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Trial of high early-strength grout-hardening accelerating admixture for cable bolts

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Abstract

A specialised hardening accelerating admixture for addition to the low-heat cement mix for cable bolt grouting used at Nova Operation, SikaRapid-700 L (Additive 1) and SikaRapid-440P (no longer available [Additive 2]), was trialled to improve the early strength properties of the cable bolt grout. These products were trialled to reduce installation turnaround times for grouted cable bolts and improve long-term grout strengths. The hardening accelerating admixture promotes early strength development while positively influencing final strength. The properties of the hardening accelerators trialled allow for bringing cable bolts into service sooner through high early strength gain with no negative effects on final strength of the grout.

This paper outlines the practical aspects for the application of a high early-strength grout for cable bolting. Testing included pull testing of cable bolts at set time intervals to establish cable bolt capacity over time and uniaxial compressive strength testing of grout to establish a curing curve to estimate the grout strength over time.

Keywords: *cable bolting, grout, high early strength, uniaxial compressive strength testing, pull testing*

1 Introduction

IGO Limited's 100%-owned Nova Operation (Nova) is 160 km east-northeast of Norseman in Western Australia, Australia, and 380 km northeast of the Port of Esperance. Nova utilises a single jumbo for all development as the current rates are approximately 150 m of lateral development per month (IGO Limited 2022).

Cable bolting at Nova uses a cementitious grout to bond the metal cable strands to the rock mass. The current product used is low-heat cement, historically used with success in the mining industry due to its gradual release of heat (and hence gradual curing time) in a confined space, in particular areas of higher internal rock temperature. Excess heat generation during the hydration of cement process is thought to cause temperature-related issues such as cement cracking and shrinkage (Hutchinson & Diederichs 1996, pp. 72–75). Rapid setting grout products have been avoided for this reason; however, cementitious grouts have been developed to contain plasticisers and anti-shrinking agents to minimise these effects.

The low-heat cement products' gradual curing time requires a minimum of 12 hours before the plating and tensioning of the cable bolt and bringing the bolt into service, as per the current site standard. Other industry standards include a minimum of 12–24 hours of curing time before plating and tensioning the cable bolt to 5–10 t (M. Brockman, pers. comm., 2020). A specialised accelerator product (Additive 1 and Additive 2) added to the grout mix was trialled at Nova to improve the early strength properties of the cable bolt ground to reduce installation turnaround. An added benefit is the improvement of final grout strengths (Sika Australia 2023a).

2 Testing of early strength in grout

2.1 Hardening accelerating admixture

Both admixtures are hardening accelerating admixtures for Portland cement systems based on multifunctional inorganic salts. The admixtures act to both reduce setting times and increase early strength development by increasing the rate of cement hydration. The addition of the admixture increases calcium ion concentrations, promoting faster saturation levels of calcium hydroxide and cement phase solubility. This acts to accelerate setting and increases the hydration rate of cement resulting in higher early strength development of cementitious systems (Sika Australia 2023a).

2.2 Methodology

Two different trials of liquid (Additive 1) and powder (Additive 2) were conducted at Nova. For each trial, several single strand bulbed cable bolts of varying lengths (2, 4, and 6 m) were installed and grouted into horizontal drill holes in the waste rock of the mine (Figure 1). The first trial only tested cable bolts grouted with Additive 1, while the second trial used a 'control' low-heat mix to compare the ability to pull test a standard cable bolt grout mix (Table 1).

Table 1 Cable bolt tested lengths and additives tested at each trial

Cable bolt length (m)	Trial 1	Trial 2
2	Additive 1	Additive 2
4		
6		
6	–	Low-heat cement and methocel

Grout for all batches was mixed at a 0.35 water cement ratio (84 L of potable water measured into the grouting bowl). This was mixed for one minute before the application of bags of low-heat cement. For Additive 1, one bottle was added per cement bag and for Additive 2, one bag was added per cement bag. Additive 1 was mixed using 10 bags of cement with 65.6 L of water due to the Additive 1 solution having water in it with solids by weight of 50%. Additive 2 was batched with 10 bags of low-heat cement and 70 L of water.

