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Optimising fibrecrete for deep shaft support: lessons from the Wira Shaft sink

Rachael Coad [a,*], Gavin Chadbourn [b], Christopher Hill [c], Daniel Lagacé [d]

[a] *pitt&sherry, Australia*

[b] *Optima Asset Advisory, Australia*

[c] *Byrnecut, Australia*

[d] *BHP, Australia*

Abstract

In shaft construction, achieving rapid and reliable ground support is critical to safety and productivity. This paper presents the development and implementation of a high-performance fibrecrete mix tailored for use as the primary temporary ground support element in the Wira Shaft at Prominent Hill Mine, South Australia. Engineered for early strength gain and optimised for slickline delivery, the mix incorporated high cement content, steel fibres, and admixtures to overcome challenges in pumpability, workability retention, and application consistency. Comprehensive testing, including workability, early and late age compressive strengths, and LiDAR-based thickness mapping, were conducted across more than 1,200 m of shaft. Operational learnings, such as the impact of deleterious fines, admixture handling, and fibre selection, informed real-time adjustments and long-term recommendations. This paper provides practical insights for future fibrecrete only support regimes, emphasising the importance of quality control and assurance, operator training, and material control in achieving safe and efficient shaft sinking.

Keywords: *shaft sinking, fibrecrete, early-age strength, quality control, slickline delivery*

1 Project overview

Prominent Hill Mine, located in northwestern South Australia, is an underground copper operation owned by BHP. To enhance the production rate of the mine, an expansion project is being undertaken. A key part of this expansion was the construction of the Wira Shaft. Byrnecut Australia was appointed as the principal contractor for the project, with pitt&sherry providing both onsite and offsite geotechnical expertise. Jetcrete Australia operated the batch plant and supplied the fibrecrete, playing a critical role in the ground support strategy implemented. The Wira Shaft is a 1,331 m deep, 7.55 m finished diameter concrete lined haulage shaft, excavated using 2 methods.

The shaft's pre-sink (94 m) was excavated using a Herrenknecht Vertical Sinking Machine, with pre-cast concrete segments forming the permanent liner in this area.

The remainder of the shaft was excavated using a strip and line method, involving drill and blast advancement in 3 m rounds at an excavated diameter of 8.3 m; a raisebored disposal hole was reamed along the length of the shaft. The in situ concrete liner followed the excavation face by 9 to 25 m, leaving a lag distance where temporary ground support was required (Figure 1). In this zone, a fibrecrete only support system was implemented, designed to function as a standalone solution without bolting wherever feasible. To ensure the support system was tailored to encountered ground conditions, significant geotechnical processes were implemented.

[*] Corresponding author. Email address: rcoad@pittsh.com.au

Construction works for the Wira Shaft began in late 2021. The strip and line phase of the sink began in December 2023 and concluded in May 2025.

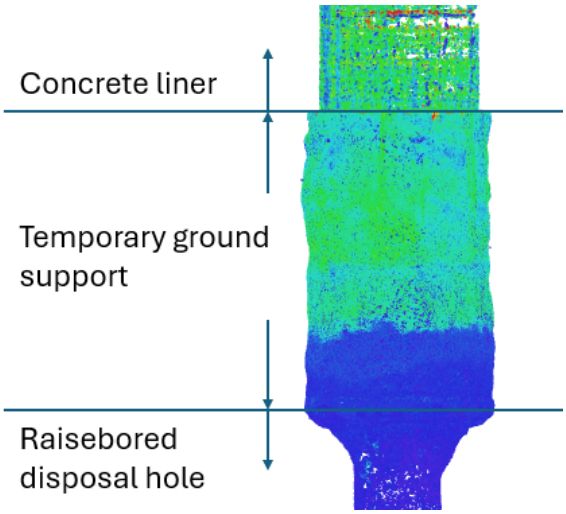


Figure 1 Between the shaft bench and poured in situ concrete liner, temporary ground support is required

2 Temporary ground support

2.1 Intention

The temporary ground support system designed was developed with 2 primary objectives. These were:

1. to ensure stability under anticipated ground loading conditions
2. to facilitate efficient ground support installation.

The overarching priority throughout the design process was worker safety. To achieve this, a comprehensive geotechnical inspection and quality control and quality assurance (QA/QC) regime was implemented, with 24-hour geotechnical coverage during shaft sinking to provide input into the critical stages of excavation and support installation. This enabled the geotechnical engineers to confidently propose a near-boltless fibrecrete support system, selected for its suitability to the ground conditions. This approach enabled site-specific support recommendations and avoided reliance on overly conservative, blanket designs.

2.2 Fibrecrete capacity design

2.2.1 Ground support capacity calculations

The process for determining the support capacity of the fibrecrete is outlined in Coad et al. (2025). Equation 1 gives an empirical relationship between the specific fibrecrete thickness and compressive strength, for the available support capacity of the fibrecrete (t/m^2), equivalent to the resistance of fibrecrete in shear over a surface area of 1 m^2. The primary failure mechanism is assumed to be direct shear failure. Although shear strength governs the support capacity, the final relationship is expressed in compressive strength as this is easier to assess in the field. This equation was used to develop the ground support standards and set the parameters for the allowable support pressure, and required strength and thickness.

$$Support\ capacity_{FRS} = (112 f_c^{0.6} - 44)t \quad (1)$$

where:

t = fibrecrete thickness (m)

f_c = fibrecrete compressive strength (MPa).

The required ground support standard was specified following geotechnical mapping and determination of the rock mass parameters. From these, the required support pressure (i.e. the maximum load imposed by the rock mass) was determined. Once the required support pressure was calculated, the limits of the ground support standards were used to determine the required support class. Coad et al. (2025) outlines in detail the support calculation and recommendation process.

2.2.2 Failure criteria

According to Kaiser et al. (1996), the maximum allowable crack width in fibrecrete, beyond which it can no longer maintain its load-bearing capacity, ranges between 2 and 5 mm. Once cracking exceeds this threshold, the reinforcing fibres are no longer able to effectively bridge the fracture, resulting in a significant reduction in the material's structural integrity. For the purposes of the temporary fibrecrete support system at the Wira Shaft, a conservative approach was adopted; a crack width of 2 mm was defined as the boundary between minor and major cracking. Any crack exceeding 5 mm was considered indicative of structural failure of the fibrecrete support. This criterion was used to guide visual inspections throughout the excavation and support phases.

