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Development, trials and testing of an innovative method to improve strength characteristics of hollow cable bolts

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DEVELOPMENT, TRIALS AND TESTING OF AN INNOVATIVE METHOD TO IMPROVE STRENGTH CHARACTERISTICS OF HOLLOW CABLE BOLTS

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ABSTRACT: The 70 t Sumo is a resin point-anchored, pre-tensioned, post-grouted hollow cable bolt for tunnel roof support, particularly in poor ground conditions. An innovative ancillary product to the 70 t Sumo is the Booster cable, which is designed to reinforce the Sumo and enhance the systems shear and tensile performance. The Booster cable is an 11 mm 7-wire PC strand with a nominal breaking load of 15 tonnes, which is inserted into the hollow centre tube of the 70 t Sumo after grouting, while the grout is still pliable. Theoretically, the Booster can increase the tensile and shear capacity of the 70 t Sumo by up to 20%. The Booster reinforced 70 t Sumo is useful in high demand conditions where additional support strength is required without the need to install new support.

This paper will present results from laboratory tests undertaken to quantify the tensile and shear characteristics of the 70 t Sumo reinforced with the Booster cable. A case study of a support trial using Booster reinforced 70 t Sumo cable bolts at a Dendrobium is also presented in this paper. The Booster cable successfully reduced 70 t Sumo cable bolt densities by 25%, from four cables per meter to three.

INTRODUCTION

High-strength, post-grouted hollow cable bolts have become ubiquitous in the coal mining industry for both primary and secondary support in demanding conditions. The popularity of the hollow cable bolt stems from a combination of its high load bearing capacity, flexibility and convenient installation method, when compared to other types of cable bolt products. Hollow cable bolts are installed by point anchoring cable with polyester resin capsule (either off the continuous miner or as a secondary process out-bye), pre-tensioning (using hydraulic tensioners or a torque-tension device) and then fully encapsulating in grout. The grouting process uses a top-down technique facilitated by the hollow centre tube. In general, cable bolts are used to anchor the immediate roof to deeper, more competent rock formation as well as reinforce roof strata beyond the extent of shorter, rigid rock bolts.

The 70 t Sumo is a high-capacity hollow cable bolt manufactured by Jennmar Australia. The 70 t Sumo is constructed from 12 smooth, high-tensile steel wires helically wound around a corrugated steel centre tube. The centre tube has two primary functions i.e. transmission of an encapsulating medium (typically a thixotropic, cementitious-based grout) to the end of the cable and radially supporting the outer wires under load. The corrugation in the centre tube provides rigidity in the radial direction to support the inward pressure from the outer wires when under tension whilst maximising flexibility in the longitudinal direction by minimising wall thickness. The latter aspect is critical for reducing manual handling efforts when manoeuvring the cables underground, particularly when installing off a continuous miner where space is limited. However, once the centre tube has fulfilled its function as a conduit for grout, the void within the centre tube provides little to no value to the functionality or mechanical properties of the system. A new innovative product called the Booster cable was developed to take advantage of this fact by introducing a secondary reinforcing element to occupy the hollow centre tube after grouting and enhance the mechanical properties of the system. The Booster cable is a seven wire 11.1mm steel strand with a nominal breaking strength of 15 tonnes. The Booster cable is inserted into the hollow centre tube immediately after grouting while the grout is still wet and pliable. The Booster cable displaces excess grout, which is expelled from the drill hole, and is eventually encapsulated by the grout as it settles around the wires. The Booster cable is retained in the centre tube by a plastic plug that engages with the grout adaptor. The plug supports the weight of the Booster cable until the grout has set.

The 70 t Sumo Booster system is adaptable. The Booster system can be deployed regularly to reduce support densities or sporadically to boost support capacity as conditions change and demand fluctuates.

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The Booster cable requires little to no additional time to install, as the process of inserting the Booster into the centre tube is concurrent to grouting.