The trial cables were grouted from shortest (2 m) to longest (6 m). For the second round of trials, grouting of the Additive 2 mix was completed first, following the cleaning of the pump and mixer, then a standard cable bolt grout mix with low-heat cement and methocel was batched at 0.35 W:C ratio and pumped into the remaining holes.

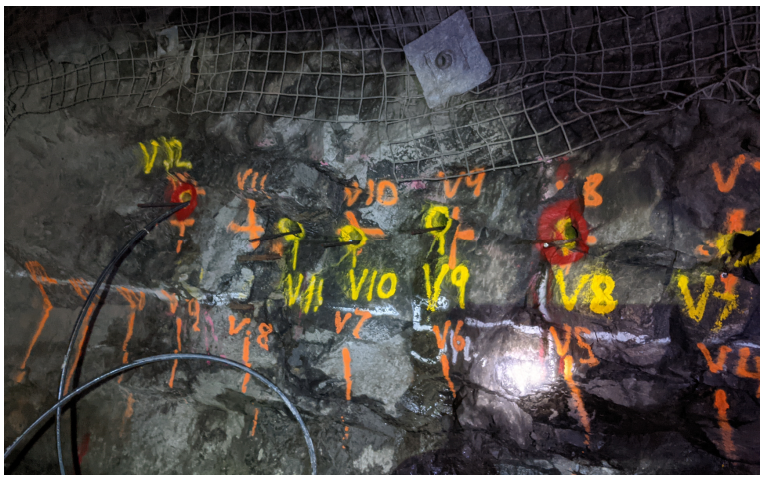

Figure 1 Example of the cable bolt trial area arrangement

2.3 Pull-out testing

Pull testing of cable bolts installed for both trials from each length took place at four, five and six hours. During the second trial, pull testing of the standard cable bolt grout mix was only completed at six hours. Pull testing was taken to slip or 10,000 psi, whichever occurred first. The pressure was recorded in psi and converted to kN by Rocktech (Rocktech, pers. comm., 24 March 2021). Figure 2 shows the trial area after pull testing was completed with pressures recorded for each cable bolt.

Figure 2 Post pull testing cable bolts with pressures in psi recorded on the wall

2.4 Lab accredited uniaxial compressive strength testing

Uniaxial compressive strength (UCS) testing of grout is the industry standard for QA/QC of grout strength due to the simple process stream and has been adopted as the quality control for cable bolt grouting at Nova. Early UCS strength testing of grout is difficult to complete on site due to the inability to perform accredited UCS testing, which therefore requires transporting samples to SGS laboratory in Perth or Kalgoorlie. Early grout strength testing is required within 24 hours to determine the rate of the curing of the cement grout. Due to this restriction, a mixture of accredited offsite testing and site-based testing was performed to gain early strength data for cement grout mixes.

2.5 Site-based UCS testing

Six sets of grout cylinders were collected from the Additive 2 trial batch and one set from the low-heat batch with a total of 14 sets collected. Of the 14 sets collected, 12 sets were tested on site at the Nova paste plant for early UCS strength with results shown in Figures 7 and 8. Two sets – one of the Additive 2 batch and one of the low-heat batches – were sent offsite for 28-day strength testing at the SGS laboratory in Perth, as per standard grout testing procedures. These samples were used to compare with the site UCS testing.

The samples were tested from two hours every two hours up to 12 hours for Additive 2. The low-heat samples were tested from four hours, every two hours up to 12 hours then again at 24 hours. The set time for Additive 2 is estimated to be between 4–18 hours, depending on grout mix design, grout temperature and curing conditions (Sika Australia 2023a). Photos showing the change in grout sample texture or fabric following UCS testing are shown in Figure 3. The low heat remains ductile even after 12 hours of curing time, while the Additive 2 samples shows more brittle failure signs from eight hours curing. This indicates a difference in early strength gain.

