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Direct impact load tests on mechanical hybrid rockbolts

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Abstract

A mechanical hybrid rockbolt is comprised of a tendon mechanically anchored within a friction unit. The rockbolt is driven into the pre-drilled borehole using a percussive force and can be efficiently and effectively installed in conditions where the application of resin cartridges is either challenging or impractical. The potential for higher installation rates and quality in friable or fractured rock masses, compared to resin grouted rockbolts, has resulted in the use of mechanical hybrid rockbolts for both static and dynamic conditions.

Mechanical hybrid rockbolts are installed using percussion techniques. On completion of the percussive drive cycle, a rotation is applied to the tendon to activate the mechanical anchor. The frictional resistance of the friction unit generates the reactive force against which the mechanical anchor is activated with the tendon mechanically coupled at the distal and proximal end.

Currently, there are limited data on the performance of mechanical hybrid rockbolts under different loading conditions in a controlled environment. This paper presents the results of a series of tests on mechanical hybrid rockbolts under direct impact loading. Direct impact continuous tube tests are one of the tools used to understand the performance of rockbolts under seismic loads. They are typically used to simulate a strainburst event where the seismic load acts on the interface (face plate) between the surface support and the rock reinforcement element. These results complement earlier work by the authors that focused on quasi-static axial and shear tests.

Keywords: *mechanical hybrid rockbolt, impact testing*

1 Introduction

High energy-absorbing rockbolts are widely adopted in seismically active mines or where large convergence of an excavation is anticipated. The earlier applications of energy-absorbing rockbolts, such as the cone bolt (Jager 1992), modified cone bolt (Simser et al. 2007) and the paddled energy-absorbing rockbolt (Li 2010) were chemically anchored with either a cementitious or resin-based grout. Like conventional grouted rockbolts, a pre-drilled borehole is filled with grout prior to the insertion of the rockbolt.

In heavily fractured or friable rock masses, the installation of resin grouted rockbolts can be problematic. Issues such as closure of the borehole and resin penetration into fractures can extend the installation time and potentially result in poor installation that will prevent a rockbolt from attaining its design capacity. Under these difficult installation conditions, the mechanical hybrid rockbolt, which is considered to be an energy-absorbing rockbolt, can be an attractive alternative to chemically anchored energy-absorbing rockbolts. Overcoming the need for a chemical anchor and making use of percussive installation ensures that the rockbolt can be driven through obstructions in the borehole improving the installation success rate and quality. An additional benefit is the simplicity of the installation procedure which facilitates an efficient installation with twin boom drill rigs (Figure 1), platform bolters and specialised bolters.

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Although the popularity of mechanical hybrid rockbolts is on the rise, there is still limited technical literature on site applications and laboratory investigations. Darlington et al. (2018) described the application of the MDX, a mechanical hybrid rockbolt at Telpher Mine (Australia), while Andrews (2019) refers to the use of the Garford Hybrid Dynamic Rockbolt at Agnew (Australia) and the Vulcan Bolt at South Deep (South Africa). There are additional applications of mechanical hybrid rockbolts at several mine sites, but this is not reported in the technical literature.

Figure 1 Installation of a mechanical hybrid rockbolt with a twin boom drill rig

Laboratory testing is often used to better understand the reinforcement action of rockbolts under different loading conditions in a controlled environment. A major advantage of laboratory testing is to provide a means to compare the relative performance of different rockbolts under similar conditions. In recent years, it has also become common to investigate the anticipated performance of energy-absorbing rockbolts in the laboratory prior to conducting underground trials. The emphasis in these cases is to demonstrate that a rockbolt can meet a specific energy dissipation capacity. Although the performance requirements can vary depending on the needs of different mines, it is common to report the following: input parameters of impact energy and velocity of the drop mass at impact, sample configuration, and whether the direct impact continuous tube or indirect impact split tube was used. Typically, continuous tube impact tests are performed to demonstrate the performance of a rockbolt subjected to a strainburst event (Li et al. 2021), whereas the split tube configuration is implemented to demonstrate the performance of the rockbolt during a rock-block-thrust ejection event.