Roof deformations such as bedding plane separation and lateral movement can induce both tensile and shear strains in cable bolts. Therefore, it was important to understand and quantify the effect of the Booster cable on the 70 t Sumo cable performance under such strains. As a result, laboratory test work in the form of single (guillotine) shear tests and double embedment pull tests were undertaken during product development. This paper will present the test methodology and results from each set of tests. To assess the in-situ performance of the 70 t Sumo Booster cable system an underground support trial was completed at Dendrobium.

LABORATORY TENSILE AND SINGLE SHEAR TESTS

Single (guillotine) shear test

Single (guillotine) shear tests were conducted on 70 t Sumo cables with and without Booster cable reinforcement to quantify the effect of the Booster on shear performance of the 70 t Sumo cable bolt. A single (guillotine) shear test setup was adopted due to its simplicity and availability to the authors at the time of product development. The shear frame was derived from the shear test setup detailed in British Standard 7861-2 (2009) for flexible roof support systems. **Figure 1** shows a schematic and photo of the single (guillotine) shear test frame and setup. A total of four shear tests were completed during development; two 70 t Sumo cables reinforced with Booster cables and two unreinforced.

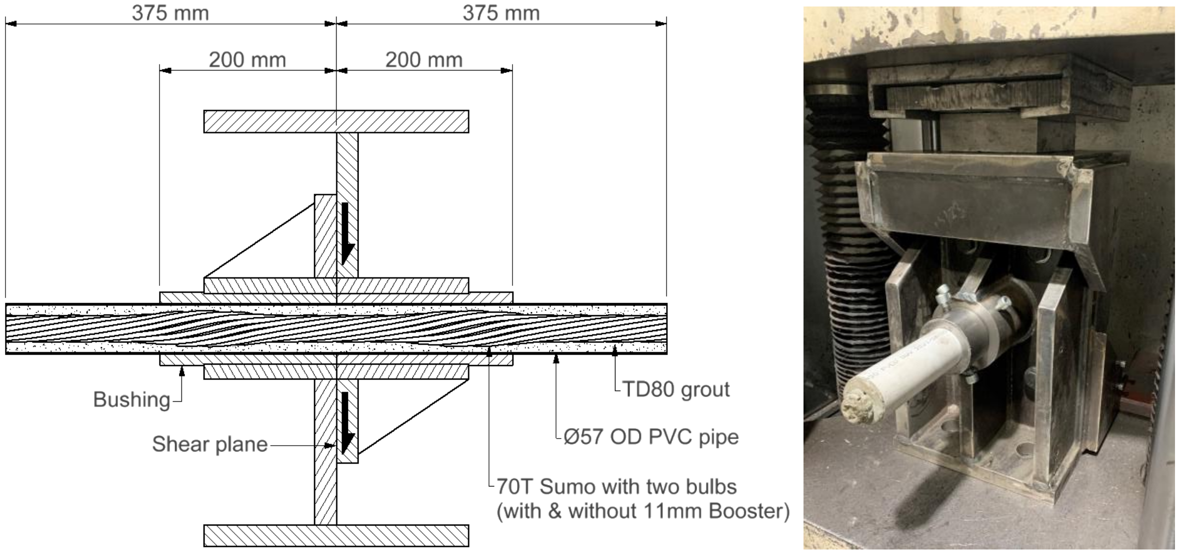

Figure 1: Single (guillotine) shear test setup (derived from BS 7861-2, 2009)

The test specimens were prepared by casting 750mm long 70 t Sumo cable, with and without Booster cables, into PVC pipe. The 70 t Sumo had two 42 mm bulbs spaced 300 mm apart in an attempt to anchor the cable either side of the shear plane. One end of the PVC pipe was taped closed and TD80 grout was poured into the pipe, mixed at the 7 litres per 20 kg bag. The cable centre tube was filled with grout, using a hand operated piston pump, and then lowered into the grout-filled PVC pipe. The cable was gradually twisted during insertion to ensure full grout penetration between the wires, particularly at the bulbs. For test specimens with Booster cables, the Booster cable was then inserted into the centre tube. The test specimens were left to cure for 28 days before shear testing was completed. Uniaxial compression strength (UCS) testing on three 50mm grout cubes yielded an average UCS of 78 MPa.