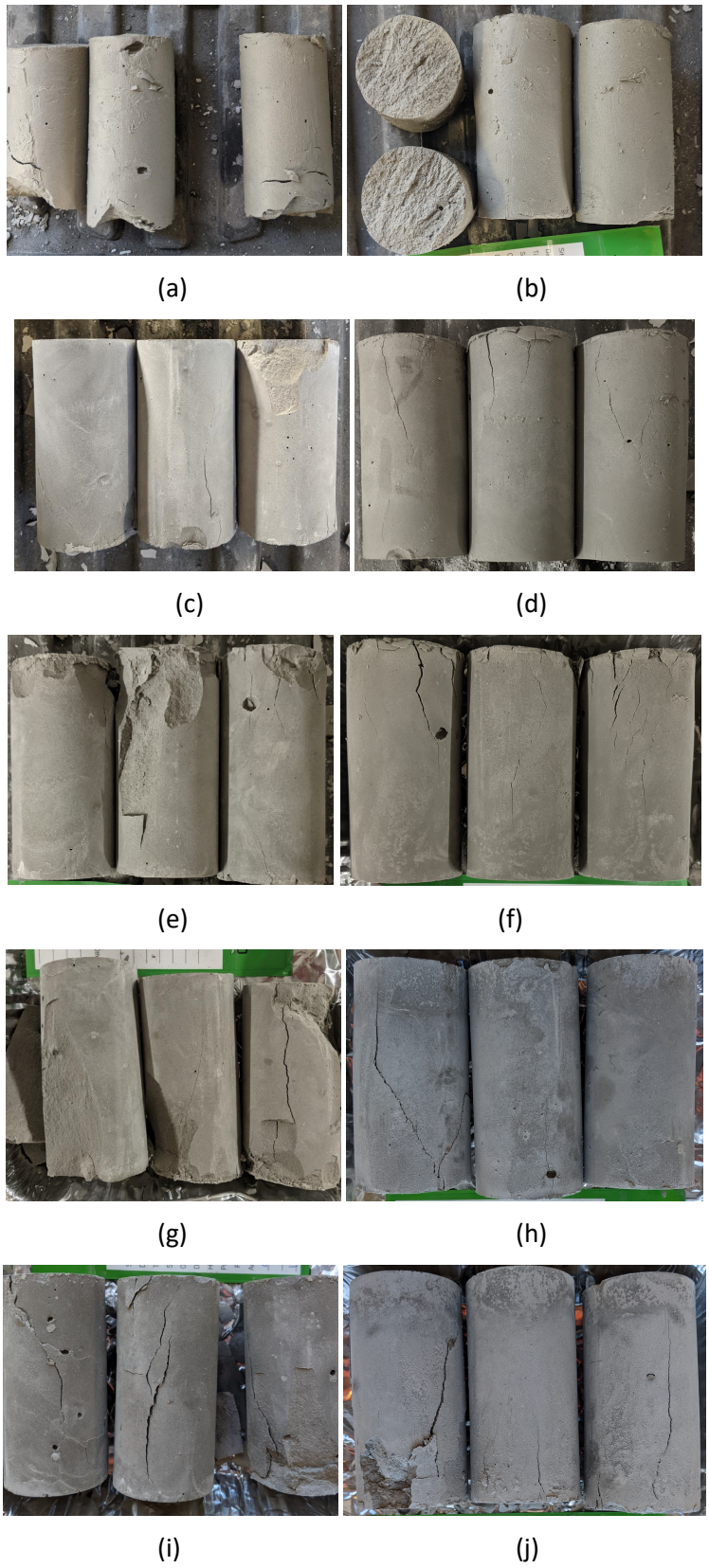

Figure 3 **Grout sample fabric following UCS testing. (a) Additive 2 four hours curing; (b) Low-heat cement four hours curing; (c) Additive 2 six hours curing; (d) Low-heat cement six hours curing; (e) Additive 2 eight hours curing; (f) Low-heat cement eight hours curing; (g) Additive 2 10 hours curing; (h) Low-heat cement 10 hours curing; (i) Additive 2 12 hours curing; (j) Low-heat cement 12 hours curing**

The test samples were cut, where possible, to ensure flat perpendicular ends of the sample specimen prior to testing; however, given the relatively low strength of the low-heat cement grout samples, this was not always possible. As a result, the reliability and reported strength achieved may not represent the full strength of the sample at the tested curing time.