It is interesting that the limited published laboratory data on mechanical hybrid rockbolts have been using quasi-static axial and impact testing procedures. To the authors knowledge only Knox & Hadjigeorgiou (2023) investigated the performance of mechanical hybrid rockbolts under shear loading. Furthermore, all impact testing investigations have been conducted via a continuous tube configuration (Darlington et al. 2023; Vallati et al. 2022; Evans 2022). The justification for the use of the continuous configuration is based on the design and energy dissipation function of the rockbolt. The tendon anchored within the friction unit of a mechanical hybrid rockbolt is assumed to be loaded independently and consequently, the direct loading of the tendons is justifiable. This assumption is supported by the observed response of the rockbolt, reported by Knox & Hadjigeorgiou (2023), where during a quasi-static split tube loading case within concrete blocks, the friction unit offered negligible additional support resistance.

Vallati et al. (2022) reported the loss of load, which manifests as a saw-tooth profile in the recorded load response during dynamic testing, illustrated in Figure 2. Using the term ‘further mechanical activation’, it is suggested that the wedge mechanism requires further activation post-tensioning, which, due to the nature of the rockbolt design, is activated against the frictional resistance offered by the friction unit. The frictional resistance offered by the friction unit is a function of the embedded length. Consequently, the frictional resistance would be negatively affected if a rock-block-thrust ejection model was to be considered. An alternative hypothesis is that the radial confinement surrounding the wedge mechanism is insufficient to prevent further seating of the wedge or movement between the friction unit and borehole. Therefore, there appears to be a need to also consider indirect impact split tube tests to further investigate the effect of the loading configuration on the performance of the rockbolt.

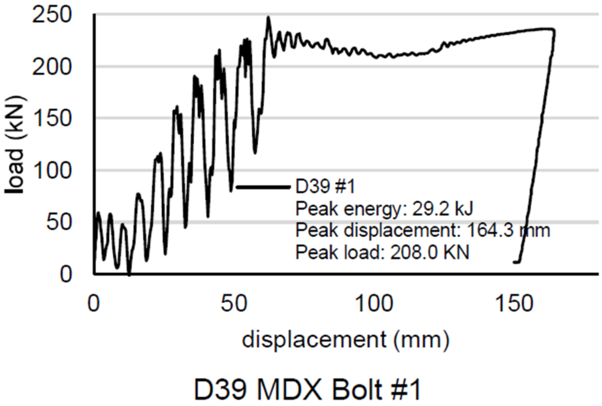

Figure 2 Saw-tooth profile indicating activation of the wedge mechanism during dynamic loading (Vallati et al. 2022)

Another consideration in designing the experiment reported in this paper was whether to install the rockbolts in a borehole cored in granite or in a grout constrained in the testing tube. It was decided to use engineered grout as this could allow a direct comparison to the results conducted on paddled energy-absorbing rockbolts Knox & Hadjigeorgiou (2022). This paper reports the results of a series of direct impact continuous tube tests that were performed on mechanical hybrid rockbolts in a controlled laboratory-based environment. Future work will focus on the use of the indirect impact split tube test that in addition to the present work will provide a comprehensive database on the performance of mechanical hybrid rockbolts under multiple loading mechanisms.

2 Mechanical hybrid rockbolt

A typical mechanical hybrid rockbolt consists of a steel tendon mechanically anchored within a friction unit, Figure. Multiple suppliers, as reported by DSI Underground (2023), Jennmar (2023), Sandvik (2023), and Epiroc (2023) offer a variant of this rockbolt design with some differences in appearance and performance capacity. However, the design principle and installation process are shared by all mechanical hybrid rockbolts currently in use at mine sites. As illustrated in Figure, the rockbolt is driven to depth into a pre-drilled hole and then tensioned to activate the mechanical anchor. A percussive force is applied to the back of the nut with the rotation on the rockdrill disengaged. The final step in the installation processes is the rotation of the nut to tension the bar and activate the mechanical anchor. On a conventional mechanical anchor, a wedge is affixed to the bar and two leaves are radially expanded, by the wedge, during tensioning. Similarly, in a mechanical hybrid rockbolt the wedge is affixed to the bar and the friction unit is radially expanded during the tensioning process. The difference is that the frictional resistance generated by the friction unit prevents the axial movement of the components of the mechanical anchor during initial radial expansion of the friction unit. Once activated, the frictional resistance generated by the radial displacement of the mechanical anchor components exceeds the friction resistance of the friction unit which is consequently the primary anchoring mechanism.