It should be noted that the PVC pipe was intact across the shear plane and could contribute to the measured shear force. However, the shear capacity of the PVC pipe was considered negligible compared to the shear strength of the cable and grout. Once the grout had cured, the test specimens were shear tested. The shear frame was prepared by applying grease (specifically, Puma Minegrease Moly EP2) to the contact faces and bolting the two halves together. The grease reduced the shear force contribution from sliding friction between the shear frame contact faces. The four M20 bolts holding the two halves of the frame together were torque-tensioned to 20 Nm. The shear guillotine frame was mounted in a 100 t universal test machine and compressive load applied to the frame at a displacement rate of 5.0 mm/min. Loading was continued until wire/strand fracture occurred or the maximum displacement limit for the shear frame was reached. The shear frame was dismantled after each test to inspect the shearing surfaces, repair any damage to the bushings and reapply grease.

Figure 3 shows a plot of the shear load versus crosshead displacement and **Table 1** provides a summary of the peak shear load and corresponding crosshead displacement for each test. The unreinforced 70 t Sumo cable achieved an average shear strength of 506 kN (or 51.6 tonnes). The 70 t Sumo reinforced with the Booster cable achieved an average shear strength of 657 kN (or 66.9 tonnes). On average, the Booster increased the shear breaking strength of the 70 t Sumo by 30%, which is higher than the theoretical increase of ~20%, based on the individual breaking strength of both cables. However, it is expected that a larger data sample size would trend towards the theoretically predicted increase of 20%. The ratio of ultimate shear strength (USS) to ultimate tensile strength (UTS) was approximately ~75% for three of the four tests as highlighted in **Table 1**. This is consistent with the general understanding that the USS of steel is approximately 75% UTS.

It should be noted that the ends of each cable specimen were terminated by welding the individual wires together. During shear loading, the welds broke allowing the wires to slide independently of one another and pull through the grout annulus.

Without Booste With Booster

Without Booster (top); With Booster (bottom)

Without Booster With Booster

Figure 2: Various photos of 70 t Sumo with and without Booster after single (guillotine) shear testing

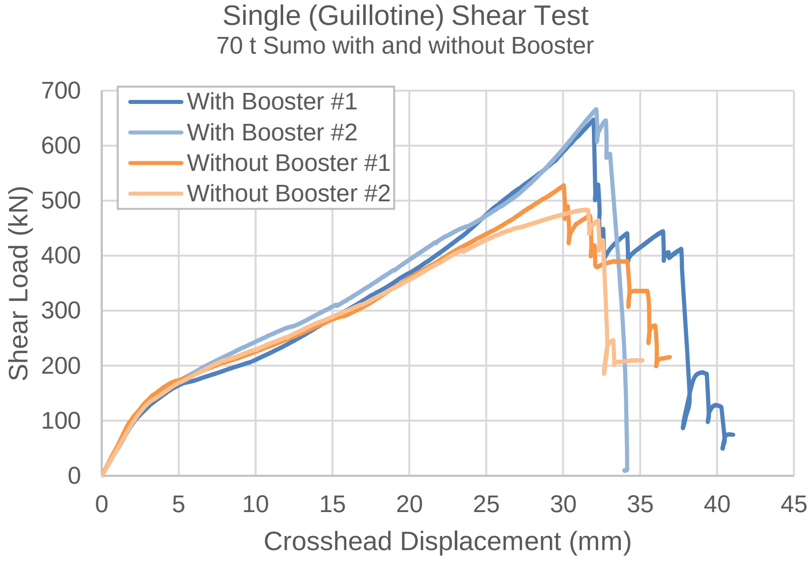

Figure 3: Load vs crosshead displacement results for single guillotine shear tests on 70 t Sumo with and without Booster reinforcement