3 Lab accredited UCS testing

A subsequent testing program was developed in addition to the UCS testing completed on site. This test program used freshwater from Nova mine to best replicate conditions during mixing of grout while underground. This included four sets of UCS tests at one day/24 hours, seven days, 14 days, and 28 days. These intervals were used to assess the early strength (24 hours) of Additive 1, as well as develop a curing curve for long-term strength.

4 Pull test results

4.1 Additive 1 trial

The first trial was completed on 9 March 2021 in the BOLL 1855 OD 72. A total of nine cable bolts were installed and pull tested after four, five and six hours of curing time. The results (Figure 4) show that there is an almost doubling in pull-out resistance as the cable bolt length doubles. For each cable bolt pulled, there is a rapid increase in strength by five hours. Cable bolt yield strength is 212 kN and as such, the cable bolts pulled beyond this load had similar performance. No baseline testing against standard low-heat cement was completed at the time of the trial.

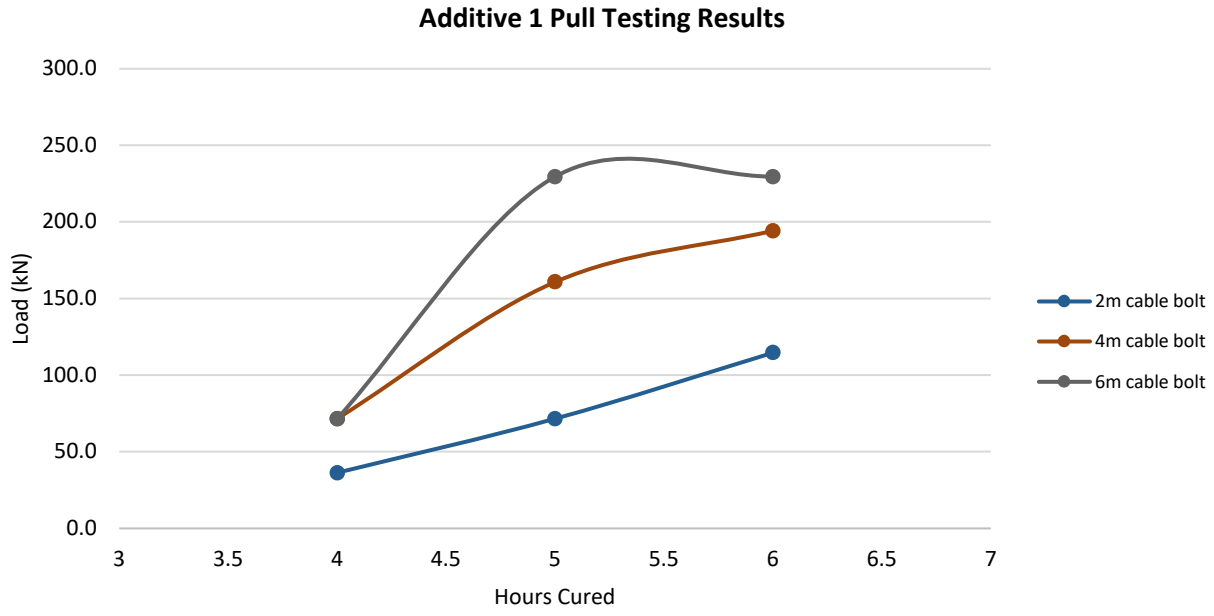

Figure 4 Pull test loads against curing time for different length cable bolts for Additive 1 trial

4.2 Additive 2 trial

The second trial was completed 28 July 2021 in the NOVA 2030 OD. Twelve 64 mm diameter horizontal holes were drilled in the wall of the drive for ease of grouting and pull testing access. There were 4 × 2 m, 4 × 4 m, and 4 × 6 m length holes with matching single strand bulbed cable bolts installed. For each length, three of the samples were to be installed using a grout mix with the Additive 2. The final hole had a standard grout mix, without the additive added. Pull test results for the powder additive are shown in Figure 5.