2.2.3 Minimum thickness and strength

A minimum fibrecrete thickness of 75 mm was specified for application in the Wira Shaft, as the fibrecrete was intended to function as the primary ground support element (in most cases). Increased thickness enhances load resistance and improves structural performance under static and dynamic conditions. In contrast, thinner fibrecrete layers (e.g. 50 mm) are more susceptible to early-age cracking and shrinkage related defects, which can compromise long-term durability and load-bearing capacity. The 75 mm target thickness was selected to accommodate typical variability in shotcrete application while ensuring that even the thinnest sections retained sufficient structural integrity. This approach provided a practical balance between constructability and performance.

A minimum early-age compressive strength of 1 MPa was specified to ensure that the fibrecrete developed adequate internal cohesion and bond strength during the critical early stages of curing. Strengths below this threshold are associated with increased risk of delamination, cracking, and overall support failure.

2.2.4 Design considerations for wedges

A detailed evaluation of the boltless fibrecrete system's capacity to support wedge failures was undertaken during the sinking phase. This assessment focused on the ability of the fibrecrete lining to provide sufficient confinement and structural resistance to wedges formed by intersecting discontinuities. The fibrecrete support effectiveness was highly dependent on the orientation, persistence, and surface conditions of the joints forming each wedge. Preliminary kinematic assessments were conducted from the investigation hole acoustic televiewer data. Due to variability in discontinuity orientations and ground conditions along the excavation profile, individual assessments were conducted in-cycle based on the mapped shaft conditions. These assessments were conducted using Rocscience's UnWedge software (version 5.019) (Rocscience Inc 2024) and informed both design verification and the development of trigger action response plans for wedge related instability during excavation.

2.3 Utilisation of fibrecrete

Initial design assessments estimated that approximately 75% of the Wira Shaft could be supported using fibrecrete alone, with the remaining 25% expected to require supplementary bolting. However, as shown in Table 1, the final outcome significantly exceeded expectations; 98% of the shaft was successfully supported using only fibrecrete without the need for mechanical anchorage. Only 8 instances of temporary bolting were recorded throughout the shaft sinking process. Of these, 2 involved full-profile bolting (first 2 cuts of strip and line process), while the remaining 6 were spot bolting for small wedges encountered during the early stages of excavation. All bolting events occurred within the upper 200 m of the shaft and were implemented as a conservative measure while QA/QC procedures were still being established. It should be noted that this

assessment excludes permanent bolting installed around plat brows, which was part of the final shaft outfitting rather than the temporary support system.

Table 1 Ground support type used throughout strip and line process (count of cuts and % of total cuts)

Support type	Count of cuts	% of Total cuts	Comments
Fibrecrete only	396	98.02	
Fibrecrete with spot bolting	6	1.49	Spot bolt wedges, very conservative at start of project (<6 bolts installed per occurrence)
Fibrecrete with pattern bolting	1	0.25	Issues with accelerator delivery in first spray of strip and line process, had not cured after 12 hours, bolting required
Mesh and bolt	1	0.25	Used due to issues experienced with fibrecrete batching (second spray of strip and line process)

2.4 Lag distance

The lag distance is the length of shaft wall between the poured concrete liner and the bench. The required lag distance varied along the shaft based on the requirements of the liner designers. The fibrecrete temporary ground support was not limited by allowable exposure length and was able to accommodate the required lag distances. This is a significant difference to typical shaft sinking projects, where placement of the concrete liner is often dictated by the allowable exposure of the temporary ground support. The longest unbroken fibrecrete only exposure was 25.3 m, while the longest total lag distance including plats, was 42.9 m. Figure 2 shows the planned lag distance versus the actual achieved lag distance.

