washer. Gal + 10% wastage	4.20	27	29.7	125
Drill consumables	3.0 m per 45 mm diam bolt hole	2.00	18	19.8	40
Eg Jumbo + labour and on costs	Twin boom, jumbo and operator	310/hr	2.5		775
					Total approximately $1385
					Cost/2.8 m advance, approximately $495/m

TABLE 2

Ground support costs, bolt only/2.8 m round.

Item	Specification	Unit cost estimates	No.	No. incl wastage	Cost $
Mesh		42			
Back bolts	2.4 m long, 47 m dia, friction stabilisers. Gal + 10% wastage	13	8	8.8	114
Wall bolts	2.4 m long, 47 mm dia, friction stabilisers. Gal + 10% wastage	13	8	8.8	114
Washer and plates	Butterfly plate and washer. Gal + 10% wastage	4.20	16	17.6	74
Drill consumables	3.0 m per 45 mm diam bolt hole	2.00	16	17.6	35
Eg Jumbo + labour and on costs	Twin boom, jumbo and operator	310/hr	1		310
					Total approximately $647
					Cost/2.8 m advance, approximately $231/m

TABLE 3

Ground support costs, reduction in bolts in the wall and backs/2.8 m round.

Item	Specification	Unit cost estimates	No.	No. incl wastage	Cost $
Mesh		42	0	0	0
Back bolts	2.4 m long, 47 m dia, friction stabilisers. Gal + 10% wastage	13	6	6.6	86
Wall bolts	2.4 m long, 47 mm dia, friction stabilisers. Gal + 10% wastage	13	0	0	0
Washer and plates	Butterfly plate and washer. Gal + 10% wastage	4.20	6	6.6	28
Drill consumables	3.0 m per 45 mm diam bolt hole	2.00	6	6.6	13
Eg Jumbo + labour and on costs	Twin boom, jumbo and operator	310/hr	0.5		155
					Total approximately $282
					Cost/2.8 m advance, approximately $101/m

Note: An analysis of wall support has been undertaken using Unwedge. The example as previously discussed has been used with specific reference to wall wedges. They are shown in Figure 6. The upper part of the wedges have been analysed with a covering of 50 mm of fibrecrete and no other form of support, ie bolts, have been used.

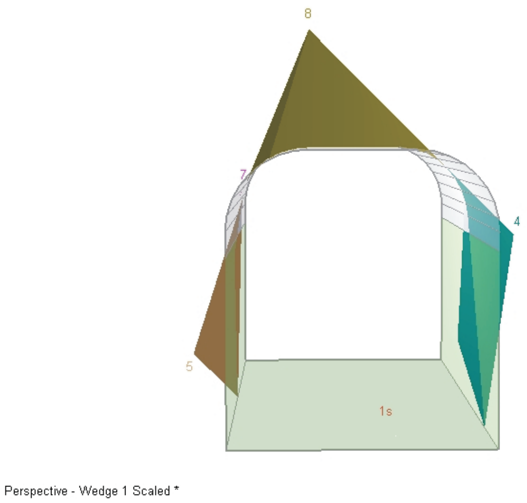

FIG 6 - Back and wall wedges.

The factors of safety are:

Left wedge 14

Right wedge 10

If bolts without fibrecrete are used in this example, (two wall bolts, each wall), the factors of safety are:

Left wedge 13

Right wedge 10

These high factors of safety reflect the relatively low driving forces on these wedges, ie the wedges are not in the backs and therefore the resultant effects of gravity are low and consequently the 'demand' on the support is low.

It is interesting to note that in all of the above examples the largest component of these costs is the cost of the jumbo and operator and poor ground the number of bolts and the time taken to install each bolt, increases significantly. The author has witnessed may examples where it has taken in excess of eight hours to bolt and mesh one heading. Without increasing the bolt density, using the data provided shown in Table 1, the cost of bolting/meshing for eight hours would be approximately $1100/m.

It is possible to reduce bolting meshing costs by:

1. reducing the cost of the operator,
2. taking less time to bolt, or
3. reducing the cost of the jumbo.

Taking each point in turn:

- The first is unrealistic given today's demand upon experience operators.
- It is possible to reduce the time taken to bolt removing the complication of meshing.
- *If* it is possible to remove both meshing and bolting, the operating cost of a jumbo will be reduced by a consequential lowering of jumbo maintenance and drill string costs. A task that is now performed by jumbo, 'rattling the backs' or machine scaling, increases jumbo maintenance and drill consumable costs. Whilst this paper makes no attempt to quantify this cost, drilling equipment suppliers and maintenance personnel at operating mines are extremely critical of this use of jumbos.