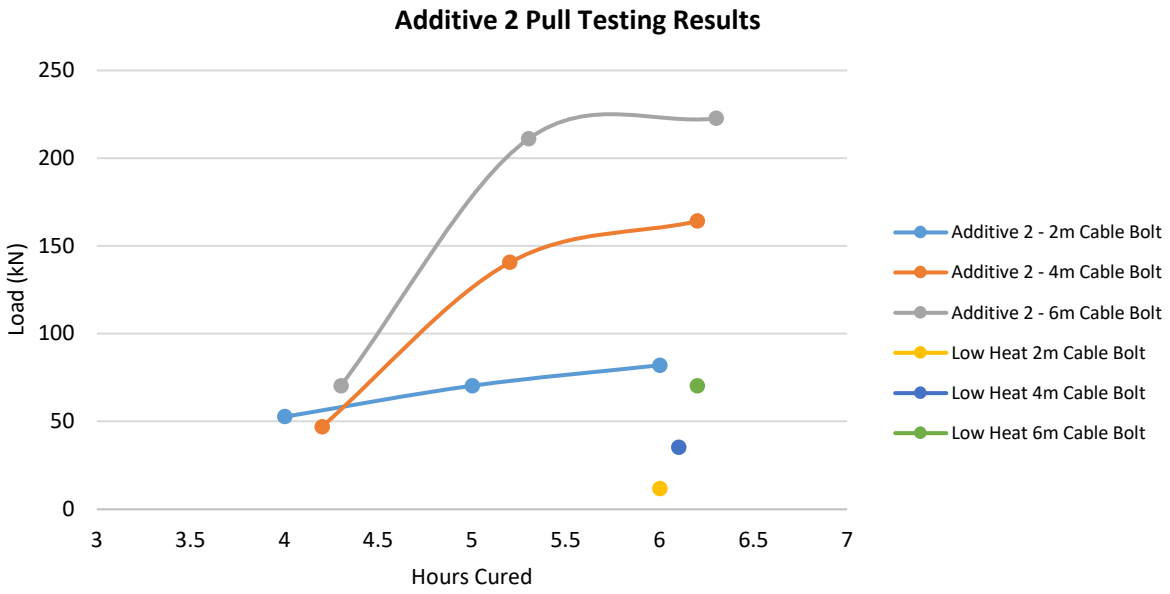

Figure 5 Pull testing Results from powder additive cable bolts tested

The Additive 2 trial produced similar pull test results as the Additive 1 trial. The most noticeable difference between the Additive 2 grouted cable bolts and the low-heat cement grouted cable bolts is the rapid increase in pull-out strength for each interval. The peak loads achieved at five and six hours for the 6 m cable bolt show that the cable bolt has reached yield strength (212 kN [Normet 2023]). Figure 6 shows the combined results for both trials.

