Ground Support 2023 – J Wesseloo (ed.)
© 2023 Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-5-8
doi:10.36487/ACG_repo/2325_40

Improving underground development cycle time using performance mine grouts

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Abstract

Cementitious grouts are a staple in underground mining cable bolting and other ground support regimes. Application options include mechanised installation, however, grout batching remains a manual process. Therefore, the grout quality is reliant on the operators' proficiency and the equipment being used.

Generally, cement suitable for working conditions by considering workability, temperatures, water quality and desired strength performance are used.

Some operations have gone further and encompassed pumpability, chemical resistivity, strength development and extended performance in their adopted cement selection criteria. However, grout adaptation has remained outdated, with the majority of operations utilising ordinary Portland cement, or equivalent variations, as it is assumed to be fit for purpose.

Significant developments have been made with grouting technology, offering sites customised alternatives. They can potentially improve quality, durability and efficiency while limiting adverse operator and equipment effects. The following paper will examine available technologies, highlighting their performance advantages, limitations and scenario-based potential improvements to development cycle times.

Keywords: *cable bolts, mine grout, cycle time, early re-entry*

1 Introduction

Cementitious grouts play a crucial role in underground mining cable bolting and other ground support regimes, providing essential structural reinforcement to ensure the safety and stability of mining operations. Traditionally, the selection of cement for grouting operations has primarily focused on its suitability for working conditions, taking into account parameters such as workability, temperature variations, water quality and desired strength performance. Some mining operations have expanded their cement selection criteria to include additional factors such as pumpability, chemical resistivity, strength development and extended performance. However, despite these considerations, the adaptation of grout materials has been slow to evolve, with the majority of operations relying on ordinary Portland cement (OPC) or its equivalent variations, assuming its adequacy for the intended purpose.

Recent years have witnessed significant developments in grouting technology, presenting mines with customised alternatives that offer improved quality, durability and efficiency while also addressing potential issues related to operators and equipment. These advancements provide an opportunity to optimise the performance of cementitious grouts, ensuring enhanced safety and reliability in underground mining applications.

The aim of this paper is to examine the available technologies in cementitious grouts for underground mining cable bolting, shedding light on their performance advantages, limitations and the potential improvements they offer in different scenarios, particularly in terms of development cycle times. By exploring these advancements, we can unlock the potential for superior grout quality and more effective ground support measures, leading to increased safety, productivity and cost-effectiveness in underground mining operations.

2 Methodology

2.1 Cable bolts

A conventional cable bolt is a flexible tendon consisting of a number of steel wires wound into strand that is grouted into a borehole (Hutchinson & Diederichs 1996). There is a wide range of cable bolts available in different wire configurations, strand diameters and profiles for various reinforcement applications.

Within the context of underground hard rock mining, a widely utilised variant of cable bolts is seven-wire, 15.2 mm diameter bulbed strand, installed as either single or twin strands. Figure 1 is an illustration of a single strand plain and bulbed Garford cable bolts.

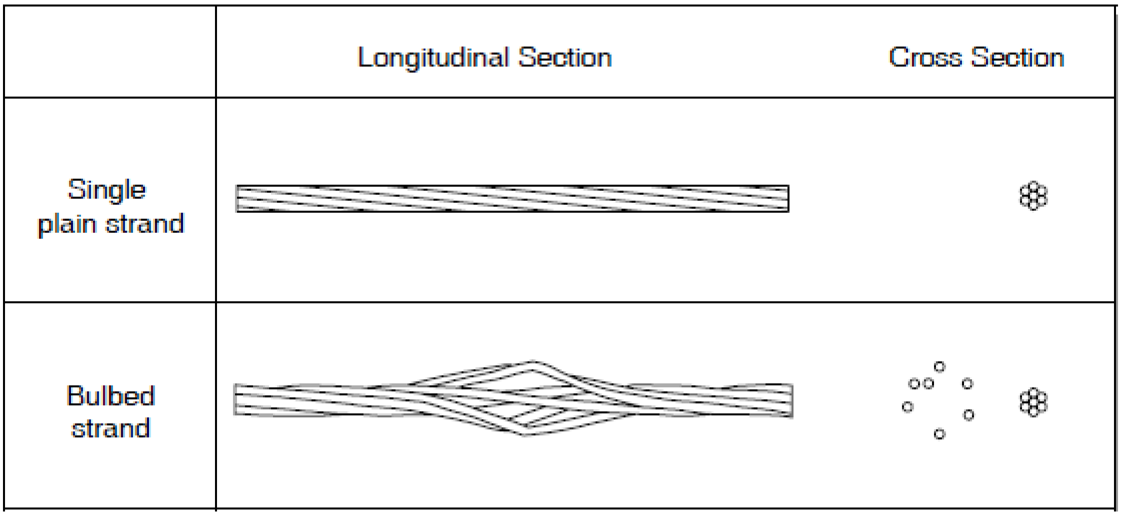

Figure 1 Illustration of a plain single strand and a bulbed Garford cable bolt for underground mining (Windsor 1992)

2.2 Cable installation cycle

The general concept of cable bolt installation is the placement of the cable into a borehole with grout fully encapsulating it, where the grout behaves as mechanical coupling between the steel tendon and the rock mass. There are several ways of installing and grouting cable bolts, including manual, semi-mechanised and fully mechanised options.