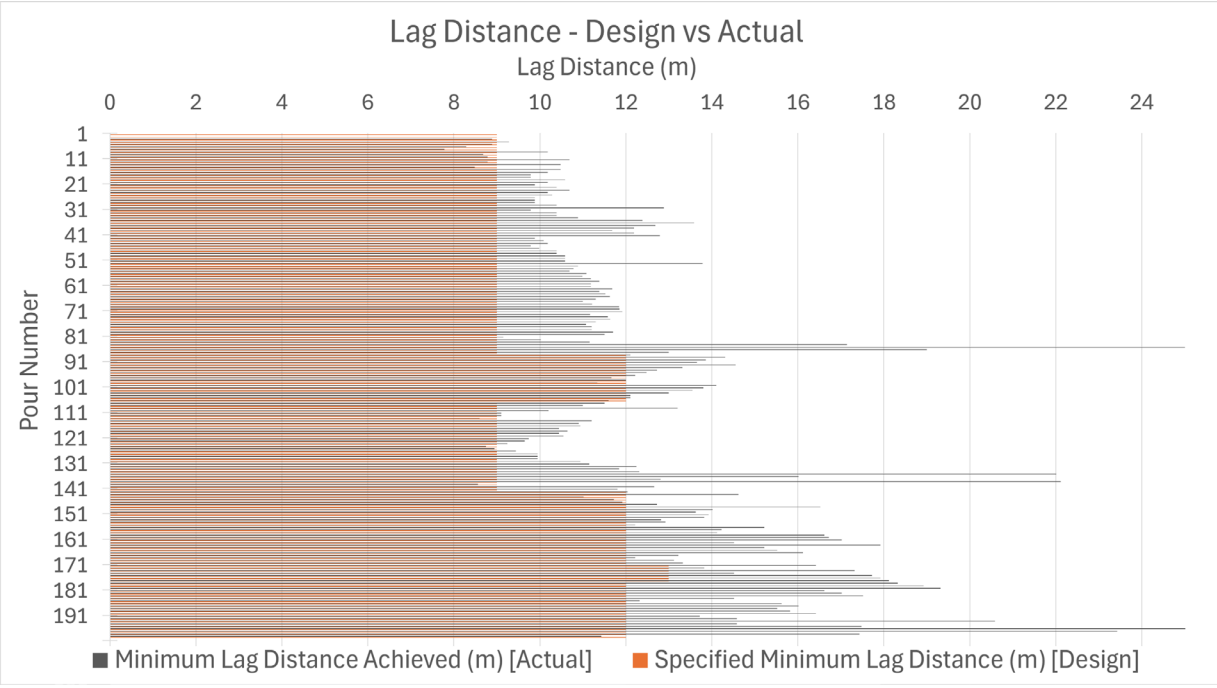


Figure 2 Lag distance across the full shaft sink: design versus actual

3 Fibrecrete mix design

3.1 Cementitious materials

The intention of the fibrecrete mix designed for the temporary ground support within the Wira Shaft was to achieve high early strength. One of the key components to this was the high cement content. The fibrecrete mix used 550 kg/m^3 of cement. Fly ash was not substituted for any cement in the shaft's fibrecrete mix (although it was used in the shaft's permanent liner concrete mix). While the round shape of the particles may have assisted with lubricating the mix and improving workability retention in the slickline, the negative impact of slower early-age strength gain and the governing requirements for rapid re-entry, precluded its use in the shaft's fibrecrete mix.

3.2 Aggregates

No fixed aggregate proportions were specified in the fibrecrete specification, instead it was the responsibility of the batch plant to adjust the proportions of each aggregate (fine sand, sand and 10 mm aggregate) based on the particle grading analysis results, to achieve continuous grading. Figure 3 shows an example of a fibrecrete mix where continuous grading was not applied to the aggregates (trial of new aggregate supplier, significantly coarser fine sand, minimal fines on any of the aggregates); complete segregation of the mix occurred when the same ratios of new aggregates were applied to the normally used aggregates (mix was not sent down the slickline).



Figure 3 Backing up of segregated fibrecrete mix in surface hopper during trial (surface only) of new aggregates with minimal fine particles (aggregates used not continuously graded)

The most critical aggregate in the fibrecrete mix is the fine sand (crusher dust). This is required for internal lubrication of the mix which impacts workability and pumpability, it also provides lubrication of the spray system and slickline. It ensures the mix is sprayable and assists in ensuring a uniform distribution of fibres and larger aggregates within the mix. Fine sand, however, also has the highest likelihood of the 3 aggregates to be significantly impacted by deleterious fines. Deleterious fines are the silts and clays (i.e. finer than sand particles) that have an impact on the workability, slump retention and strength of the mix. The deleterious fines that were encountered through the project were typically swelling clays; when they come into contact with water and admixtures in the mix, they absorbed these liquids and reduce workability. This was exacerbated by the water losses through the slickline. Not all fine particles will have a major impact on the workability of the mix; generally, only active clays will cause this negative effect. Deleterious fines in the aggregates occasionally impaired workability retention, with this impact reflected in the strength results presented in Section 4.2. Increases in these fines typically occurred after large rain events around the quarries. It is recommended to implement a Methylene Blue Testing regime, to determine the Methylene Blue Value in accordance with Australian Standard AS 1141.66 (Standards Australia 2022) to assess the level

of deleterious clay bearing fines in received aggregates, together with clear criteria and capacity to reject trailers that do not meet the required standard.

The inclusion of a clay neutralising admixture for ad hoc use should be considered when writing the fibrecrete specification and during preliminary mix testing. The use of Clarena CM150C (Chryso Australia 2025) was investigated for the Wira Shaft; however, it was never trialled onsite. Laboratory testing of site aggregates containing deleterious fines showed a reduction in clay content from 1.37% (untreated) to 0.55% when dosed with Clarena CM 150 C at 6 L/t. If implemented onsite, this may have significantly improved mix performance during periods of aggregate difficulties.

3.3 Admixtures

The superplasticiser used in the Wira Shaft fibrecrete mix was MasterGlenium SKY 8708 (Master Builders Solutions 2025). The dose rate was varied along the shaft to improve workability retention without significantly increasing the water content. At high dose rates, Glenium can make the mix sticky and affect its viscosity and flowability, which is particularly relevant in mixes with a high level of fines. The maximum dose rate used was 5.6 L/m³; this is just over the manufacturer's recommendation of 1,000 mL per 100 kg of cementitious material. No major adverse effects were observed at this rate. Although slightly lowering the Glenium and increasing the water may have reduced minor workability issues on the stage, the higher Glenium approach was maintained as it had less impact on early strength gain.

The hydration control admixture used in the shaft's fibrecrete mix was MasterRoc HCA20 (Master Builders Solutions 2023). The dose rate was varied with ambient temperature, with 2.0 L/m³ used through the hot months and 1.1 L/m³ through the cooler months. This ensured the mix had sufficient pot life to allow a 2-hour stand time from initial water addition, while minimising the impact on the point of hydration and the time required to reach 1 MPa.

3.4 Water

A broad water-to-cement ratio (w:c) range was provided in the initial fibrecrete specification to allow the water content to be modified as depth and workability requirements increased. The geotechnical engineer would incrementally increase the allowable w:c based on the workability results obtained down the shaft. The full w:c range was 0.25–0.45, with the initial batch plant limit set at 0.35. It was critical that no raw water (i.e. potable water only) was added to the fibrecrete mix. As potable water was used for the fibrecrete, specific assessments of total dissolved solids and chloride concentrations were not undertaken.

3.5 Steel fibres

Fibres improve the mechanical properties of the fibrecrete including the flexural capacity and crack resistance. Polypropylene fibres are the most typical type of fibre used; at the time the underground operation at Prominent Hill was using SikaFiber Radmix 65s (Sika Australia Pty Ltd 2022). It was determined in the design stages that steel fibres would be the most appropriate for use in the Wira Shaft fibrecrete mix, due to the increased potential for balling of the polypropylene fibres causing a slickline blockage risk. The steel fibres used were Dramix 4D65/35 (Bekaert 2026), SikaFiber Novocon HE5535 HT (Sika Australia Pty Ltd 2023), and Fibrecon 6635 (Enviromesh Pty Ltd 2023). No issues were observed with the steel fibres used in the Wira Shaft fibrecrete mix.