The wires exhibited characteristic shear-type failure as illustrated by photos of the cables after testing in **Figure 2**. The shear failure resulted from steel on steel contact between the wires and the bushing, also highlighted in **Figure 2**. It is quite apparent that this type of contact does not occur in-situ and is one of the main drawbacks with this particular type of shear test setup; a point that was also highlight by Aziz, et al (2016). When cables are sheared underground, the less stiff rock tends to crush locally allowing the cable to bend rather than shear. Bending allows the wires to load in tension rather than shear, resulting in a higher shear force resistance. Therefore, the single (guillotine) shear test is considered more aggressive and conservative compared to other types of shear test setups that more realistically simulate rock with concrete blocks; such as double shear test setups used by Aziz et al (2015 and 2016) and Craig and Aziz (2010) and single shear setups used by Aziz et al (2017). That being said, the single (guillotine) shear test does provide an effective means to compare the shear performance between similar systems. Future testing of the 70 t Sumo Booster with double or single shear test setups that use concrete blocks would be beneficial.

Table 1: Summary of single (guillotine) shear test results

Specimen configuration	**Ultimate shear strength, USS (kN)**		**Crosshead displacement at USS (mm)**	**USS / UTS$_{avg}$ (%)**
	#	Average		
Without Booster	528 (53.8)	506 (51.6)	30.81	74%
	484 (49.3)		30.80	68%
With Booster	647 (66.0)	657 (66.9)	32.81	75%
	666 (67.9)		33.03	77%

Double embedment pull test

The double embedment pull test aimed to determine the tensile performance benefit of the Booster cable to the 70 t Sumo cable bolt system. It was unknown to what extent tensile load would be transferred through the various components in the 70 t Sumo Booster cable system. The composite nature of the system results in numerous interfaces, through which load must be transferred. Of particular interest was the load transference from the outer wires through the centre tube. It was predicted that the combination of regularly spaced bulbs and the corrugated centre tube would provide the best degree of load transference to engage the full capacity of the Booster strand. The bulbs spaced at 500 mm centres allows grout to penetrate between the wires and encapsulate the corrugated centre tube. The corrugations in the centre tube create a mechanical interlock between the inner and outer grout annuli that can more effectively transfer loads to the Booster cable than a straight, smooth tube.

The test specimens for the double embedment pull test were prepared by casting 1.5m long 70 t Sumo cables, with and without Boosters, into an axially split pipe. Two 750 mm long high-tensile steel pipes were joined end-to-end with a plastic PVC coupler and tape. The PVC coupler ensured the longitudinal axes of the pipes were properly aligned. The end of one pipe was sealed closed with tape. The high-tensile steel pipe was internally threaded along the entire length with a M42 x 2.0 metric thread to simulate a rough drill hole and ensure bond failure occurred at the cable/grout interface as opposed to the grout/pipe interface.

TD80 cement grout was mixed at 7 litres per 20kg bag and pumped into the centre tube of the 70 t Sumo cable using a hand-operated piston pump. The cable had four bulbs located along its length to anchor the cable inside the steel pipe. Two bulbs were positioned either side of the pipe joint, leaving a straight section of cable across the joint as illustrated in **Figure 4**. The bulbs were spaced 250mm from each other and the centremost bulbs 275mm from the pipe joint. The pipes were filled with grout and the 70 t Sumo cables were lowered into the pipes. For test specimens with Booster cables, the Booster cable was then pushed into the grout-filled centre tube. The specimens were left to cure for 28 days before testing. Uniaxial compression strength (UCS) testing on three 50 mm grout cubes yielded an average UCS of 78 MPa. Once the grout had cured, the test specimens were pull tested. The specimens were mounted into a 100 tonnes universal testing machine using two sets of gripper jaws. The gripper jaws were spaced 740mm apart and equidistant from the pipe joint as illustrated in **Figure 4**. Tensile load was applied to the specimens at a displacement rate of 25 mm/minute until wire fracture occurred. Four double embedment pull tests were completed; two 70 t Sumo cables reinforced with Booster cables and two without.