Traditionally, manual installation has been conducted by skilled operators (on average, three people) working on an elevated platform utilising inexpensive pneumatic grout bowls and grout pumps to mix and place the grout into pre-drilled boreholes. This application is labour intensive and time consuming, which can impact productivity and increase costs.

The various mechanised options utilise a specialised piece of equipment with borehole drilling, cable bolting and grout placement capabilities. This is increasingly becoming the more popular option due to skilled labour shortages, increasing ground support requirements, and an industry-wide drive towards full mechanisation and automation.

However, with these installation alternatives, the batching of grout remained a predominantly manual process with subjective visual and physical checks utilised to determine the quality of the grout. Figure 2 is the breakdown of the process involved in the installation cycle of a cable bolt.

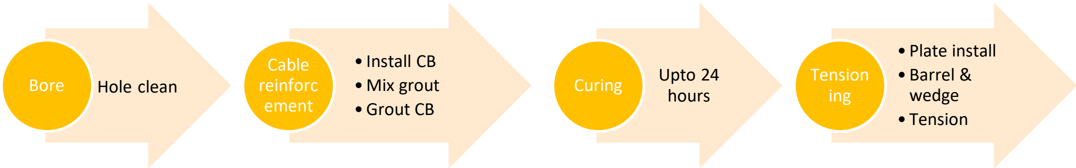

Figure 2 Cable bolt installation cycle

Based on underground mine application and current industry practice, the minimum strength required to tension a standard 6 m twin strand 15.2 mm cable bolt to a load of five tonnes is generally attained within 12 hours of curing. However, the actual uniaxial compressive strength (UCS) of the grout has not been quantified and this is planned for investigation in further studies. In addition, the average target yield strength is a minimum of 32 MPa at 28 days of curing. Note no guidance on the maximum yield strengths for grouts appear to have been widely adopted in the industry.

2.3 Grouting equipment

Due to the nature and limitation of underground operations, the preferred grouting equipment has naturally been pneumatic and hydraulic-driven paddle mixers and piston pumps. These are suitable equipment, with advantages including availability of compressed air and simplicity of use. Despite this, the wear and tear caused by working conditions, inadequate service, and poor handling and cleaning reduce their capabilities. This is often one of the most critical factors that drives poor grout quality.

2.4 Thixotropic grouts

The process of batching a thixotropic grout involves the preparation of a viscous cement and water mortar with unique flow properties. Thixotropic grouts exhibit a non-Newtonian behaviour characterised by a decrease in viscosity under shear stress and a subsequent recovery of viscosity when the stress is removed. This behaviour is ideal for grout placement in ground support applications. To batch such a grout, precise measurements and controlled mixing procedures are necessary.

The batching procedure typically entails the following steps:

- Gathering and verifying the required ingredients.
- Accurate measurement.
- Mixing procedure.
- Quality control.

2.5 Cement types and admixtures

Due to the large array of cements and admixtures available and used in underground mining operations, the products will be analysed in categories based on design performance and popularity of use. It is worth noting that the admixtures are generally used in conjunction with low heat cement and OPC, and have been analysed as such. The products discussed are outlined in Sections 2.5.1 to 2.5.7.

2.5.1 Low heat (LH) cement

LH cement, also known as low heat of hydration cement, is a type of cement that generates significantly less heat during the curing process compared to OPC. It is specifically designed to minimise the risk of thermal cracking.

2.5.2 Ordinary Portland cement

OPC is a hydraulic cement widely used in construction due to its excellent binding properties and versatility. It is worth noting that OPC comes in different grades, such as OPC-33, OPC-43 and OPC-53, which indicate the compressive strength of the cement after 28 days of curing.

2.5.3 Prebagged high yield strength cement (HYS)

Prebagged grouts are specialised grout mixtures that are conveniently packaged in bags or containers. The desired performance is improved workability, shrinkage compensation and high yield strengths.

2.5.4 Prebagged high early strength cement (HES)

High-performance grouts refer to specialised grouting materials that are engineered to possess exceptional properties and performance characteristics compared to standard grouts (Sika Australia 2023). High-performance cement is a general purpose cement designed for use in applications where there is a need for enhanced early-age strength gain in the grout (Cement Australia 2011). The performance offers improved workability, shrinkage compensation, and early-age strength development in as little as two hours post placement.

2.5.5 Admixture: accelerator

Accelerators are used to increase the rate of initial set and subsequent strength development (Hutchinson & Diederichs 1996). Generic accelerators that contain chlorides are not recommended for cable bolting application as they are detrimental to reinforcement steel. However, calcium nitrite-based accelerators are suitable for this application and have corrosion-inhibiting effects. Precautions to avoid overdosing accelerators are imperative to avoid flash setting, cracking, and compromising yield and ultimate strengths.

2.5.6 Admixture: Methocel

Methocel, also known as methylcellulose, offers a range of water-soluble polymers derived from cellulose ether. Commonly used as an additive in grouts, they have a wider range of formulations and applications (DuPont 2019). The polymers function as thickeners, binders and film formers in water-based formulations, essentially working as a viscosity modifier in grouts.