Late in the project, there was a short period where the steel fibre supply onsite was at risk of being exhausted. Alternative solutions were investigated, including the use of SikaFiber Radmix 65s down the slickline. This trial showed that these polypropylene fibres were not ideal for slickline use and should be avoided; there were multiple points where the mix partly segregated, and fibres backed up on grates in the fibrecrete delivery system. This does not preclude the use of polypropylene fibres in a slickline, however the size and manufacturer should be carefully assessed and properly trialled prior to use with the specific mix.

3.6 Accelerator

The accelerator used with the shaft's fibrecrete mix was MasterRoc SA167 (Master Builders Solutions 2026). SA167 is a high early strength accelerator used with wet-mix shotcrete. It allows for rapid strength gain in the fibrecrete and improved re-entry times. Different dose rates of SA167 were trialled in the early stages of the project, with rates ranging from 18 to 35 L/m^3. The aim was to achieve 1 MPa as soon as possible, with the mix still being sprayable without the risk of the mix flash setting (i.e. accelerator too high). The selection of dose rate ultimately came down to the feedback from operators on the sprayability. The optimal dose rate of SA167 was determined to be ~32 L/m^3; when considering the 550 kg of cementitious material, a dose rate of 5.8% is determined.

4 Fibrecrete testing and performance

4.1 Workability testing

Correct workability of the fibrecrete is critical to enable the mix to be pumped, sprayed, and compacted while achieving the required early-age strength without segregation or bleeding. Workability testing occurred on every load at both the batch plant and the brace prior to discharge, with stage testing undertaken where necessary. It was typical to see the fibrecrete lose 100–150 mm of spread between the surface and the stage.

Results of workability testing are presented in Figure 4. The initial workability testing method used was a standard slump test, before moving to a spread test at ~730 m down shaft when the allowable workability (new spread range of 550 to 650 mm) and w:c content changed. In practice, the slump test should have been discontinued, and a spread test used, from ~330 m (when the allowable slump changed to 270 +/− 10 mm). At this point the mix was collapsing and the measure of slump at this stage was no longer a meaningful measure of workability. Moving to the spread test allowed for an accurate check of the workability.

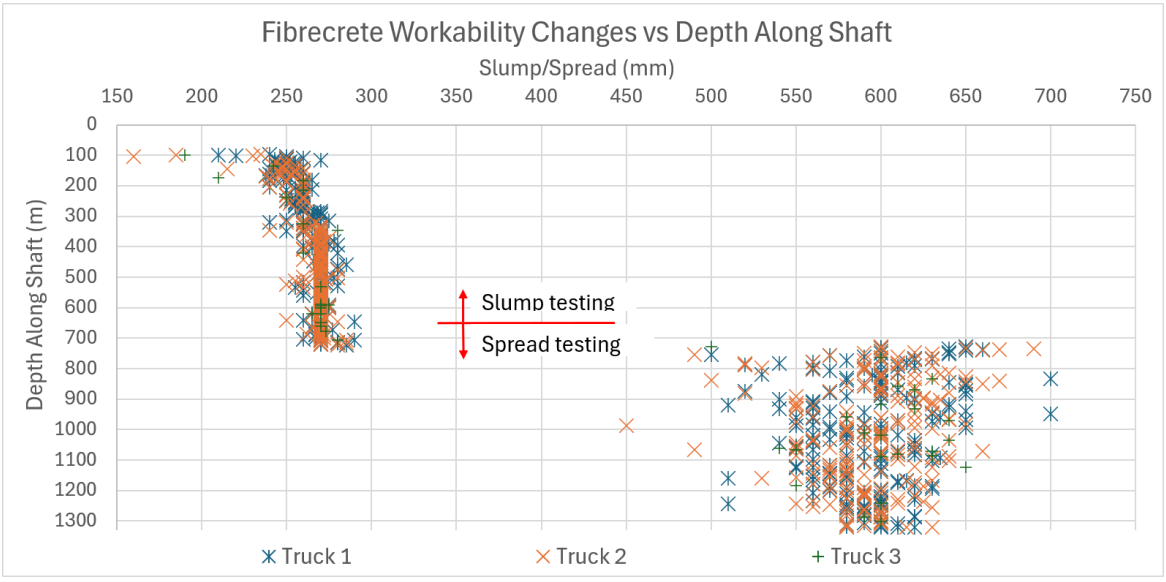


Figure 4 Fibrecrete workability changes (brace testing prior to discharge) versus depth along shaft

4.2 Early strength testing

Fibrecrete early strength was a significant part of the fibrecrete only ground support regime. Given the fibrecrete was the primary support element used in the shaft, a higher level of detail was applied to testing than would typically be seen in an underground development heading. Initially, early compressive strength was assessed using methods that did not directly test the fibrecrete compressive strength, namely using the penetrometer and Hilti re-entry methods (Bernard 2005). These were difficult to perform in situ and tended to underestimate strength at very low strength values, leading to extended re-entry times (Figure 5). Beam tests are the only readily available means of directly testing the early compressive strength of

fibrecrete, although they can be difficult to spray and prepare. A method of spraying beam panels with minimal out of cycle time was developed, and beam testing became the primary means of re-entry. Following its implementation, significant improvements were seen in both repeatability and results, together with improvements from training mining personnel on the fibrecrete QA/QC requirements. Coad et al. (2025) outlines the assessed re-entry testing methods and associated issues in detail.

The data presented in Figure 5 includes all available re-entry strength data for the life of the project, normalised to 1 MPa, with time to reach 1 MPa plotted against shaft depth. The sporadic nature of the first ~330 m of data is likely due to the early testing method issues discussed above, together with implementation and training around spraying and QA/QC processes. Two main occurrences of deleterious fines in the aggregates, at ~750 and ~1,030 m, adversely affected workability retention, required additional water, and delayed the point of initial hydration, with clear impacts on re-entry times.