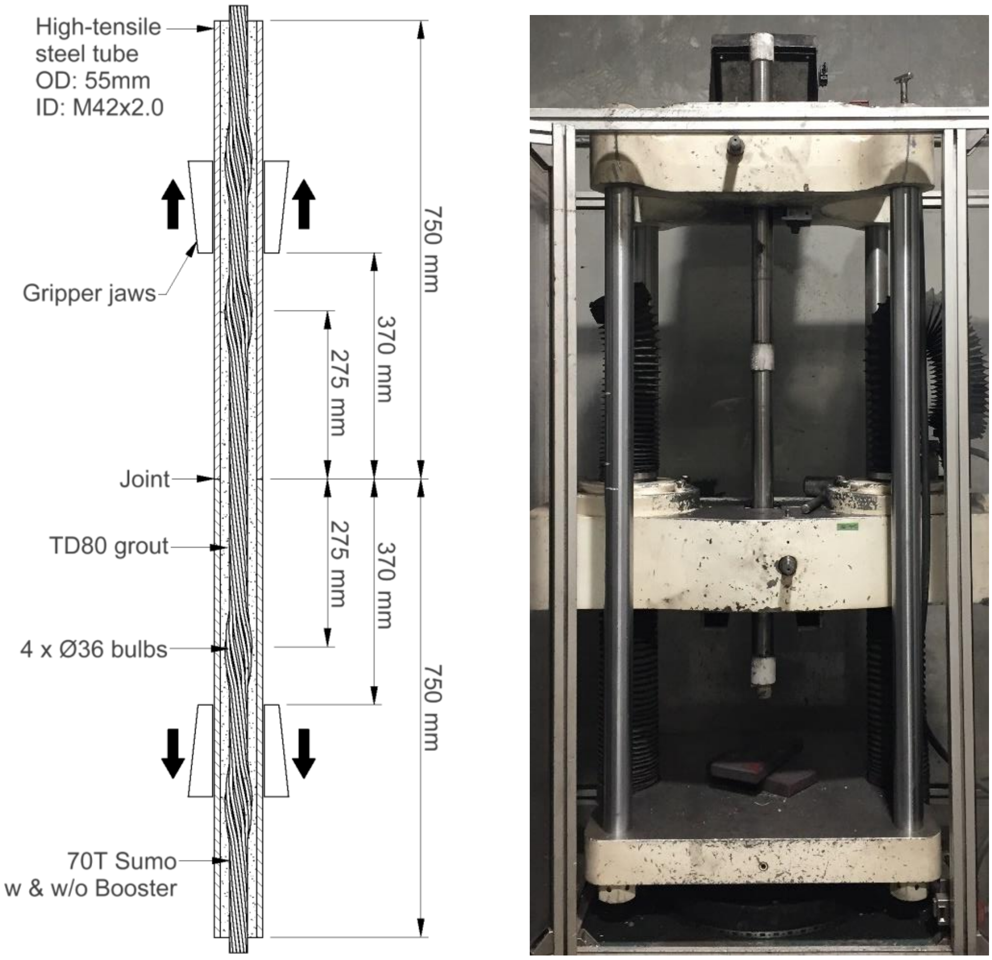

Figure 4: Setup for double embedment pull test

Figure 6 shows load versus crosshead displacement graph for all four double embedment pull tests. **Table 2** provides a summary of the peak load and corresponding crosshead displacement for each test. The unreinforced 70 t Sumo cable reached an average breaking strength of 711 kN (or 72.5 t). The

70 t Sumo reinforced with the Booster cable achieved an average breaking strength of 861 kN (or 87.8 tonnes). On average, the Booster increased the tensile breaking strength of the 70 t Sumo by 21%, which is close to the theoretical increase based on the individual breaking strengths of both cables.

The majority of crosshead displacement could be attributed to gripper jaw movement as well as some degree of debonding between the cable and grout annulus. The extent of debonding was unknown but most probably extended along the straight section of cable between the two, centremost bulbs on either side of the pipe joint. Confinement from the gripper jaws may have also influenced the level of debonding.

All wires fractured simultaneously in all four tests, including the Booster cable. **Figure 5** shows the wire fracture surfaces for both the unreinforced 70 t Sumo and 70 t Sumo reinforced with the Booster cable. As can be seen in the photos, the wires exhibited cup-cone type fracture, which is typical of a ductile tensile failure.