2.5.7 Admixture: plasticiser and superplasticisers

Plasticisers are commonly used additives in grouts to improve their workability and flow characteristics. A plasticiser, also known as a water-reducing agent, is a chemical compound that interacts with the water in the grout mixture, reducing its surface tension and increasing its fluidity (Sika Canada 2023). This class of admixtures allows reduction of the water-to-cement ratio and hence induces higher strengths and stiffness without affecting the mixing, pumping and flow characteristics (Hutchinson & Diederichs 1996). Similar to other admixtures, precaution must be taken when dosing as errors may result in adverse effects such as grout segregation and inability to place the grout.

3 Data

Several parameters need to be considered when analysing the performance and effectiveness of any ground support. This remains a valid point in the case of cable bolts encapsulated in cementitious grout, however, for the purpose of this study, the focus is the performance of the grout; in particular, the curing time required to achieve sufficient strength to tension the cable bolt and complete the installation cycle. In addition, the long-term strength development and yield strength were captured and analysed as these determine the effective performance of the cable bolt.

3.1 Grout performance summary

Grout is a mortar derived from mixing cement and water, with no other aggregates included. The design of the grout for the cable bolt application is often critical to the success of the operation (Hutchinson & Diederichs 1996). Table 1 shows the performance of several cements under similar conditions.

Table 1 Grout performance matrics of the different cements under similar conditions

Product	Package	Shelf life	Ease of use	W:C ratio	Grout mixing	Set time @ < 21°C	Thixo-tropic	Pump-ability	Shrink comp.	Early strength <4 hours
LH	20 kg PWDR	12 months	✓	0.35	◐	2–4 hours	✓	◐	⊗	⊗
OPC	20 kg PWDR	12 months	✓	0.35	◐	2–3 hours	✓	◐	⊗	⊗
LH + Admix	20 kg PWDR + 750 ml LQD	12, 9 months	◐	0.35	✓	1–2 hours	✓	✓	◐	✓
HYS	20 kg PWDR	12 months	✓	0.3	✓	2–4 hours	✓	✓	✓	⊗
HES	20 kg PWDR	6 months	✓	0.2	✓	45 mins	✓	✓	✓	✓

✓ Yes ◐ Achievable, dependent on operators, equipment and/or controls ⊗ No

3.2 Uniaxial compressive strength

The different types of cement were batched per recommended water-to-cement ratios as noted in Table 1, under similar conditions and with cylinder mould samples collected for testing. The UCS was tested at intervals, with three samples per grout per time interval tested. The average strength results are presented in Tables 2 and 3.

Table 2 Early strength development uniaxial compressive strength results

	Uniaxial compressive strength (MPa)				
Age (hrs)	LH	OPC	LH + admix	HYC	HES
0	0	0	0	0	0
4	0.05	0	0.7	0	15.0
8	0.5	0	2.0	1.6	20.0
12	1.4	1.2	4.0	5.6	24.0
24	6.8	5.0	15.0	16.0	30.0

Table 3 Long-term development UCS results

Age (days)	Uniaxial compressive strength (MPa)				
	LH	OPC	LH + admix	HYC	HES
0	0	0	0	0	0
1	6.8	5.0	15	16	30
3	18	17	31	29	39
7	33	26	55	46	47
14	41	30	59	55	49
21	49	38	62	59	52
28	54	48	65	62	54

3.2.1 Early-age strength development

The early-age strength development has been defined as the average UCS achieved by the samples within the first 24 hours. Figure 3 shows the strength development curve of the samples. Note that some samples could not be tested in under eight hours.