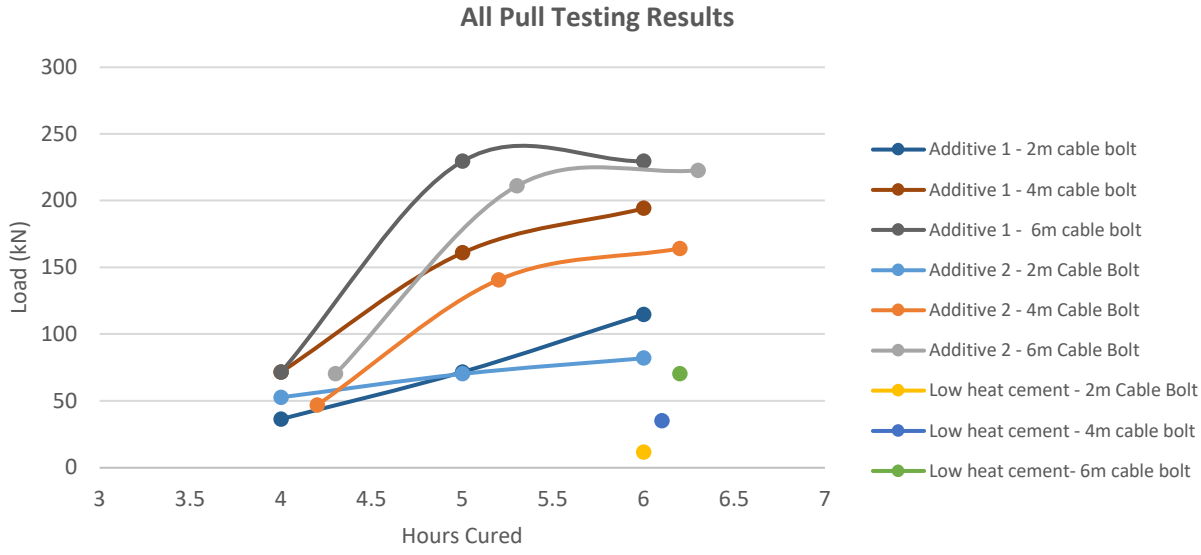

Figure 6 Combined pull testing results for liquid and powder additive

Based on the pull test results, when using Additive 2 for 6 m cable bolts in development cable bolting applications, plating, and tensioning can reasonably be achieved after six hours of curing time. This time allows for potential variations in mixture and grouting of the cable bolts.

5 UCS testing results

Results for both the site-based UCS testing and SGS-based UCS testing are shown in Figure 7. The low-heat test results show a large amount of variability due to testing samples at the paste plant and difficulties de-moulding low strength samples.

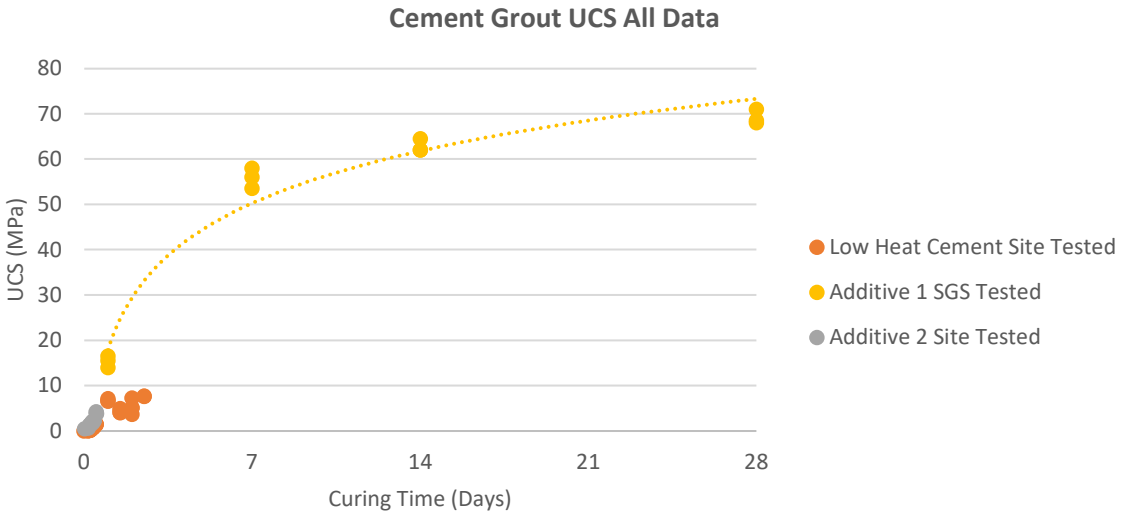

Figure 7 Comparison of uniaxial compressive strength (UCS) testing on site, accredited laboratory testing and site QA/QC data

5.1 Additive 2

The Additive 2 grout samples site-based lab testing was somewhat inconclusive about peak strengths that can be achieved within 12 hours of curing. The site-based UCS data was highly variable, likely due to the poor end preparation of test specimens due to low strengths in the first four to six hours. The National Association of Testing Authorities accredited SGS suite of testing conducted on Additive 1 provided a much more reliable dataset to review against the current low-heat cement testing data. In addition to Additive 1 results, the current Builders Choice low-heat cement (BGC Cement 2023) used for cable bolt grouting and another product, SikaGrout HES (high early strength) (Sika Australia 2023b) testing data, was added for comparison (Figure 8).

