Deep Mining 2024 – P Andrieux & D Cumming-Potvin (eds)

doi:10.36487/ACG_repo/2465_30

The development of the peg bolt

Bradley Darlington [a,*], Matthew Farrington [b], Osvaldo Vallati [a]

[a] *Sandvik, Australia*

[b] *Fosterville Gold Mine, Agnico Eagle Mines, Australia*

Abstract

Installation quality of ground support elements is critical to the overall safety of underground mining environments. Visual inspection of rockbolt installation quality is a common practice. For some products it is difficult to visually determine a successful installation. The Sandvik MD and MDX bolts are examples of bolts which are difficult to visually determine correct installation, due to the blind nut configuration lacking tail protrusion. Sandvik has recently developed the peg bolt, a simple reliable visual indicator of bolt rotation to provide mine site personnel with an easy method to visually inspect bolt installation quality. This device has the capability to improve and simplify ground support installation quality assurance practices of the mine site. This paper will present the development of the peg bolt along with a case study.

Keywords: *ground support, quality assurance, product safety*

1 Introduction

Ground support plays a fundamental role in the safe operation of underground mines. Without appropriately designed and installed ground support, the underground mining environment presents significant risk to the safety of miners (Dunn 2013). The past several decades have seen significant improvements to ground support elements (rockbolts) and installation methods. These improvements have seen a move away from hand-held bolting practices and towards larger more remote bolting machinery; more recently towards automated bolting equipment. With this move away from hand-held bolting methods, there is potential for a disconnect between operator and installation, which can provide opportunity for reductions in installation quality.

Ground support installation quality is paramount to implementing an effective ground support scheme, where poor quality or incorrect installation can lead to increased safety hazards or production loss (Viljoen & Murphy 2019). Assessing installation quality post installation can be a difficult task, as such, several methods can be utilised across the industry including visual inspection, material and component strength testing, operator auditing/installation monitoring, documentation, operator training and certification and non-destructive pull testing (Stephenson & Sandy 2017).

Product quality management can be divided into two categories:

1. quality control (QC)
2. quality assurance (QA).

These terms are often used interchangeably but are in fact quite different. QC involves methods to ensure a product meets specifications or standards and is aimed at detecting and correcting defects or deviations in product quality prior to the product reaching the customer. Whereas QA is the process of ensuring that quality standards are followed to prevent defects or deviations from occurring.

* Corresponding author. Email address: bradley.darlington@sandvik.com

Visual inspection is used to determine any visible installation quality issues, such as installation angle, loose components (observable gaps between components and the rock surface) and partially installed components. However, visual inspection cannot determine the quality of the product installation inside the rock mass.

Ground support suppliers conduct component testing to determine/demonstrate product conformance to design specifications and standards. This testing is typically conducted on completed products and forms part of the suppliers QC process. This testing can include tensile testing, corrosion testing, compression testing, weld quality testing and coating quality testing.

Operator auditing and installation monitoring is another method used, which provides firsthand information on the conformance to installation methodology and procedures. This method allows determination of whether the support component has been installed using the correct procedure, and any complications experienced during installation. However, this process again does not necessarily assess whether the component installation has achieved the desired/designed system strength.

Operator training and certification is essential for an effective QA system, as the operators have the responsibility to correctly follow installation procedure and practices. Operator training and certification is not only conducted to ensure operator competence with the machine, but also the operators’ competence to install the specific ground support element. It is common practice for ground support suppliers to provide operator training when introducing new or modified ground support products. This ensures the operators are aware of changes to products and procedures.

Non-destructive pull testing is used across the world at mines of all types to test the installation quality on a sample of bolts. This method can be utilised to test all bolting products and has the best ability to determine if a bolt has been installed correctly. However, this process is typically conducted sometime after bolt installation, which leaves a potentially long feedback cycle. Additionally, if rockbolts are found to fail the non-destructive pull test, the question remains on the condition of all installed bolts in that mining area.

QC documentation provides an administrative control to installation quality by providing a method for collecting quality procedures, standards, certifications and reports. These systems provide a formal framework for mine site personnel to effectively manage the different quality systems and allow compliance with required legislation.

If these quality practices are not followed, poor installation quality can lead to many consequences. These range from lost production efficiency (longer time required to support headings), additional rehabilitation requirements, increased product waste (additional bolts required to ‘replace’ poorly installed bolts) and increased risk of fall of ground events.

2 Peg bolt design development

The Sandvik MD and MDX bolts are hybrid mechanical friction bolts, utilising an external tube, internal rebar, wedge assembly at the toe end and blind nut at the bolt head, as shown in Figures 1 and 2. These bolts require percussive installation and rotation to 350–450 Nm to correctly activate the wedge system, maximising bolt anchorage. Both bolts are designed with a blind nut, which minimises bolt protrusion from the rock surface. This design feature minimises the risk of bolt interaction with passing machinery, services and mining personnel.

This blind nut design does not provide a ‘tail’ when tightening the bolt, which removes the potential for a visual aid in correct bolt installation. As such, the MD and MDX bolts prove difficult to visually determine correct installation, which is full insertion and rotation to the required torque value.