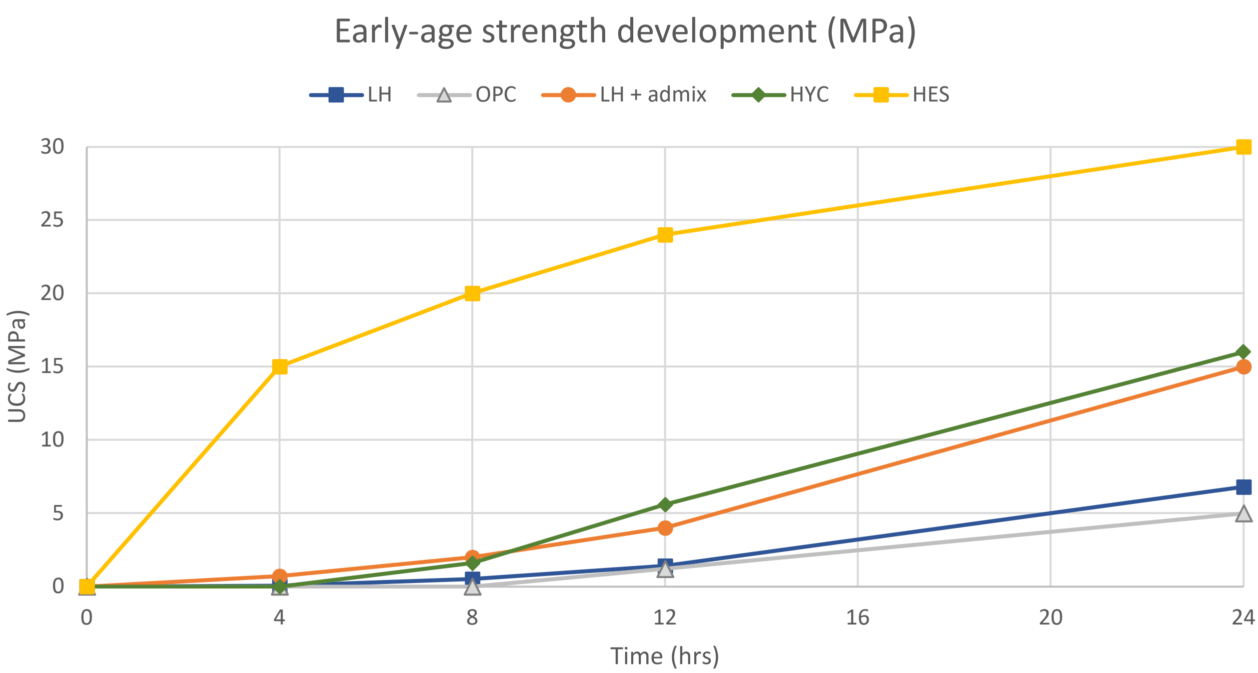

Figure 3 Average uniaxial compressive early strength development curves

Based on the minimum strength required to tension the cable bolts, the results indicated the following minimum curing time for the different cements:

1. HES minimum time = two hours.
2. LH + admix minimum time = six hours.
3. HYC minimum time = eight hours.
4. LH & OPC minimum time = +12 hours.

3.2.2 Long-term strength development

The grout strength development is one of the critical performance indicators in a cable bolt installation cycle. Throughout the installation the most time-consuming stage is the curing process. A majority of sites allow anywhere between 12 to 24 hours of curing before tensioning is conducted to complete the installation process. Improvements on the required cure time before tensioning have a direct positive effect on cycle time and an attainable development rate. Figure 4 shows the long-term strength development curve of the samples up to 28 days.

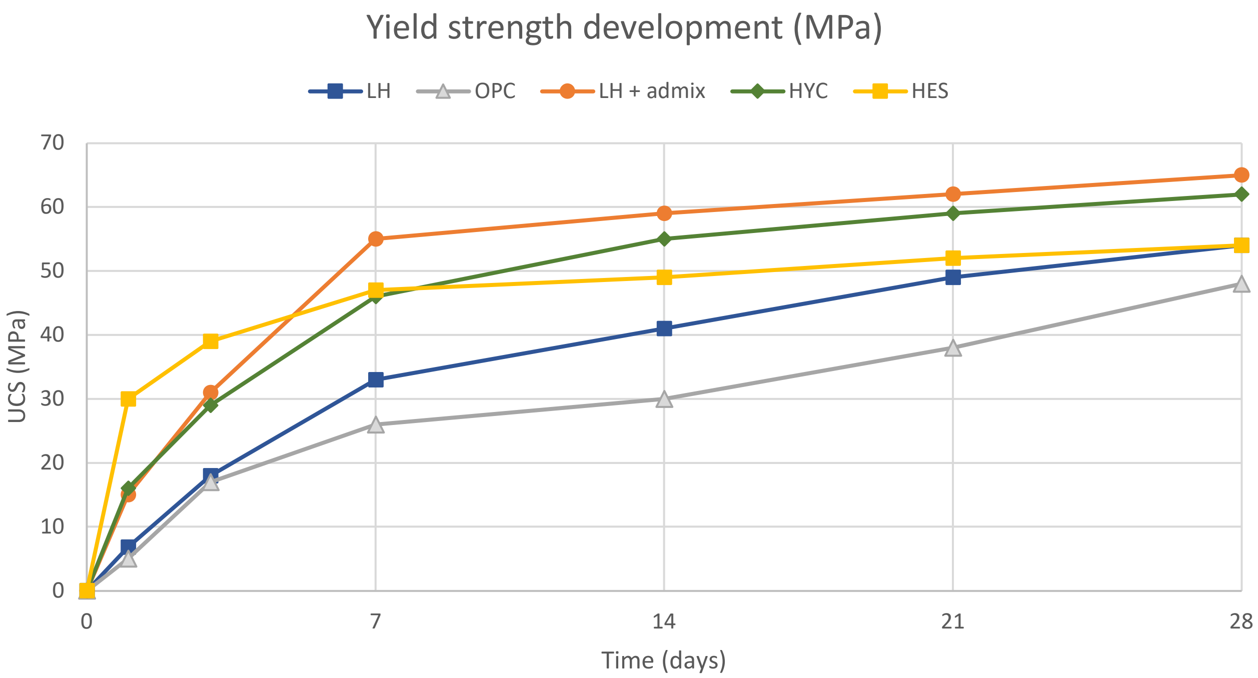

Figure 4 Average long-term UCS development curves

Based on the minimum yield strength targeted for cable bolt installation at 28 days of curing, the results indicated that all the cement exceeded the target:

1. HES strength at 28 days = 54 MPa, with a target of 32 MPa achieved in approximately one day.
2. LH + admix strength at 28 days = 65 MPa, with a target of 32 MPa achieved in approximately three days.
3. HYC strength at 28 days = 62 MPa, with a target of 32 MPa achieved in approximately three days.
4. LH strength at 28 days = 54 MPa, with a target of 32 MPa achieved in approximately seven days.
5. OPC strength at 28 days = 48 MPa, with a target of 32 MPa achieved in approximately 14 days.

4 Case study 1: secondary development support installation

One of the common areas cable bolts are utilised in underground mines is in wide span development, usually in the form of an intersection. A typical three-way intersection of 5.5 × 5.5 m development drive and cable bolt pattern can be seen in Figure 5.