The operationally optimal re-entry time was 45 minutes, as clean up and pack up after spraying generally took this amount of time. A re-entry time of 60 minutes was considered the maximum operationally allowable re-entry time, with a 15-minute delay acceptable on irregular occurrences. Beyond this, higher re-entry times were considered unacceptable. Based on the beam testing dataset (184 occurrences), the average re-entry time was 54 minutes. If the extended re-entry times associated with deleterious fines are removed, the average re-entry time reduces to 47 minutes. Where re-entry testing could not be conducted, a conservative re-entry time of 2 hours was applied due to the variation in results across the shaft. No re-entry testing was conducted where immediate access to the bench was not required, as the 2-hour minimum re-entry time had elapsed before the next task commenced.

It was important to ensure consistency between the 2 trucks used to spray a single round. Beam panels were sprayed at the start of the first truck, and where significant differences were noted between the trucks in workability, water content, or sprayability, beam tests were required on both to ensure the re-entry time was not being underestimated when only the better-performing mix was tested. It was important for the geotechnical engineer to be aware of the quality of both trucks to make this decision. Reliance on operators alone to ensure consistency was not recommended, particularly during periods of deleterious fines issues, when some operators occasionally sprayed panels with a stiffer mix and then correct the mix afterwards to improve sprayability for the rest of the round. This could significantly affect both the test result and the actual strength gain of the sprayed round. This practice was quickly corrected following discussions around the importance of fibrecrete strength on safety.

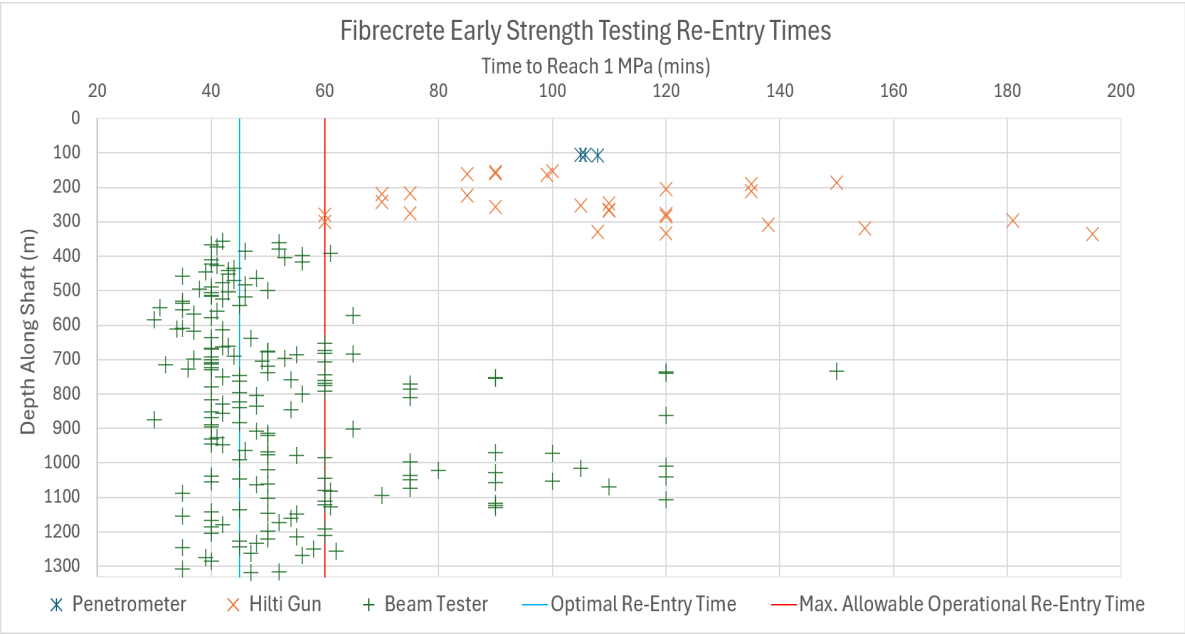


Figure 5 Fibrecrete early strength results versus depth along shaft (with varying re-entry methods and allowable re-entry times). Re-entry data normalised to 1 MPa

4.3 28-day compressive strength testing

28-day compressive strength testing was required on every third round sprayed of shaft fibrecrete. The test results did not impact the strip and line cycle and were for quality control purposes only. The data shows (Figure 6) that high 28-day compressive strengths were achieved for the fibrecrete mix, with results sitting around 70–80 MPa, up until ~700 m. When the allowable w:c content was increase to the maximum 0.45, and the allowable workability range was modified (as well as the workability testing method) at 730 m, average 28-day compressive strength decreased significantly; the results from ~730 m onwards, were seen to be 50–60 MPa. This large drop in ultimate compressive strength is a result of significantly increasing the allowable water. Across the length of the shaft, only one result was below the 40 MPa targeted design strength which was related to overwatering of the mix.