A valid requirement to remove personnel from the hazards at the face has meant that jumbo scaling has increased to be the norm rather than the exception. A mining system such as water scaling, that reduces or eliminates jumbo scaling has great cost and safety benefits. Water or hydraulic scaling incorporated onto the shotcreter boom blasts the 'loosest' material away from the face and importantly cleans the rock face. The author's experience with water scaling is that it does not provide enough scaling to allow personnel to work under the ground at a non supported face, however when coupled with the fibrecreting there are great benefits of water scaling, ie:

- Elimination of personnel to unscaled rock face.
- Removal of loose material.
- Cleaning of rock face that in turn improves fibrecrete adhesion strength.
- Reduction of damage to jumbo and rock drill string resulting in lower maintenance costs.
- After water scaling any rocks that cannot be 'scaled' are fibrecreted into place so that movement cannot occur. If a rock cannot be displaced by scaling the fibrecrete will effectively hold it in place and it becomes part of the rock mass.

Referring to the previous Unwedge examples, ie examples one, two and three, a typical rock scaled from a development drive is considered, ie a rock with an apex height of 0.5 m and a weight of 116 kg. When this rock is sprayed with 50 mm of fibrecrete, with a shear strength of 0.45 MPa, an Unwedge analysis indicates a FoS of in excess of 30. Further investigation using the Unwedge program indicates that such a rock will have a FoS of 1.6 if the shear strength of the fibrecrete is as low as 0.025 MPa. This again indicates why fibrecrete works so well as ground support especially when the loose material is relatively small.

It is also worth noting that the time taken to fibrecrete poor ground does not increase in any where near the same proportion as when bolting/meshing poor ground. In some cases the time taken to fibrecrete poor ground compared to good ground, does not increase at all.

Fibrecrete costs

Operating

The cost of fibrecrete can vary significantly however, it is the author's experience that 50 mm thick fibre reinforced fibrecrete, supplied and installed by third parties can cost from $45/m^2 to $80/m^2.

The cost of owner operator fibrecreting can be significantly less than this:

Tables 4 and 5 show an indicative cost structure for the material, labour, maintenance and capital depreciation components of owner operator fibre reinforced fibrecrete derived from costs experienced at the Woodlawn Mine in 1998 and updated to reflect some current changes in component costs.

TABLE 4

Fibrecrete material costs.

	Amount per m^3	$/Unit	$/m^3
10 mm rock (kg)	600	0.019	11.40
Sand (kg)	1100	0.014	15.40
Cement (kg)	360	0.181	65.16
Silica fume (kg)	40	0.650	26.00
Pozzolith (kg)	1.4	1.000	1.40
Delvo stabiliser (L)	2	3.180	6.36
Steel fibre(kg)	40	1.800	72.00
Activator (L)	10	4.200	42.00
		Sub total	239
Using wastage @ 50% 239 × 1.5 = 359			359

Note: The 'wastage' factor is an allowance to accommodate, over-spray, variation in fibrecrete thickness, rebound and general wastage.

TABLE 5

Labour and equipment costs.

Labour and equipment		$/m^3
2 men × 4 hr @ $45.5/hr spraying 5 m^3		72.80
Depreciation/Op hr		25.14
Fuel, oil and maintenance	$15/operating hour	12
Sub total		109.94
Total - material, labour and equipment		469

The total of the above equates to $23.5/m^2 or $211/m for 50 mm thick fibrecrete.

Cost comparison

With a reduced bolting pattern, ie as described in Table 3, the support cost would be:

Reduced bolting pattern	$101/m
Fibrecrete	$211/m
Total	$312/m

This is a cost reduction of approximately $200/m compared to the standard, $495/m, bolting pattern shown in Table 1.

If bolts can be totally removed from the process the and the lower cost of fibrecrete can be employed the total cost for ground support would be simply be $211/m a reduction of approximately $300/m compared to the standard bolting pattern shown in Table 1.

Presuming a development budget of approximately 5000 m/year and reduction in support costs of $300/m, the saving would be in excess of $1.5 million per annum.

In Table 6 an operating cost summary is shown for the various support scenarios mentioned above.

TABLE 6

Operating cost summary.

Support component	A$/m
Bolts and mesh	495
Bolts (no surface support)	231
Reduced bolting pattern and fibrecrete	312
Fibrecrete only	211

Capital costs

The capital costs of a fibrecreting system usually include the cost to:

- batch,
- transport, and
- spray.