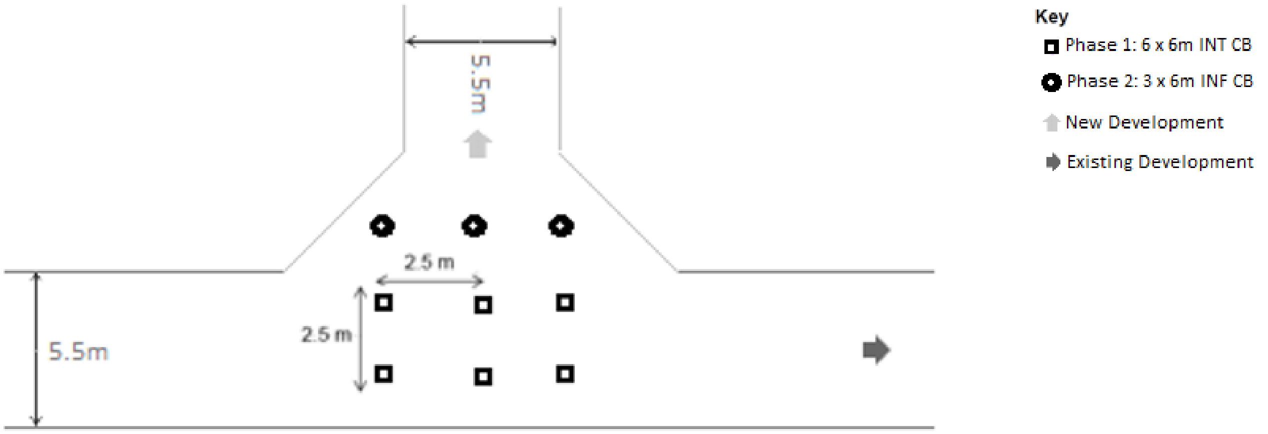

Figure 5 Three-way intersection and cable bolt support pattern

During the development and installation of the intersection, some restrictions are put in place to mitigate the risks involved. The steps taken to develop an intersection can be summarised in Figure 6.

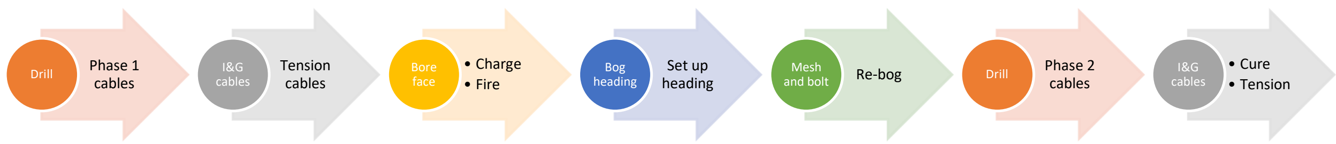

Figure 6 Three-way development cycle

The active development cycle time for a standard three-way intersection, using LH cement or OPC and requiring +12 hours of curing time prior to cable bolt tensioning, has been quantified. The data was generated from an average development scheduling allocated time per task. Note these may vary for individual sites. Figure 7 shows the estimated active time to develop and support a three-way intersection underground.

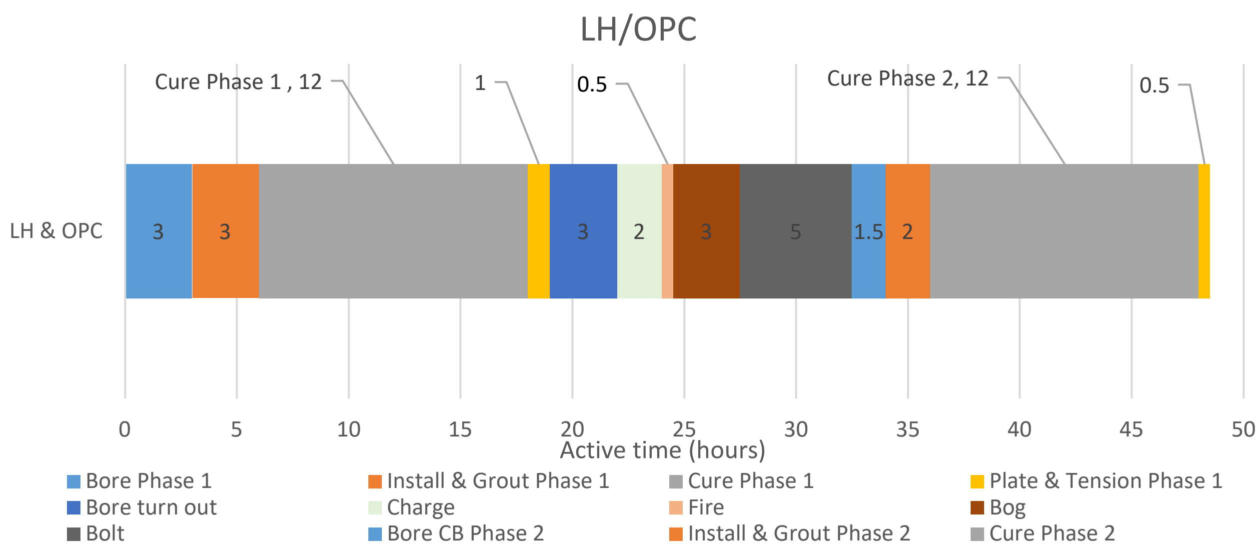

Figure 7 Active time analysis to develop and support a three-way intersection using standard cements

The total active time required to complete one cycle is approximately 48.5 hours. The curing time is defined as the time required for grout to gain enough strength to allow for plating and tensioning. It is evident that the curing time is the bottleneck in the installation cycle, adding to the time this development is under some access restrictions. The active cycle time using the different types of cements and their equivalent minimum curing time has been represented in Figure 8. Significant improvements were achieved, with up to a 42% reduction in curing time.