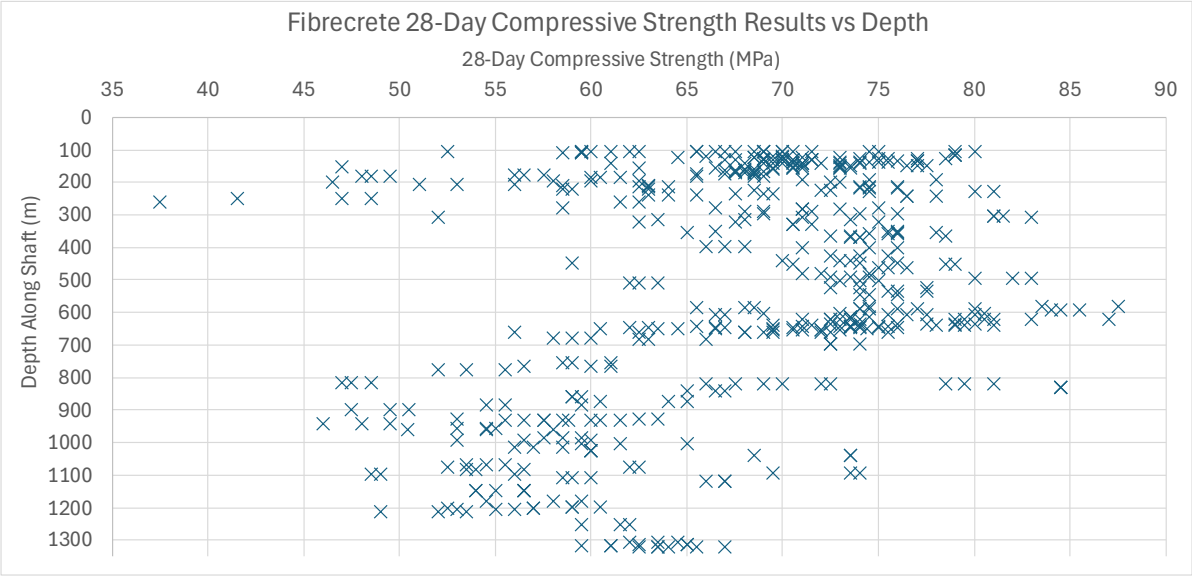


Figure 6 Fibrecrete 28-day compressive strength results versus depth along shaft

4.4 Thickness testing

Fibrecrete thickness was the other major component of the temporary support calculations, together with early strength, and had a major impact on the support pressure the fibrecrete could achieve. At the start of the project, thickness was tested by drilling 8 holes around the shaft to obtain an average thickness. This method had a high probability of missing under sprayed areas that may not meet the specified support requirements. To improve the understanding of the thickness achieved, pre and post spray LiDAR scans were implemented. This allowed thickness around the full round to be assessed and provided actionable feedback to operators on application quality and deficiencies. The heat map produced provided a clear method of displaying the actual thickness. Although there are inherent accuracy errors in the LiDAR assessments, correlations with drillhole results were found to be suitable for thickness assessment purposes.

The fibrecrete volume used per metre advance and the calculated required volume per metre advance are shown against shaft depth in Figure 7. Areas where the volume used fell below the calculated required volume are those where thickness concerns may have been present. For the volume used, it was assumed that all ordered fibrecrete was used and that 1.5 m^3 was lost to testing, dumping, and other system losses. The calculated required volume used a roughness factor of 1.6, with required thickness varied based on the ground support recommendations. In poorer ground, particularly in leg 2, cut lengths were typically greater than 3 m and more fibrecrete was required. Some thin patches were accounted for in the design process when considering the minimum recommended thickness, such that minor thin patches were not of great concern; large areas which were significantly thinner than recommended required monitoring and/or rectification.

Figure 7 shows that above 380 m, the volume of fibrecrete used was significantly less than that required to provide adequate coverage. This was during the period when drill holes were being used for depth testing, drilled on re-entry without a geotechnical engineer present. Although the drillhole results suggested adequate thickness had been achieved, the validity of these results was questionable. LiDAR scanning was introduced at pour 47 (top of concrete – 366.1 m), and it was quickly realised that the fibrecrete volume being ordered was inadequate, as losses in the system and the roughness/rebound factor had not been properly accounted for. This was rectified immediately upon identification. The final volume required should be informed by operator experience, with an initial indication provided by the geotechnical engineer.

One limitation of the LiDAR thickness testing method was that it did not provide real-time feedback, with thickness checks conducted only after re-entry to the bench. A system such as Normet's SmartScan (Normet 2026) could provide real-time feedback to operators, although its use in other applications would need to be considered. One area that could still have been improved, even at the end of the project, was achieving the correct overlap between rounds to ensure there were no under-supported areas. This was discussed regularly; however incorrect overlap was still observed towards the end of the project. It was difficult to assess on the LiDAR scans and relied largely on operator experience to ensure sufficient coverage into the previous round.

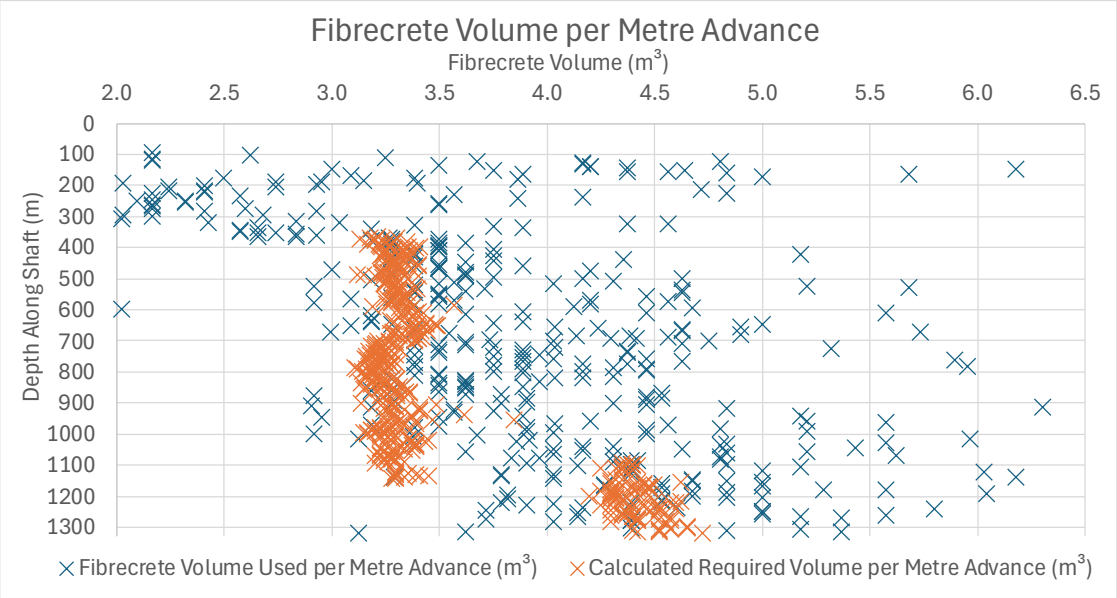


Figure 7 Fibrecrete volumes (used and calculated) along the length of the shaft. No calculated required volume above 366 m (pour 47) as LiDAR sections were used from this calculation

4.5 Other testing

Adhesion testing was not achieved at the Wira Shaft, as in-shaft testing would have taken too much time out of the mining cycle. A method similar to the beam test was developed but never used, involving a semi-flat rock set in concrete in a frame that could be lowered down, sprayed, and returned to surface for coring and testing. In future fibrecrete only support regimes, adhesion testing should be conducted from the start of the project, as it is an important part of QA/QC for ensuring the fibrecrete behaves in the designed direct shear failure mode. Ideally, adhesion should be tested in situ to assess the system as a whole, including the surface preparation stage.