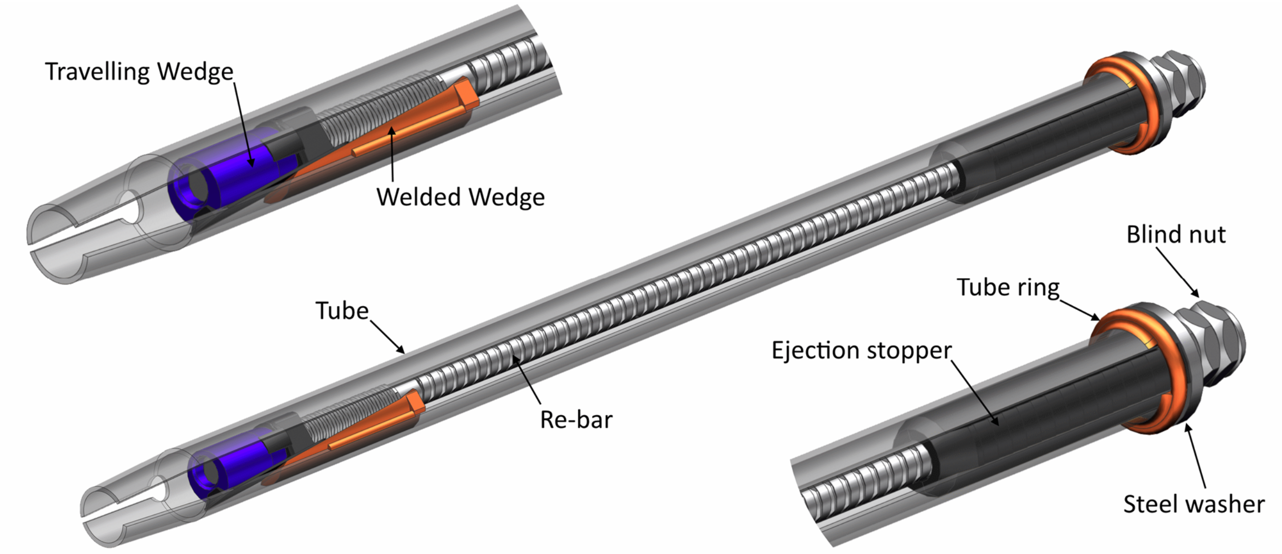


Figure 1 Anatomy of the MD bolt

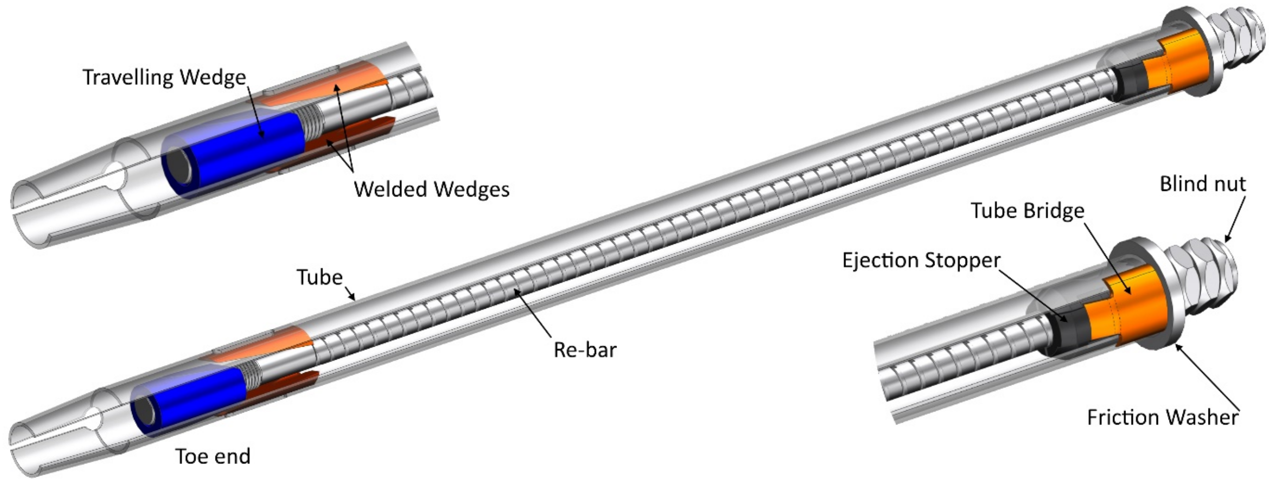


Figure 2 Anatomy of the MDX bolt

During installation, to the casual observer, the MD and MDX bolts do not show a clear visual difference before and after rotation. This makes it difficult for post installation visual inspection of installation quality, which was one of the motivations for Sandvik to develop a clear visual indication of positive bolt rotation.

During the peg bolt development phase, significant market research was conducted to establish if there was an existing concept (within Sandvik or DSI) that could be easily implemented into the MD and MDX bolts. This research identified several concepts currently utilised to identify bolt installation: compression washers, crushable components, and direct rotation indicators. However, through the initial design investigation, compression washers and crushable components were eliminated due to the chance of premature activation during percussive installation.