Capital costs of fibrecreting systems are often considered to be prohibitive and when 'written off' in fibrecreting unit rates, can increases these rates significantly. Capital costs can be however, dramatically lowered by using second-hand mining equipment intelligently modified with a clear understanding of fibrecreting requirements and fibrecreting capabilities. Previous papers (Davison, 1995; Davison and Fuller, 1998) have described the capital costs of shotcreter constructed for the Woodlawn operation in NSW. At the time, the total cost for a new commercially built fibrecreting system (shotcreter, truck and batching plant) was approximately $750 000. At Woodlawn a refurbished jumbo and agitator reduced this to approximately $220 000.

The author has been involved in another project for Lightning Nickel at Long Shaft near Kambalda in WA. The capital cost of new equipment seemed prohibitive so an Atlas Copco 282 jumbo and a Normet NT 120 mine dump truck were used as carriers for a shotcreter and small purpose built agitator truck. These are shown in Figures 7 and 8 respectively.

The capital cost was approximately:

Shotcreter	$150 000
Agitator	$125 000

This provided Lightning Nickel an inexpensive manner to convey and spray fibrecrete. At the time of writing, Lightning Nickel were purchasing fibrecrete from a third party; however, plans are in place to batch their own fibrecrete on site. Theses are significantly advanced with a completion date expected to be approximately November 2004.

FIG 7 - Lightning Nickel shotcreter. Atlas Copco 282 carrier.

FIG 8 - Lightning Nickel agitator, Normet NT120 carrier.

Other than the lower capital cost the advantages of building a 'site specific' shotcreter or agitator are numerous:

- They can be built on carriers that match the existing fleet, eg Atlas Copco or Tamrock carriers.
- Boom lengths can match the specific application. In some instances the length of boom is more important than the height at which fibrecrete can be sprayed, as a long boom is required so that fibrecreter can be sprayed beyond a recently fired muck pile.
- Hyrdro-scaling pumps and nozzles can easily be integrated into the shotcreter design.
- Specific operational problems can be remedied before manufacture, eg some proprietary shotcreters are primarily designed for flat tunnelling. When using these models on declines the activator solution pick up pipe remains dry as the solution moves to the front of the tank at low tank levels.
- Operators can input their requirements into the design of the machine thus creating a real sense of operator ownership.
- When basing the shotcreter on a jumbo carrier, the shotcreter will be able to access all development areas as these have been excavated using the jumbo, eg some proprietary shotcreters are built on small 'bobcat' like carriers that do not tram well and suffer greater stability problems in steep declines compared to jumbos.
- Agitator trucks can be designed to match the underground openings. Commercially available low profile agitator trucks are rare and those that exist can best be described as concrete transporters. Some do not have the traditional reverse corkscrew discharge that is common on surface agitators.

IN-CYCLE FIBRECRETE

Some operations have made inroads into 'in-cycle' fibrecreting with great success. The preceding parts of this paper indicate the operational improvements that the implementation of in-cycle fibrecrete has to offer. The major advantage is that the time spent bolting and meshing can be reduced and expensive drilling equipment such as jumbos can be allocated, where possible, to other development faces. The jumbo can also then perform the tasks that they were designed to do, ie bore horizontal holes. The significance of the potential time savings is considerable as is the potential to increase advancement rates. It is the case in the majority of mining operations that jumbo development rates, by and large, are the controlling factor over mine production. The quicker an orebody can be accessed, the sooner cash flows can be secured. Since the introduction of surface support using mesh, jumbos have spent more time at the face and development rates have slowed. Jumbo manufacturers are developing more powerful drills, however the potential to fully utilise their performance benefits is absorbed by ancillary activities such as meshing.

In order to achieve enough time to allow sufficient strength and specifically shear strength, to develop in fibrecrete, a proposed fibrecrete cycle is shown in Figure 9.

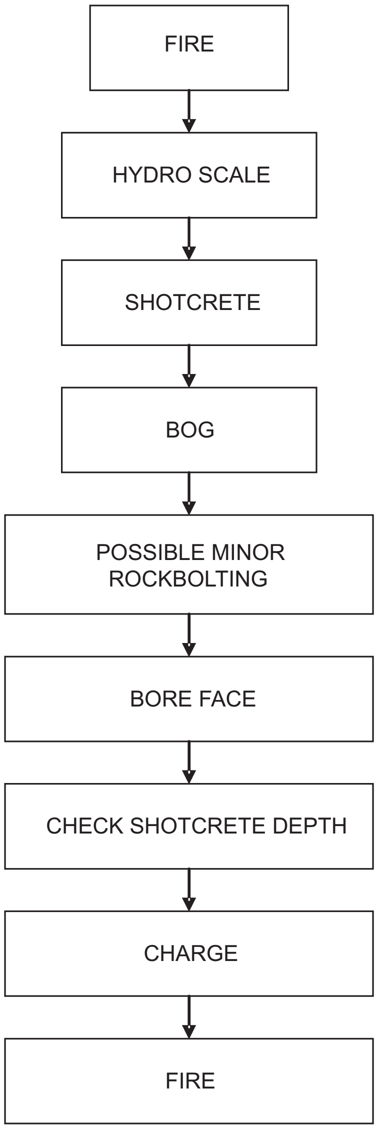

FIG 9 - A proposed fibrecrete cycle.