Regular checks of the fibrecrete temperature at the brace and on the stage were conducted to allow for optimisation of the mix. The ideal temperature for the mix was between 20 and 25°C; when the fibrecrete temperature exceeded 30°C severe workability issues were observed. If the mix was too hot aggregate, water, and bowl temperatures were lowered. Conversely, if the fibrecrete temperature was cool the water chiller could be turned off to raise the mix temperature and assist in achieving earlier initiation of hydration.

4.6 Cracking in fibrecrete

Seven instances of visible fibrecrete cracking were observed during the shaft sinking process. These occurrences began at approximately 925 m depth and were typically located within 2 cuts of the advancing bench, where stress concentrations and convergence are expected to be highest. In cases where crack widths exceeded the allowable limit, remedial action was undertaken. This involved sounding the fibrecrete to assess for delamination, followed by removal of compromised material and reapplication of fibrecrete to restore structural integrity.

Once rectified, or in cases where cracking remained within acceptable limits, no further propagation or deterioration was observed. Overall, the fibrecrete system demonstrated robust performance, even under elevated stress conditions. This performance was likely influenced by the circular geometry of the shaft, which promotes a more uniform redistribution of stress and facilitates natural stress breakout shaping.

Minor cracking, when observed, was most commonly located on the shaft walls oriented perpendicular to the major principal stress direction. These cracks were typically associated with areas where the applied fibrecrete thickness was below the design target, highlighting the importance of consistent application. Importantly, no instances of major cracking were recorded that would have necessitated the installation of bolts for structural support.

4.7 Strength gain curves

Strength gain equations were developed for the shaft's fibrecrete mix for both early and late age strengths.

Equation 2 represents the early-age strength gain of the shaft's fibrecrete mix, with early age taken as zero to 24 hours. The equation provided a reasonable representation of the anticipated fibrecrete strengths and was used to estimate likely re-entry times for higher early strength requirements. Given the variability in the early strength data, testing was still required, however the equation provided a useful scheduling estimate.

Equation 3 represents the late age strength gain of the shaft's fibrecrete mix, with late age taken as 1 to 28 days. This is based on the higher water content mix used towards the end of the project, where an average 28-day compressive strength of 58 MPa was achieved, representative of a maximum w:c of 0.45. The equation can be used to assess likely strengths of the fibrecrete at various times throughout its life. It should be noted that these results are based on cylinders taken from the fibrecrete mix and are not accelerated or sprayed samples.

$$f'_{c\,(early\ age)} = 20.018\, d^{0.8941} \tag{2}$$

$$f'_{c\,(late\ age)} = 10.01 \ln d + 25 \tag{3}$$

where:

d = time in days.

5 Improvements and learnings

There were many improvements and learnings across the project with regard to the fibrecrete design, application, and QA/QC. A summarised list is as follows:

- Clearly communicate at project commencement the importance of fibrecrete QA/QC for personnel safety, particularly where fibrecrete provides the primary support and where it differs from conventional underground development incorporating rock bolts.
- When developing the fibrecrete specification, it is advisable to engage admixture and fibre manufacturers early to identify potential concerns and provide input on current technologies. This was not undertaken during the initial writing of the Wira Shaft specification, although expert engagement occurred after issues were identified.

- It is critical to ensure the excavation walls are properly hydroscaled and that suitable surface preparation is undertaken prior to spraying, particularly where activities have occurred between blowing down and spraying. This should be clearly stipulated in the spraying procedure.
- Correct training of sprayers is crucial to fibrecrete application quality, particularly with regard to nozzle positioning relative to the wall. If the nozzle is too far from the wall it can cause severe compaction issues, which can be detrimental to the fibrecrete's load-bearing capacity.
- A number of issues were identified with accelerator delivery and distribution at the nozzle due to blockages or damage to the mixing chamber. Although the procedure required the nozzle and mixing chamber to be checked before each spray and flushed after each spray, this did not always occur. These issues can significantly delay re-entry due to inadequate accelerator dosing and distribution, and the importance of these checks needs to be clearly emphasised in the spraying procedure.
- When fibrecrete is first dropped through the slickline, fines are dragged from the mix and left on the inside of the slickline, providing lubrication to the system. The initial portion of the mix therefore has a high probability of segregation and should be dumped rather than sent to the nozzle. Many blockages below the pump hopper occurred where this was not done. Only ~0.2 m^3, or until the mix is visibly not segregated, needs to be dumped. This should be included in the spraying procedure to ensure consistency between crews.
- At times, operational practices evolved in the field, which meant that the potential impacts and broader implications for fibrecrete performance were not always fully assessed.
    - Form oil in the fibrecrete delivery system: one example involved the use of form oil to lubricate the fibrecrete delivery system. While a small initial application is commonly used for this purpose, there were instances where larger volumes, including full 20 L containers, were introduced into the pump together with the initial portion of the fibrecrete mix. The intent was to flush the system with a small quantity of oil-treated fibrecrete and discard that material prior to spraying. However, where residual oil remained in the pump or hopper, there was potential for it to become incorporated into the fibrecrete during the initial stages of spraying, potentially affecting application quality and structural performance.
    - Water addition to the fibrecrete mix: another example involved the addition of water to the fibrecrete mix at the spraying stage. This introduced 2 technical considerations. First, the volume of water added was not quantified, creating the potential for variability in the water-to-cement ratio. Second, the water source was untreated mine water rather than process water specified for batching. Both factors have the potential to influence fibrecrete performance, particularly with respect to application consistency and early-age strength development. In future projects, a larger accelerator tank should be considered. At ~32 L/m^3 on a 14 m^3 round, ~450 L of accelerator is required, meaning at least one kibble run was typically needed during each spray. Increasing the tank size to around 500 L would remove this step and keep the kibble free during the spray cycle.
- It is critical that the SA167 accelerator is adequately agitated and aerated prior to use. While some segregation during storage is expected (Figure 8), instances of excessive segregation were observed, as well as cases of accumulation of a dense residual layer that could not be resuspended. As this material represents a concentrated component of the admixture, the inability to re-incorporate into the product alters the composition, as such disposal of the entire intermediate bulk container was recommended in such cases. A shaded area for the storage of admixtures should be available to assist with maintaining their quality, and subsequently, ensuring their correct performance.