With direct rotation indicators as the most feasible design solution, several concepts were developed to identify the best solution. The design criteria for the final product were to be compatible with the existing MD and MDX bolt products, and to provide a lasting visual indication of bolt rotation, which is visible from an observer at ground level.

The MD and MDX bolts are currently supplied with ID tab in the end of the blind nut (Figure 3), which serve to provide easy product differentiation. During installation, this tab is undamaged, and was identified as an opportunity to form part of the indication device.

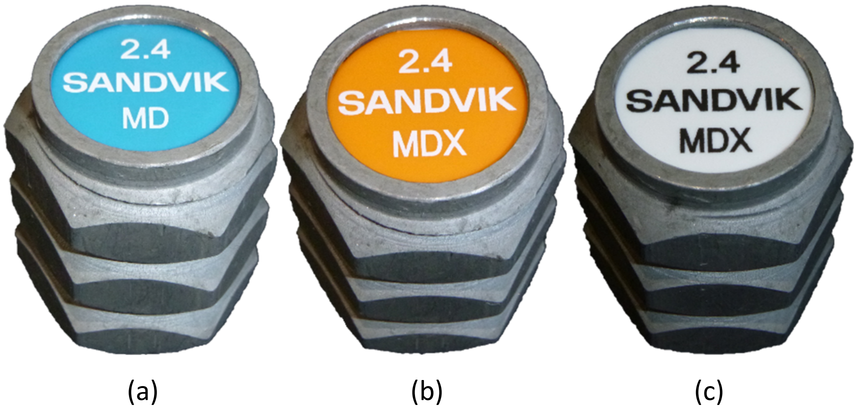


Figure 3 Bolt ID tabs: (a) MD; (b) D47 MDX; (c) D39 MDX

The concept was to use a 'peg' of sorts to protrude through or dislodge part of the ID tab, thereby showing a clear sign of bolt rotation. The method of protrusion chosen was in the form of a plastic disc positioned between the end of the rebar and the internal blind face of the blind nut, Figure 4. Upon rotation of the blind nut, the internal thread would cooperate with the rebar, providing a compressive force on the plastic disc, causing extrusion through the central hole in the top of the blind nut.

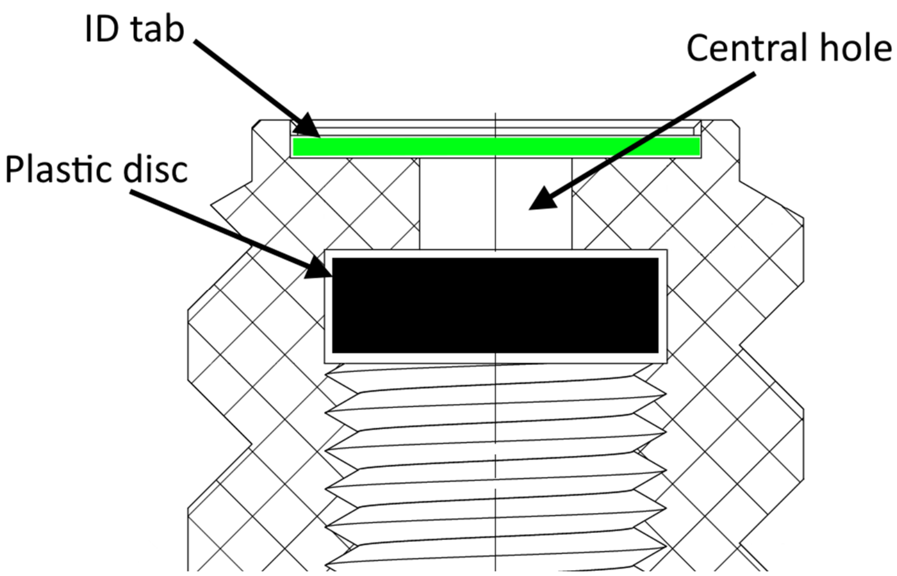


Figure 4 Blind nut geometry

The correct plastic disc material must be soft enough to extrude fully, but also maintain a solid form once extruded. Three plastics were selected to cover a range of readily available material options:

1. ultra high molecular weight polyethylene (UHMWPE)
2. polytetrafluoroethylene (PTFE)
3. high density polyethylene (HDPE).

In order to assess the suitability of these materials, each sample was assembled into a blind nut and rebar, which was secured to prevent rotation. Torque was applied and recorded for each ½ turn to provide progressive torque data and to allow photographic capture at regular intervals. The variation in the torque required to extrude the plastic discs was minimal; however, the shape of the extruded disc varied greatly between samples.

The UHMWPE extruded with an initially solid peg reaching a torque of 100 Nm within two rotations; however, as the rebar reached the end of travel within the blind nut, the extruded peg became hollow and very fragile, as shown in Figure 5. The PTFE disc showed poorer peg form than the UHMWPE, where the extruded peg was hollow and brittle for the entire test, as shown in Figure 5.