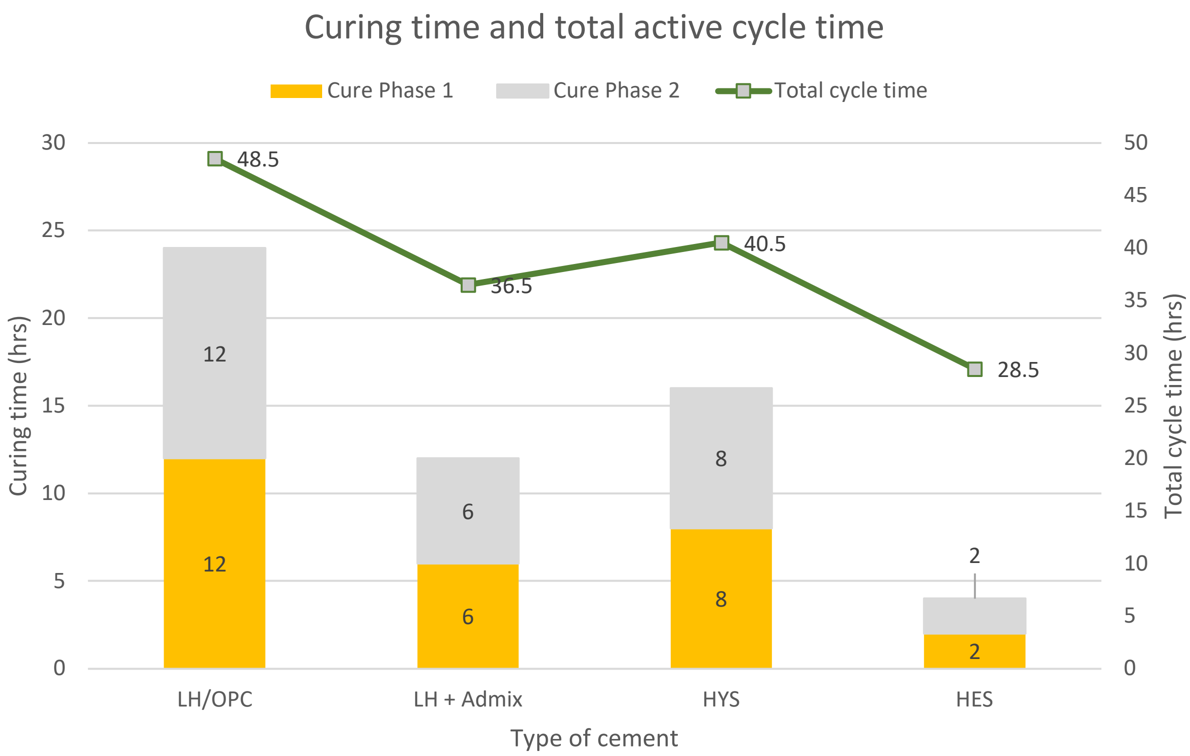

Figure 8 Curing time versus total active cycle time in hours for different type of cement

5 Case study 2: in-cycle secondary support installation

This scenario analyses the support upgrade/rehabilitation of two development drives (development north and south, Figure 9). The support upgrade requires installation of mesh and 2.4 m friction bolts, followed by secondary installation of a ring of 7 × 6 m cable bolts to be installed at 2 m intervals. The two drives have the following lengths requiring support and advancement restrictions:

- Development south
  - 50 m to support.
  - 175 cable bolts at 7 CB per ring × 2m spacing.
  - Restricted to 8 m advance (four CB rings).
- Development north
  - 50 m to support.
  - 175 cable bolts at 7 CB per ring × 2m spacing.
  - Restricted to 4 m advance (two CB rings).
- Grouting
  - Average of three rings and 21 cable bolts per shift.
  - Limited by advance restrictions.

- Curing:
  - Curing base on minimum time required by cement.
  - LH/OPC: 1 shift, LH + Admix: 0.6 shift, HYS: 1 shift and HES: 0.15 shift.
- Plating and tensioning (P&T):
  - Average of eight rings, 56 cable bolts per shift.
  - Limited by grouted cable bolts.

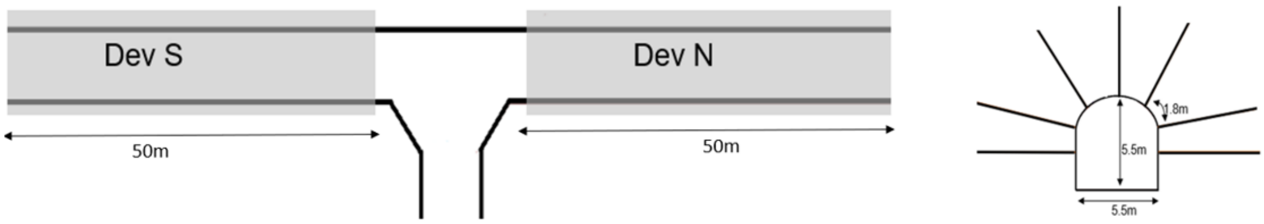

Figure 9 Illustration of development requiring support upgrade and cable bolt pattern

5.1 Time analysis

Using the parameters listed earlier, the following installation schedule (Table 4) was derived to estimate the total shifts required to complete the cable bolting portion of the support campaign. The following schedule only considered the tasks associated with installing the cable bolts as illustrated in Figure 2.