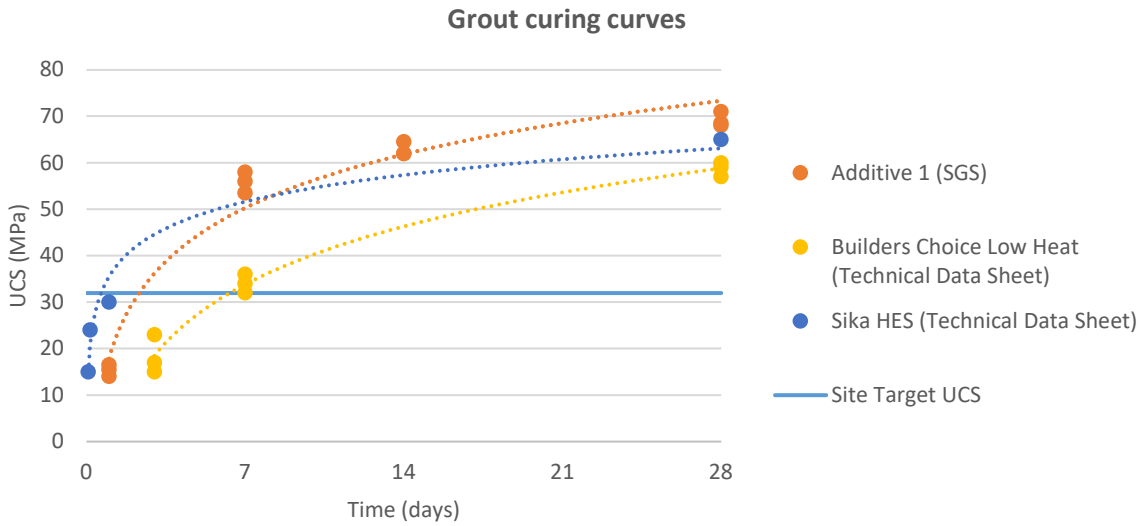

Figure 8 Grout curing curves for various cement grouts

The Additive 1 lab testing shows that the product can easily achieve the 32 MPa target UCS after approximately three days. This high early strength means bringing cable bolts into service at an earlier time. The Additive 1 grout admixture shows a lower early strength when compared to the SikaGrout HES, however, has a much higher early strength when compared to Builders Choice low heat without methocel and a higher 28-day UCS strength compared to both the HES and low-heat cement.

5.2 Low-heat cement

The low-heat cement, as expected due to its gradual curing process, does not start to solidify until after 12 hours curing and hence, cannot be tensioned or brought into service. At 12 hours of curing time, the grout is estimated to have a UCS of ~5 MPa. The cable bolts would reach a strength capable of providing the cable bolt system the capacity to match that of the steel strand (250 kN) after four to six days.

6 Discussion

The pull-out testing completed on site confirms that both additives can provide adequate grout strength to be able to plate and tension cable bolts after six hours of curing time. The site-based UCS testing does not confirm the grout strength that is achieved in the four to 18 hours, as specified by Sika, due to poor site testing conditions. A small amount of shrinkage of the UCS samples was observed, however, there was no cracking of the samples which may reduce the strength of the grout and ability to create a bond between the grout and cable bolt or grout and rock.

The lab-based UCS testing of Additive 1 and comparison of the technical data sheet testing information shows that Additive 1 adds significant early strength to the low-heat cement mix. There is also an improved 28-day UCS strength for the Additive 1 mix when compared to the low-heat cement with methocel. When reviewing the Additive 1 site-based UCS testing against the SGS lab tested data (Figure 7), the early strength data does not differ greatly and somewhat follows the curing curve of Additive 1 developed from the lab testing.