(a) (b)

Figure 5 Extruded pegs: (a) Ultra high polyethylene; (b) Polytetrafluoroethylene

In contrast, the HDPE material extruded in a solid peg for the full test, and remained intact and secured to the blind nut, as shown in Figure 6. The HDPE disc was a clear standout and demonstrated excellent extrusion while maintaining structural integrity.

Figure 6 Extruded polyethylene peg

The torque comparison between the three sample sets was quite interesting, as shown in Figure 7. The UHMWPE reached an initially high torque within two rotations, but then reduced the torque at three rotations before peaking at four rotations. The maximum travel of the thread was reached at four rotations, which explains why all samples peaked at this point. The PTFE also showed a similar initially higher torque before reducing towards 3.5 rotations. This reduction in torque seems to replicate the behaviour of the peg, where the initial solid extrusion requires a higher torque, and the torque reduces as the extruded peg loses solidity. The HDPE samples showed quite different behaviour, with a gradual increase in torque through the test and only a minor decrease at three rotations. This is reflected in the consistently solid extrusion of the HDPE peg as shown in Figure 6.

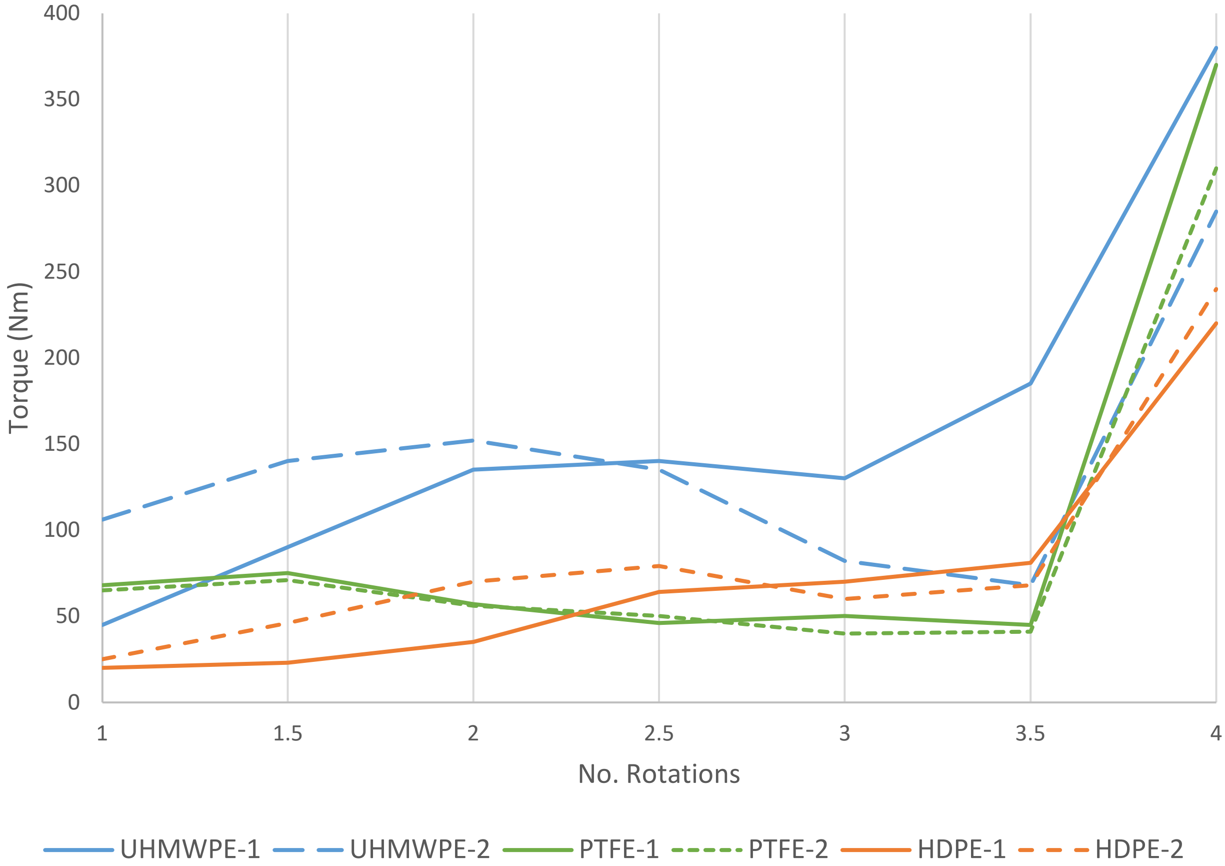


Figure 7 Rotations versus torque results

As the HDPE disc extrudes through the central hole, it will push against the ID tab, which should remain in place after bolt installation. As such, a central flap was pre-cut into the ID tab, to allow the central portion of the ID tab to displace while leaving the remainder of the ID tab in place.

In order to determine the functionality and suitability of the plastic HDPE disc for the MD and MDX bolt, percussive installation was utilised. Typically, this requires a field trial to utilise a mine sites' jumbo; however, Sandvik Ground Support R&D has recently designed, built and commissioned a Bolt Installation test stand (BIT). This rig combines existing Sandvik components, including a rockdrill and a feed, with a custom-built hydraulic control system. Test samples are installed into pre-cast and drilled concrete blocks secured onto the self-resisting frame. The rig is operated from a touch screen control panel and joysticks. Joystick mode replicates the underground operations, while the touch screen control allows for fine adjustment and automated test sequences.