Table 4 Cable bolt installation cycle time in shifts for different cements

N & S Drive Ground Support Upgrade					LH/OPC			LH + Admix			HYC			HES		
Location	Advance	Lateral dev (m)	Cables	Drill shifts	Grout shifts	Curing Shift	Plate & Tension	Grout shifts	Curing Shift	Plate & Tension	Grout shifts	Curing Shift	Plate & Tension	Grout shifts	Curing Shift	Plate & Tension
Dev S	4 rings (8m) cycle	50	175	8	8	8	8	8	6	5	8	5	5	8	0.2	5
Total Shift to complete Dev S cable bolts installation:					25			19			19			14		
Dev N	2 rings (4m) cycle	50	175	13	13	13	13	10	9	10	13	8	13	8	0.2	5
Total Shift to complete Dev N cable bolts installation:					38			29			33			14		
Total		100	350	21	46	21	21	37	15	15	39	13	18	31	0.4	11
Total Shift to complete rehab cable bolts installation:				21	63			48			51			28		

The curing shifts and total installation shifts using the different types of cements have been summarised in Figure 10. Significant improvements in time savings were observed, with up to an 80% reduction in time required for curing shifts when using HES cement.

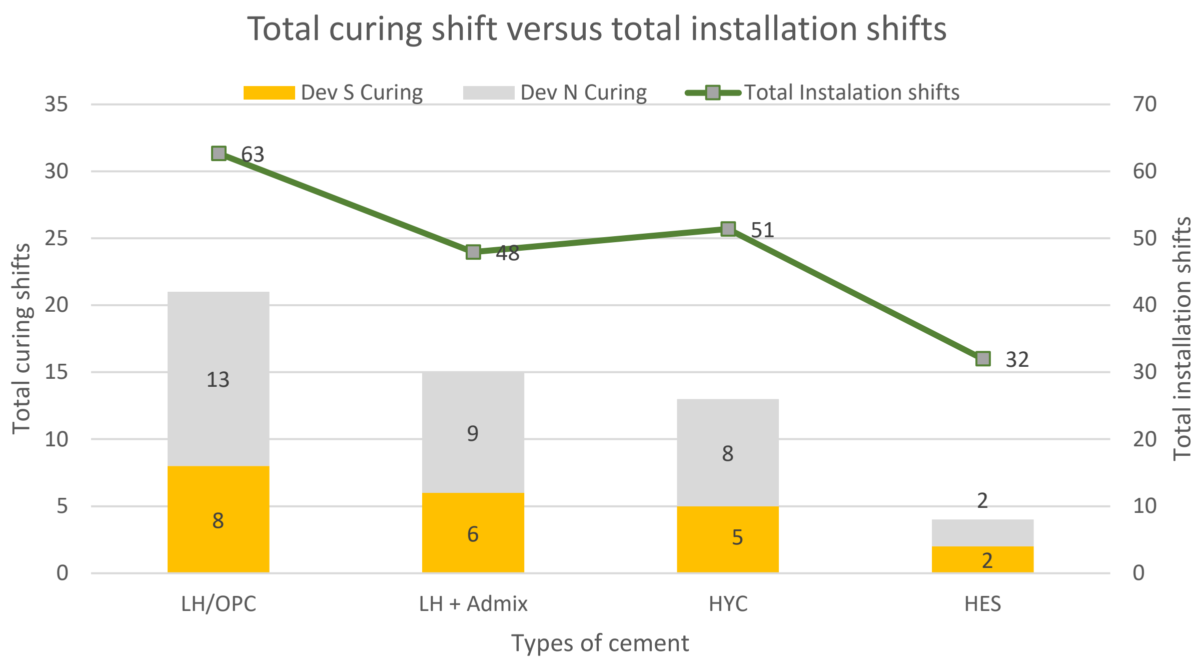

Figure 10 Curing time versus total active cycle time in shifts (12 hours per shift) for different types of cement

5.2 Cost analysis

To further comprehend the holistic effect of using the different cements, a cost versus performace analysis was conducted. Table 5 is a breakdown of the quantities and unit costs of the ground support material required to complete the upgrade, with the cost of cement as the variable.

Table 5 Cost of ground support material required to complete the support upgrade

Material	Unit	Quantity per 4 m advance	Unit cost (AUD)	Total cost (AUD)
Mesh	ea	5	68.75	343.75
Split set + plate	ea	24	18.85	452.40
Cable bolts + plate	ea	17.5	94.98	1,662.15
Total non-grout material cost per metre				**2,458.30**
LH/OPC grout	m^3	0.76	486.88	370.03
LH + admix grout	m^3	0.76	1,408	1,070.08
HYS grout	m^3	0.76	1,448.28	1,100.69
HES grout	m^3	0.76	2,272.73	1,727.27
Total material cost per metre		**(Total non-grout material cost + grout)/4 m**		

Figure 11 illustrates the relationship between the total installation shifts, and the cost of cements, grout and total material cost per metre, required to complete the support upgrade.