Mechanical hybrid rockbolts are typically available in two of the common friction unit diameters; a Ø46 mm or a Ø39 mm diameter (DSI Underground 2023; Jennmar 2023; Sandvik 2023; Epiroc 2023). The tendon anchored within the rockbolt is typically shared between the two friction unit diameters, consequently, the performance is similar. The options co-exist due to operational requirements, with the Ø39 mm variant being installed by fleets with lower capacity rock drills and the Ø46 mm variant installed in ground support systems which employ Ø46 mm friction rock stabilisers due to the shared drill bit diameters and boom configurations.

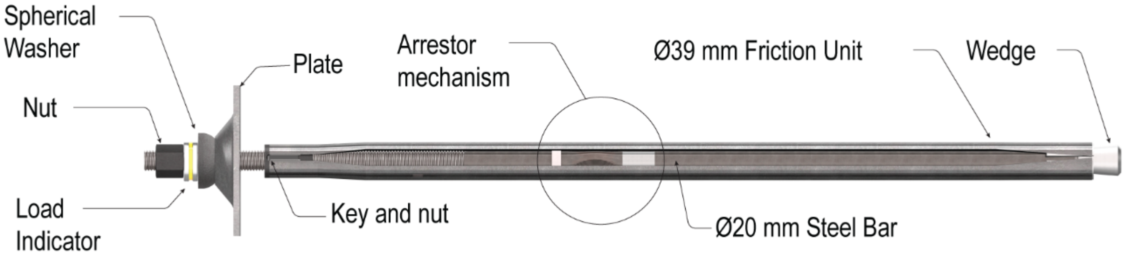

Figure 3 An example of a mechanical hybrid rockbolt

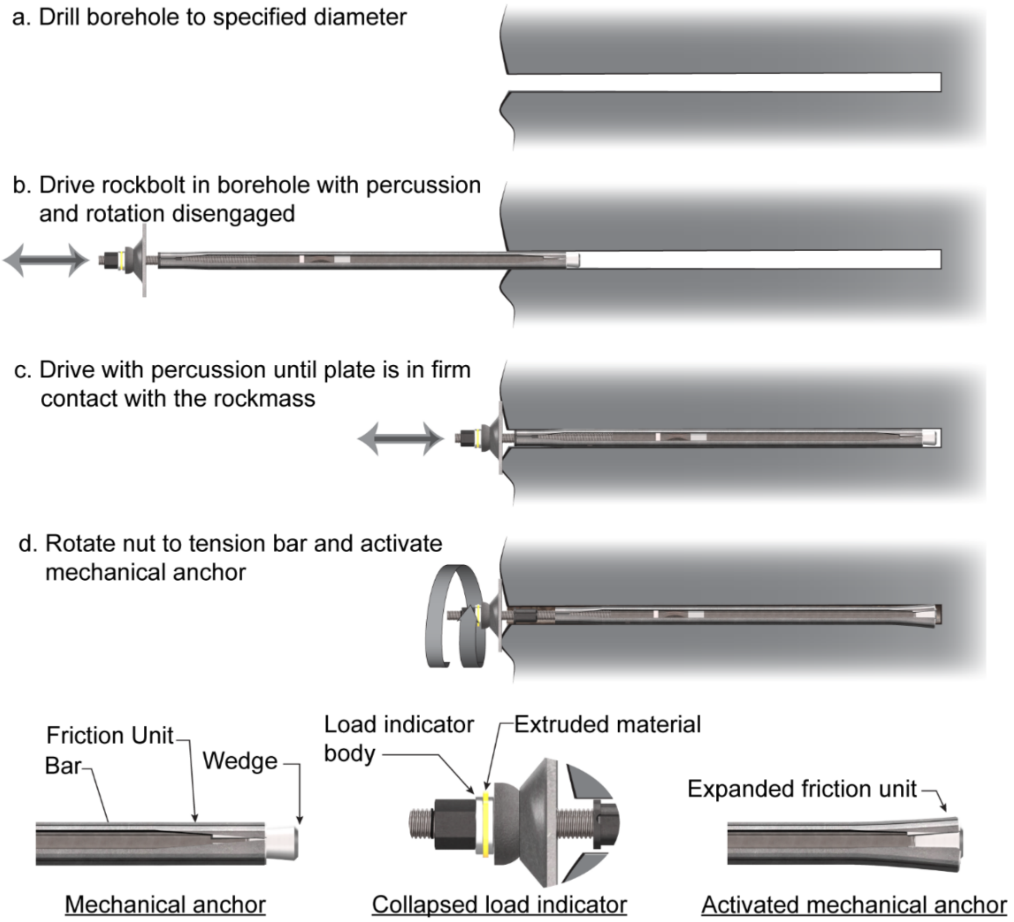

Figure 4 Installation procedure of a mechanical hybrid rockbolt

This investigation was conducted using the 2.4 m Ø39 mm Vulcan Bolt with a Ø200 mm round 6 mm face plate. This is consistent with previous work by Knox & Hadjigeorgiou (2023) that investigated the performance of the rockbolts in quasi-static axial and shear tests.

3 Laboratory impact testing of mechanical hybrid rockbolts

Laboratory-based impact testing can be used to quantify the capacity of a rockbolt in a controlled environment in a timely manner at relative cost. The primary cause for the scarcity of data on mechanical hybrid rockbolts may be due to the sample preparation procedures. Two methods of assimilating the boundary conditions of the borehole exist. In the first approach, a granite core is placed in the two halves of a steel tube which are subsequently welded along the axial length. In the second approach, a high strength concrete is cast within a steel host tube. The mass of the host tube is thus increased which presents a logistical challenge during sample preparation and instrumentation. The borehole is then drilled with a percussive drilling process to replicate the conditions of the borehole in situ, thus simulating the frictional resistance between the borehole and friction unit of an in situ installation.