As with most laboratory based tests, the double embedment pull test does not exactly simulate in-situ loading conditions. However, the test setup did provide a good method for assessing the relative tensile performance enhancement of the Booster cable, similar to the single (guillotine) shear test.

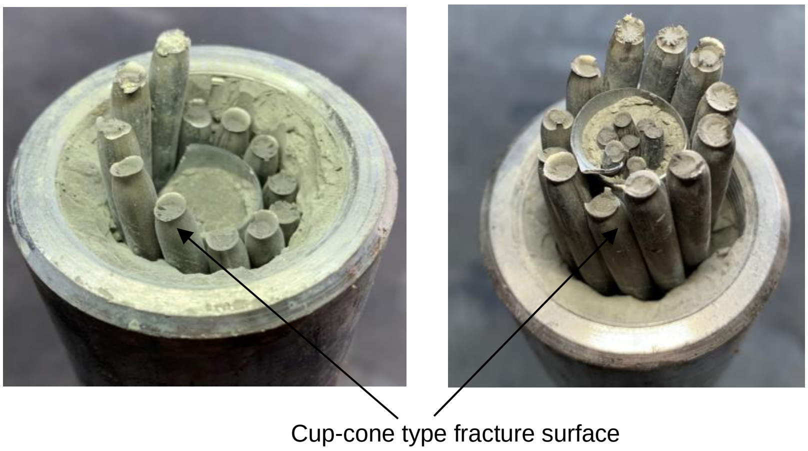

Figure 5: Typical wire fracture surfaces from tensile overload: 70 t Sumo (left), and 70 t Sumo with Booster (right)

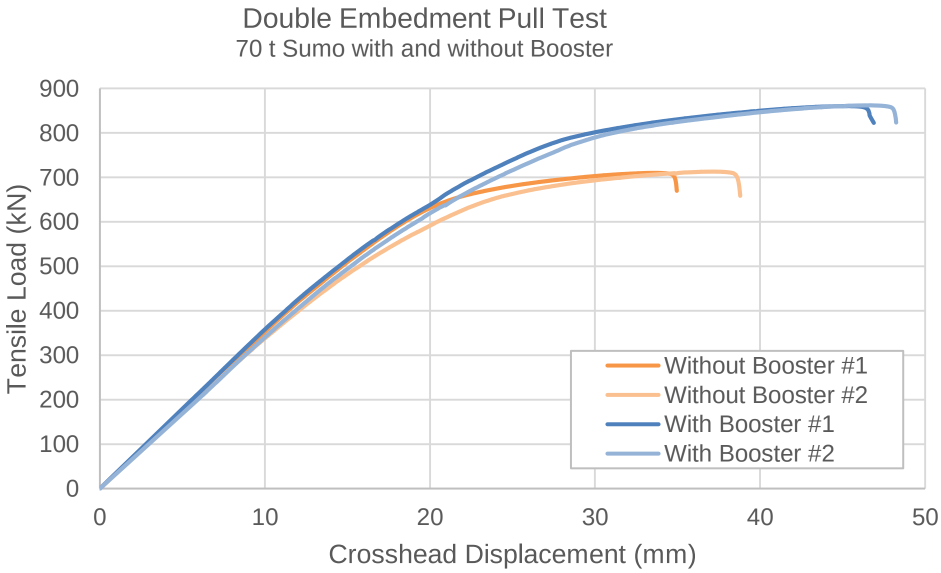

Figure 6: Load versus crosshead displacement results for double embedment pull test on 70 t Sumo cable with and without Booster cable reinforcement

Table 2: Summary of double embedment pull test results.

Specimen configuration	Ultimate tensile strength , UTS (kN (t))		Crosshead displacement at UTS (mm)
	#	Average	
Without Booster	710 (72.4)	711 (72.5)	35.55
	713 (72.7)		37.16
With Booster	860 (87.7)	861 (87.8)	46.50
	862 (87.9)		46.67

UNDERGROUND INSTALLATION TRIALS

The first underground support trial for the 70 t Sumo Booster cable was conducted at South 32's Dendrobium Coal Mine. Over 1,000 70 t Sumo Booster cables were installed as secondary support in a maingate heading. The secondary support pattern consisted of three 70 t Sumo Booster cable per meter, varying in length from 8.2m - 10.2m depending on the support requirements. The pattern replaced a 4 x 70 t cable bolt per meter pattern typically used for structured and high stress notch areas in the gate roads. **Figure 7** shows the 70 t Sumo Booster cables installed in the roof. The 70 t Sumo cables were installed off a new over-belt bolting unit, which provided easier access for grouting and insertion of the Booster cables. The over-belt bolting unit also permitted even spacing of the cable bolts across the roadway.