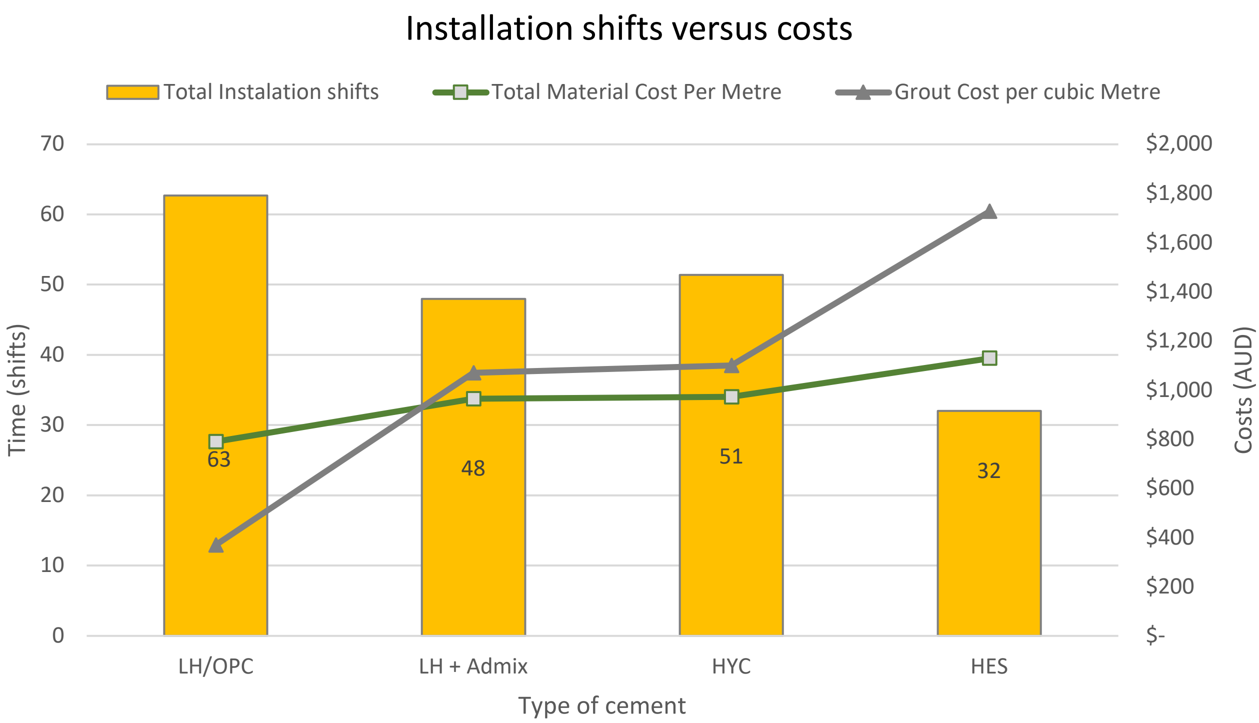

Figure 11 Total active cycle shifts versus the cost of cement and the total cost of ground support material required

6 Discussion and conclusion

The underground mining industry heavily relies on cementitious grouts for ground support, particularly in cable bolting applications. Traditionally, the selection of grout materials has been limited to OPC or its equivalent variations, assuming their suitability for the intended purpose. However, recent advancements in grouting technology offer customised alternatives that can improve quality, durability and efficiency while addressing the limitations of conventional grouts.

This paper examined the available technologies in cementitious grouts for underground mining cable bolting, focusing on their performance advantages, limitations and potential improvements to development cycle times. The study explored the cable bolt installation cycle, grouting equipment, and the characteristics of different cement types and admixtures commonly used in underground mining operations.

The data presented in the study showcased the performance metrics of various cementitious grouts under similar conditions. It highlighted factors such as ease of use, water-to-cement ratio, set time, thixotropy, pumpability and shrinkage. UCS tests were conducted to assess the early-age and long-term strength development of different grout types.

The results demonstrated that alternative grout materials such as LH cement with admixtures, prebagged HYS cement and HES cement offer significant improvements in strength development compared to OPC. These alternatives achieved minimum curing times of two hours, six hours, eight hours and 12+ hours, respectively, to reach the strength required to allow tensioning of the cable bolts. The prebagged mixtures provide additional benefits due to their ease of use and the consistency of the grout when compared to site application of cements and admixtures.

By adopting prebagged specialised grouting technologies and materials, underground mining operations can potentially reduce the overall development cycle time. While the initial cost outlay of the prebagged mixtures is significantly higher, the decreased curing time for the grout can lead to increased productivity and cost-effectiveness. With up to 10 hours saved per installation cycle using HES cement, the potential increase in productivity is significant.

In conclusion, the study highlights the importance of considering alternative cementitious grouts in underground mining cable bolting applications. The advancements in grouting technology provide an opportunity to optimise the performance of grouts, leading to improved safety, productivity, and cost-effectiveness. However, it is essential to conduct further research and field testing to assess the long-term durability and performance of these alternative grout materials. Overall, embracing these advancements can contribute to the continuous improvement of underground mining operations and the sustainability of the industry.

Acknowledgement

The authors would like to acknowledge Sika Australia & Rocktech Pty Ltd for their support.

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