The installation process follows the standard underground operation. The bolt is firstly hammered into the pre-drilled blocks using an installation driver. As the feed moves forward, the rockdrill hammering function is activated. Once the bolt is fully inserted, both hammer function and feed movement stop, and left hand rotation is applied until 400 Nm is achieved. At the end of the installation, the feed retracts exposing the extruded peg of the bolt.

The BIT testing demonstrated successful peg extrusion after percussive installation, including displacing the central flap of the ID tab, as shown in Figure 8. This successful percussive installation test was the final laboratory testing required prior to a large-scale field trial.

(a) (b)

Figure 8 (a) Peg bolt ready to be installed with the bolt installation test stand (BIT); (b) Extruded peg bolt in BIT

To maximise the visibility and functionality of the peg as a visual indication of bolt rotation, the plastic peg colour is paramount. The MD and MDX bolt ID tabs are currently three colours: blue, orange and white, as shown previously in Figure 3. To optimise the peg colour to match these three colours, and to serve as a sign of positive installation, green was selected for the peg material, which is reinforced by the universal idea that green is a positive colour.

3 Case study

A large-scale field trial is key to successfully completing the design of any new ground support product, as the underground environment can often present different challenges to a laboratory environment. In the case of the peg bolt, two crates of peg bolts were tested for installation performance. These included one crate of 120 MDX peg bolt and one crate of 120 MD peg bolts. Two different colour schemes were used for the trial: white peg with green ID tab (D47 MDX bolt) and green peg with orange ID tab (MD bolt).

These trial bolts were installed using standard installation jumbo's, drivers, operators and procedures. The trial site for these bolts was Agnico Eagle's Fosterville Gold Mine Located 30 km east of Bendigo in Victoria, Australia. The installation locations for the MDX bolt sample were: H4270 ACC, P3765 ACC and RH4580 INC, and the MD locations were RH Incline, RH 4560 SP1.

The installation locations were all areas where the drives are required to remain serviceable for many years, and where mining-induced stress change and associated rock mass damage is anticipated to cause deformation and loading of the rockbolts. When developing an intersection, cable bolts are typically installed prior to mining the fillet cut (for example first cut of RH4560 SP1). This might provide adequate support for large wedges, however the absence of cable bolts within the fillet cut (Figure 9) creates a vulnerability for rockburst damage as further development cuts increase the stress load on the intersection. Second pass cable bolts within the fillet cut will be preferred, however, to maintain development productivity, they may not be installed until much later, or not at all. The MD bolts installed in the fillet cut are now essential to control potential rock bursts and rock mass damage. The pegs provide visibility on the quality of the MD bolt installation, giving confidence that the bolts will perform as expected.

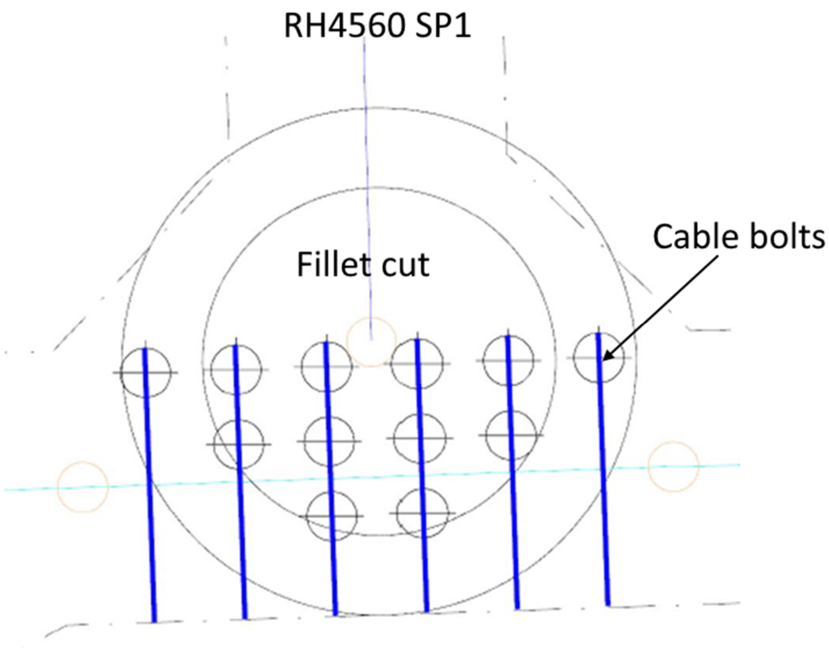
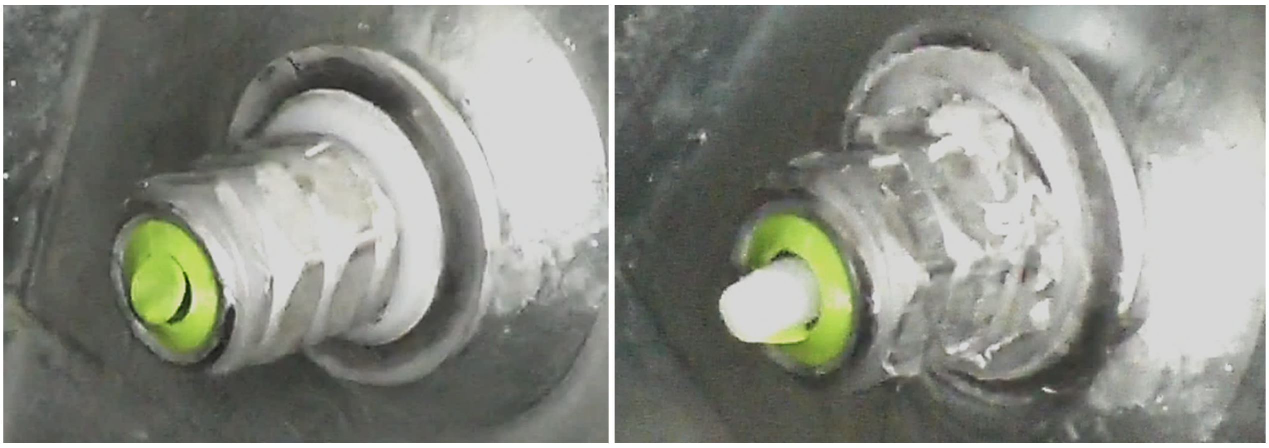