Bond strength of cable bolts can be used to simplify cable bolt performance (Hutchinson & Diederichs 1996, pp. 75–100). If the results are normalised to a tonnes/metre embedment length, the results show that the additives had a range of 1.2–2.7 t/m after four hours, 3.6–4.1 t/m after five hours and 3.8–5.9 t/m after six hours. These results show good consistency over different installed lengths. The low-heat grout mix had a range of 0.6–1.2 t/m after six hours. Tables 2 and 3 show the full set of pull testing results for both trials.

Table 2 Additive 1 pull test results

Cable bolt number	Bolt length	Hours curing	Pull test result (psi)	Test results (kN)	Pull test result (t)	t/m embed length
1	2	4	1,600	36.3	3.7	1.9
2	2	5	3,000	71.6	7.3	3.7
3	2	6	5,000	114.8	11.7	5.9
4	4	4	3,000	71.6	7.3	1.8
5	4	5	7,000	160.9	16.4	4.1
6	4	6	8,500	194.2	19.8	5.0
7	6	4	3,000	71.6	7.3	1.2
8	6	5	10,000	229.6	23.4	3.9
9	6	6	10,000	229.6	23.4	3.9

Table 3 Additive 2 pull test results

Cable bolt number	Bolt length	Hours curing	Pull test result (psi)	Test results (kN)	Pull test result (t)	t/m embed length
1	2	4	2,250	52.7	5.4	2.7
2	2	5	3,000	70.3	7.2	3.6
3	2	6	3,500	82	8.4	4.2
4*	2	6	500	11.7	1.2	0.6
5	4	4.2	2000	46.9	4.8	1.2
6	4	5.2	6,000	140.6	14.4	3.6
7	4	6.2	7,000	164.1	16.7	4.2
8*	4	6.1	1,500	35.2	3.6	0.9
9	6	4.3	3,000	70.3	7.2	1.2
10	6	5.3	9,000	211	21.5	3.6
11	6	6.3	9,500	222.7	22.7	3.8
12*	6	6.2	3,000	70.3	7.2	1.2

*Low-heat cement only

7 Conclusion

The pull-out testing completed on site shows that both SikaRapid-700 L and SikaRapid-400P hardening accelerating admixtures can provide adequate grout strength to be able to plate and tension cable bolts after six hours of curing time. Early strength UCS testing conducted on site was inconclusive about SikaRapid-700 L early strengths; however, pull-out testing confirms the ability to plate and tension and bring the cable bolts into service after six hours. Both additives also had a higher 28-day UCS strength than the standard low-heat cement.

Acknowledgement

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References

BGC Cement 2023, *Low Heat Cement 20 kg*, viewed 1 March 2023, BGC Cement, Naval Base, https://bgccement.com.au/builders-choice/lh20/

Hutchinson, D J & Diederichs, M S 1996, *Cablebolting in Underground Mines*, BiTech Publishers Ltd, Richmond, pp. 72–75.

IGO Limited 2022, *Annual Report 2022*, https://www.igo.com.au/site/pdf/200c4e90-bf4e-4231-961a-dacc64e9a556/2022-Annual-Report-to-Shareholders.pdf

Normet 2023, *Cable Bolts*, viewed 1 April 2023, Normet, Salt Lake City, https://assets.ctfassets.net/idihyv8a6g5y/311Yd38bbuJdImvK2olh8Z/cda17490fe0c3a2afd835b582e0ebcba/Garock_Cable_Bolts_-_Pre-cut_and_Continuous_Coils__-_TDS_Australia_-_20230131.pdf

Sika Australia 2023a, *SikaRapid®-700 L*, viewed 1 March 2023, Sika Australia, Sydney, https://aus.sika.com/dms/getdocument.get/b51f2127-ab10-45f3-bf24-8155726547e6/sikarapid-700-l.pdf

Sika Australia 2023b, *SikaGrout® HES*, viewed 1 March 2023, Sika Australia, Sydney, https://aus.sika.com/en/construction/grouts-landscapinganchoring/cementitious-grouts/sikagrout-hes.html