Figure 7: Photos of 70 t Sumo reinforced with Booster cable installed underground at Dendrobium

Lithology and geotechnical setting

The Wongawilli coal seam is 9 - 10m thick in the area. The bottom 3.5 – 4 m of the seam is mined, leaving ~5m of weak strata in the immediate roof horizon. The overlying unit is typically laminated sandstone and siltstones up to 60 MPa UCS. There are moderate levels of small faulting, typically normal faults of between 0.05 - 0.3 m displacement. The small faults are associated with a large fault system approximately 150 m away that has a displacement of up to 25 m. The general area has a CMRR of around 34-35 and the depth of cover ranges from 360 m to 380 m. The cables were located at the start of a main gate stress notch after coming out of the shadow of the adjacent longwall goaf. This area often sees up to 200 – 300 mm of roof sag and floor heave up to 400 – 500 mm. Typically, support designs assume a horizontal to vertical ratio of 2.5 in this area.

Trial outcomes

The 70 t Sumo Booster cables performed as expected. There were similar amounts of roof movement and roadway deterioration to previous longwall gate roads supported with a four by 70 t hollow cable pattern. For instance, tell-tale data from a 4-way indictor, located ~16 m from the longwall face, showed total roof movement of 45 mm (with 40 mm of movement occurring in the immediate 4 meters of roof). Overall, the Booster reinforced cables managed the conditions well to ensure production was never exposed to potential strata failures in the maingate. From an operational standpoint, the implementation of the 70 t Sumo Booster enabled a reduction on support densities by 25%, resulting in cost savings in both raw material and labour to install.

Insertion of the Booster cable into the centre tube could be further optimised with the development of a tool to aid installation in mines with high roof heights. Beyond a certain height, the flexibility of the Booster cable can make it challenging to insert into the centre tube, requiring the use of a ladder or platform to minimise flexure in the unsupported section of cable. Such a tool could be of simple construction; a pipe with a clamping arrangement to attach to the 70 t Sumo tail, similar to clamp-on grouting lances. The tool would effectively extend the centre tube down to a reasonable working height and negate the need for ladder use. The Booster would be pushed through the pipe using a push rod, which would also seat the retaining plug into the grout adaptor. The tool would also include a grout shield or catcher to prevent operators being exposed to excess grout coming from the holes as the Booster is inserted, which was raised as a concern during the trial. Mine personnel also suggested that an automatic cable feeder system would make Booster insertion faster and less strenuous on operators. It would be worth considering developing such a feeder system in the future.

CONCLUSIONS

Laboratory experiments demonstrated that the Booster cable improves both the tensile and shear performance of the 70 t Sumo hollow cable bolt. Double embedment pull tests showed that the Booster cable improved the 70 t Sumo tensile strength by up to 20%, from 711 to 861kN. Single (guillotine) shear tests that the Booster cable improved the 70 t Sumo cable shear strength in excess of 20%, from 506 to 657 kN. Although both tests were not truly representative of in-situ loading conditions, the test results provide sufficient comparative assessment of the performance benefit of Booster cable reinforcement.

Successful bulk support trials were completed at Dendrobium in a longwall maingate heading. Over 1000 8.2 m and 10.2 m 70 t Sumo Booster cables were installed as secondary support prior to longwall retreat. Support densities were successfully reduced by 25%, from four cable bolts per meter to three, by using the 70 t Sumo Booster cable system. The system successfully supported the gate road during longwall retreat, with the roadway exhibiting similar roof movement and deterioration to previous longwall panels using the denser cable bolt pattern.

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