Figure 9 Fillet cut geometry

The results from the MDX trial showed the peg extruded very well, with a clearly visible indication that bolt rotation was applied to the test sample. The pegs were clearly visible from ground level; however, the combination of green ID tab and white peg was not as striking as initially thought. Operator feedback from the MDX trial was that the pegs were a 'handy indication of bolt rotation' and they were particularly good to remind the operator to check any bolts that were inserted only and not rotated during mesh installation and alignment. An example of the bolt before and after rotation is shown in Figure 10.



(a) (b)

Figure 10 (a) MDX peg bolt before rotation; (b) After rotation

The MD trial, conducted with a different crew and an older jumbo, showed a mixture of results; where approximately 60% of the samples extruded the peg fully. Upon discussion with the jumbo operators, the standard practice for installing MD bolts onsite is to apply rotation until the rotation pressure reaches 120–150 bar. This rotation pressure results in a rotation torque of ~400 Nm (with an OMS125 rotation motor), which is the specification torque for the MD bolt. However, early in the trial, when it was noted that the pegs were not all extruding, the operator was requested to utilise full rotation pressure (200 bar); which for a new rotation motor would reach 625 Nm. This high torque can increase the chance of overloading bolt bars; however, this was not the case during this trial, which suggests the rotation motor may not have been converting all pressure to rotational torque, with the MD peg bolt before and after rotation shown in Figure 11.

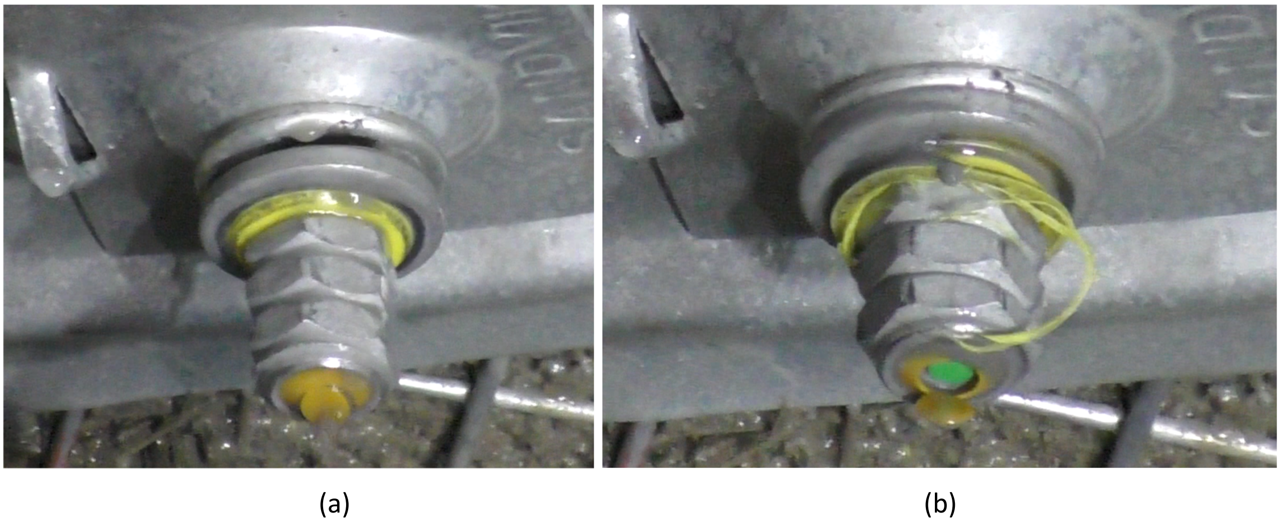


Figure 11 (a) MD peg bolt before rotation; (b) After rotation

The difference in the level of extrusion between the MDX and MD peg bolts is clear when comparing Figure 10b and Figure 11b. This was emphasised during the installations in the final location (RH4560 SP1), where the bolts were installed at an angle of 120° from centre-forward of the jumbo cab. This location was the first cut of a new stockpile, and the first 15 bolts were installed in a difficult position (as shown in Figure 12). During the installation of the bolts the operator was again requested to apply the full rotation pressure (increasing the applied torque), which slightly improved the extrusion of the pegs.