Tackling some of the issues with each job item:

- **Fire** – The firing process requires attention to ensure that a free space of approximately 2 m exists at the face after firing.

FIG 10 - Purpose built Woodlawn shotcreter 1995.

- **Hydro-scale** – Hydroscaling offers great benefits to mine personnel and reductions in mine maintenance costs. The hydroscaling nozzle and associated attachments need to be designed so that they can fit into the available free space at the face.
- **Fibrecreting** – Similarly to hydroscaling, the fibrecrete nozzle needs to be relatively compact. The boom of the shotcreter preferably needs to be telescopic with an extensive reach enabling it to extend beyond blasted rock. Figure 10 shows a shotcreter purpose built for Woodlawn mines in 1994. It had a shotcrete nozzle reach of approximately ten metres. The photos show the boom in its retracted position. The overall length as shown is similar to similarly sized jumbos. The front of the shotcreter could be modified by the installation of a grader blade. This would enable the shotcreter to clear a path through small fly-rock so that the shotcrete nozzle can more easily reach a blasted face.
- **Bogging** – When using a large bogger, eg CAT 1700, 2900 or similar, the front of the operator station is approximately 6 m behind the tip of the bucket and therefore an operator in the cab will always be 3 m away from a 3 m blasted face.

  The time spent bogging the face, say 1.5 hours, is time that the fibrecrete can progressively gain strength. An operator can also water down the fibrecrete whilst performing the same task on the muck pile thus providing optimum conditions for the curing of fibrecrete.
- **Preliminary bolting** (if necessary) – If minor bolting is required this can be done without the need for an operator to move beyond the cab of the jumbo if fold back feeds are used. The bolting procedure is less complicated than the bolt/mesh procedure and therefore there is little if any requirement for personnel to work under the newly supported ground.

  The time spent bolting is additional time for the curing of fibrecrete and also an opportunity to water it down providing good curing environment.
- **Face boring** – It is at this point that personnel are first required to work 'at the face'. At this point approximately two to three hours will have passed after the completion of fibrecreting at the face. Before any work at the face, ie under the newly fibrecreted ground, can begin, random short (no greater than approximately 75 mm) vertical probe holes can be undertaken by drilling with specially marked jumbo bits to determine average fibrecrete depth. If a marked discrepancy is apparent the fibrecrete should be re-applied before any further work is undertaken.

  As previously discussed no specific information is available on the shear strength of fibrecrete that is two hours old, however index tests of unconfined compressive strength are available and can guide operators.

  The understanding of the shear strength of 'green' fibrecrete is a missing link that needs attention.

  The boring of the face may take two hours.
- **Charge up** – A further simple system to confirm the fibrecrete depth is to use a portable hand held electric drill to probe the fibrecrete depth before charging up begins. If discrepancies are apparent the area can be marked and fibrecrete re-applied during the next cycle.

CONCLUSIONS

The significant benefits of in-cycle fibrecreting are slowly being understood by some Australian mine operators. At present the relatively minor use of this product means that the Australian mining industry is just beginning to 'scratch the surface' of understanding how it works and its potential to provide a safer and more efficient development support. There is however a great amount of justifiable caution being exercised by mine operators in its implementation because of a lack of information in relation to the early strength of fibrecrete material.

The information on the mid to late strength of fibrecrete is widely available and operators are using this as the basis for long-term designs. The attainment and use of early strength fibrecrete data will enable the confident use of fibrecrete as an overall support mechanism, if at first supplemented by the use of rockbolts, as opposed to just a surface support mechanism. With and understanding of how fibrecrete provides support and confidence in its early shear strength, mine operators will eventually increase its use in development.

Greater use of fibrecrete will provide:

- a safer work environment where personnel are removed from unsupported ground;
- excavations where unpredicted rockfalls are non existent;
- less expensive support systems resulting in a significant reduction in the cost per metre for mine development;
- reduction in jumbo maintenance and drill consumable costs; and
- improvement in development advance rates.

The importance of these improvements and savings should not be underestimated as there is the potential to significantly optimise the mine development rates and costs

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