- Procedures should be in place to properly slick the slickline prior to sending fibrecrete or concrete down, to minimise water loss. The amount of slick used should be considered against the length of the slickline.
- Only potable water should be used on the brace for fibrecrete modifications within allowable limits, and water gauges should be available for all agis and brace hoses. This would reduce the risk of overwatering and improve control of modifications.
- When assessing the amount of fibrecrete to order per round, it is important to apply a roughness factor and account for losses in the slickline and system. Although initial estimates can be provided by the geotechnical engineer, the decision to order more than calculated should come from the sprayer, based on experience, with support from the shift supervisor and geotechnical engineer as required.
- Given the importance of early strength, it is critical to ensure the correct re-entry method is selected. Having the geotechnical engineer conduct the testing on every round ensured the fibrecrete had reached the required capacity prior to personnel access and removed this responsibility from the operations team.
- The aggregates need a high level of QA/QC as soon as they arrive onsite, with deleterious fines testing and clear instruction on material rejection standards if not suitable.
- An increased presence at the batch plant would be recommended to ensure the correct QA/QC procedures are followed and to conduct regular checks.
- Shades are recommended for the aggregates, agis, and admixtures, particularly in hot environments, to assist with temperature control and subsequent fibrecrete performance.

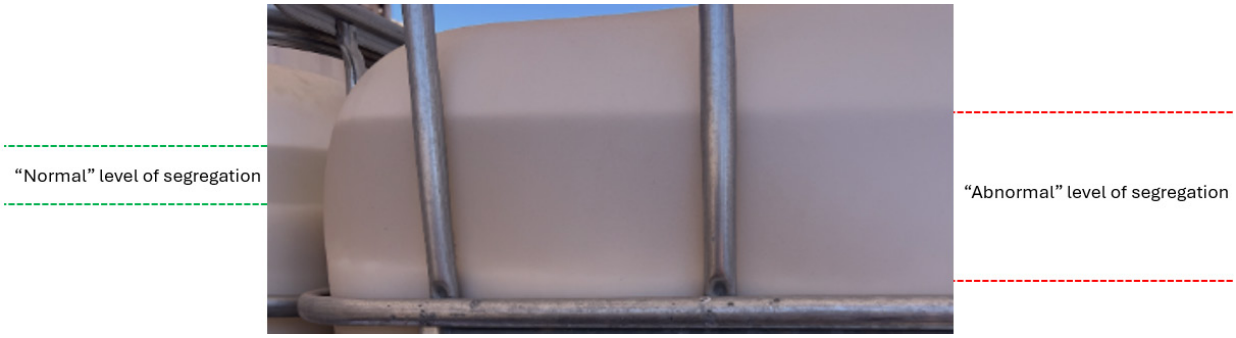


Figure 8 'Normal' and 'abnormal' segregation of SA167 accelerator

6 Future considerations

The successful implementation of a fibrecrete only temporary support system in the Wira Shaft highlights several opportunities for future optimisation and broader application. One key area for advancement lies in the adoption of autonomous or semi-autonomous fibrecrete spraying technologies. Automation has the potential to significantly improve application consistency by reducing variability introduced by human operators, which remains one of the most influential factors affecting fibrecrete quality. Enhanced control over thickness, distance to the application surface, and boom movement would not only improve performance reliability but also reduce the need for rework due to under or over application.

Given the demonstrated performance of the fibrecrete only system, particularly under high-stress conditions and with significant exposures, there is a compelling case for exploring its use as a permanent lining solution. A potential future design could involve a fibrecrete only permanent liner, with conventional concrete used solely for the curb to facilitate the installation of shaft services. This hybrid approach could offer substantial cost and schedule savings by eliminating the need for full depth cast in situ concrete liners, which can be labour and time intensive. However, transitioning to a fibrecrete-only permanent lining system would require careful consideration of several project specific factors. These include water ingress control, ventilation flow

requirements (rough versus smooth surface), and the structural requirements for permanent service attachments.

7 Conclusion

The Wira Shaft project demonstrated that a fibrecrete only temporary ground support system can be successfully implemented, achieving reliable performance under a wide range of ground conditions. Over 98% of the shaft was supported using fibrecrete alone, with temporary exposure lengths exceeding 25 m and typical re-entry times of approximately 45–60 minutes. These results represent a significant departure from conventional shaft support approaches that rely heavily on mechanical anchorage.

Field performance of the fibrecrete system validated the underlying design methodology, including the use of compressive strength-based capacity relationships and minimum thickness criteria. When combined with good QA/QC processes, the assumed failure mechanisms and support capacities were shown to be appropriate for the encountered ground conditions.

A key outcome of the project was that the success of a fibrecrete only system is highly dependent on execution. Strict control of aggregate quality, particularly deleterious fines, together with disciplined QA/QC practices, appropriate mix design, and high-quality application by trained operators, were all critical to achieving consistent performance. Variability in any of these factors had a direct and measurable impact on workability, strength development, and re-entry times.

The integration of beam testing for early strength assessment and LiDAR-based thickness mapping significantly improved confidence in support performance and enabled real-time refinement of operational practices. These tools provide a strong foundation for future projects seeking to implement similar support strategies.

The outcomes of this project demonstrate that, where supported by appropriate design, materials, and operational controls, fibrecrete only support systems can reduce reliance on bolting, improve safety by minimising manual installation activities, and maintain high productivity. Future work should focus on improving real-time thickness control, refining testing methods, and evaluating the feasibility of fibrecrete as a permanent lining solution.

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