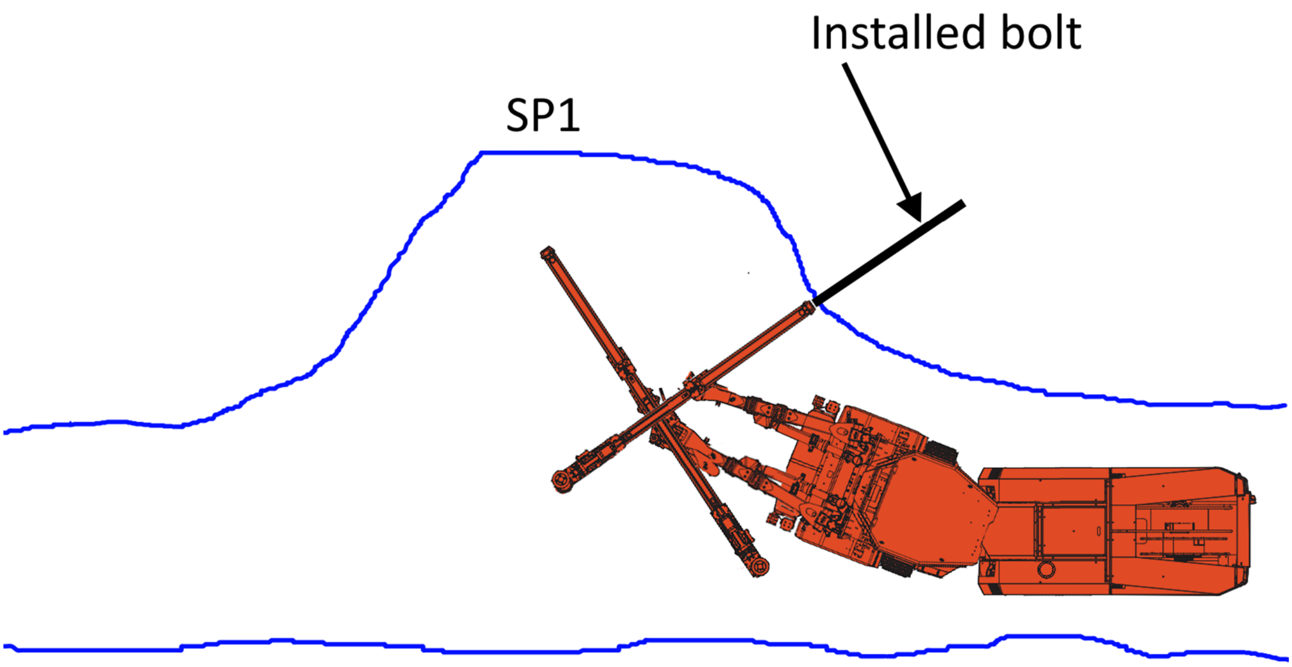


Figure 12 Jumbo boom positioning

This trial location allowed an inspection of the MD peg bolt after a full drill and blast cycle, where the dusty MD peg bolt was inspected the following day. This provided an insight into the visibility of the peg bolt after some time in the mining cycle, and as seen in Figure 13 the peg is still visible after drilling, blasting, bogging and application of shotcrete.

Figure 13 MD peg bolt still visible covered in blasting dust

Additional testing was conducted on the two plastic peg discs (MDX-white and MD-green), to determine if there was a variance in the HDPE material. However, when both samples were tested under laboratory conditions, they both showed similar extrusion behaviour at similar torque values. The torque per rotation is shown in Figure 14 to demonstrate the steady increase in torque as the peg is extruded. The four samples at 2.5 rotations (233–270 Nm torque) are shown in Figure 15.

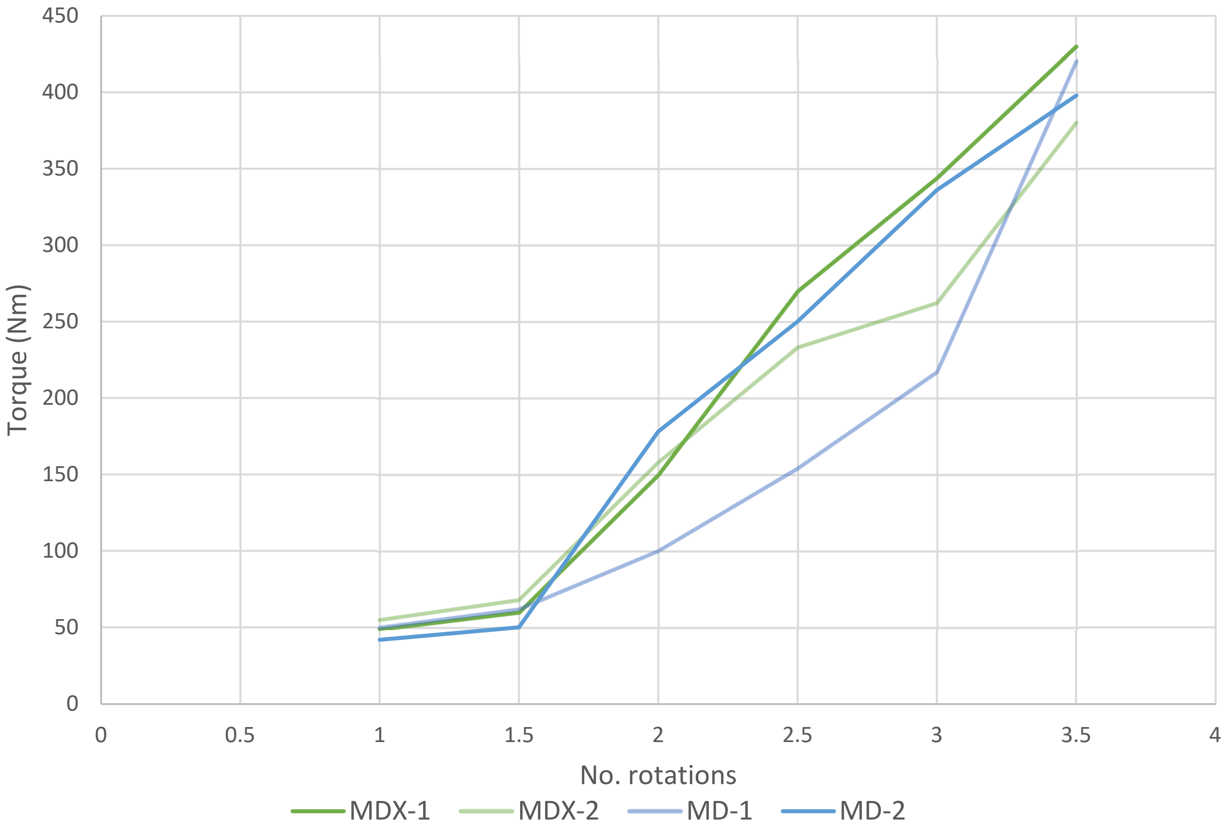


Figure 14 MD and MDX Peg torque readings

Figure 15 Extruded Pegs (a) MDX-1; (b) MDX-2; (c) MD-1; (d) MD-2

This lab testing established the two HDPE materials were in fact comparable, and the likely cause for the MD peg samples lack of extrusion was associated with the jumbo's output torque.

The MD peg bolt colour combination of green peg with gold disc was a much clearer indicator, where the green peg increased the visibility of the peg after installation.

The peg bolt provides operators with immediate feedback on installation quality, allowing for fine tuning of torque settings and alerting to potential equipment issues. Supervisors and engineers are, at a glance, able to assess bolt installation quality, providing greater confidence in the installed ground support.

4 Conclusion

Ground support quality is essential to the safe and economical operation of any underground mine. The QA methods vary from site to site, but typically include visual inspection, supplier conducted component/material strength testing, operator auditing/installation monitoring, documentation, operator training/certification and non-destructive pull testing. When these methods are used effectively, the risk of poor ground support installation (and hence performance) can be reduced.

The MD and MDX bolts have historically proven difficult to visually determine correct installation, due to the blind nut design. As such, the peg bolt was developed to provide a lasting visual indicator of correct bolt installation, that is full percussive insertion and rotation to greater than 350 Nm torque. The peg bolt development consisted of a combination of laboratory testing, including bench and percussive installation, and a large-scale field trial at Agnico Eagle's Fosterville Gold Mine. This process allowed an agile design development through laboratory testing, then confirming the laboratory test results with underground installations using standard installation, operators, practices and machinery.

The field trial successfully showed the peg bolt improved the ability to visually determine correct installation of the MD and MDX bolts. Operator feedback emphasised this fact, that the peg bolt allowed the operator a quick check that all bolts had been installed correctly.

The large-scale field trial also highlighted that one of the trial jumbos was not producing the desired torque under certain condition. This, coupled with the current operator practice to manually stop the rotation when the pressure gauge read 120 bar, could lead to under tightening the bolts.

The peg bolt has increased the capability of Agnico Eagle's Fosterville Gold Mine QC practices by providing an easy visual indication of bolt rotation. This provides the mine personnel, from operators to supervisors and engineers, an additional piece of mind and greater confidence in the installed ground support.

Acknowledgement

The authors would like to take this opportunity to thank the geotechnical and operations team at Agnico Eagle's Fosterville Gold Mine for again accommodating the Sandvik Ground support R&D team trialling new products. Also, to the R&D and product management teams at Sandvik Ground support, who provided guidance and inspiration for the peg bolt development.

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