Previous work used the Sandvik MDX rockbolt at the SWERIM test facility in Sweden (Vallati et al. 2022) and CanMET Mining in Canada (Darlington et al. 2023). The SWERIM tests used a concrete core to test both the Ø46 mm and Ø39 mm variants of the MDX, however, the accessories applied during the testing did not replicate an underground installation as the face plate – typically installed with the MDX rockbolt – was replaced by a washer, as illustrated in Figure. The testing conducted at CanMET Mining employed the granite core method. During both investigations, the direct impact continuous tube configuration was employed and the period of 'further mechanical activation' was observed in the response of the rockbolt.

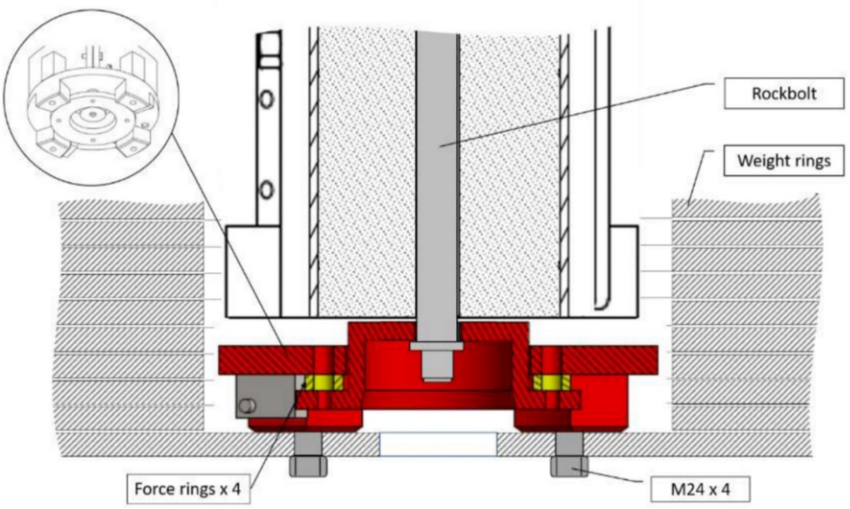

Figure 5 **SWERIM MDX testing instrumentation configuration (Vallati et al. 2022)**

The third example of a published laboratory-based impact test was conducted on the Kinloc Mechanical Hybrid Rockbolt at the Western Australian School of Mines test facility in Australia (Evans 2022). The Kinloc mechanical hybrid rockbolt arrested a mass with an input energy of 25 kJ. An average of 358 mm of sliding displacement was recorded. This provided further justification for the inclusion of an indirect impact split tube test to the testing scheme. The sliding movement of the rockbolt relative to the borehole and the diminishing load response, observed in Figure, is directly correlated to the embedded length of the friction unit. A review of these results suggests that there would be benefit in future work to also use the indirect impact split tube test procedure.

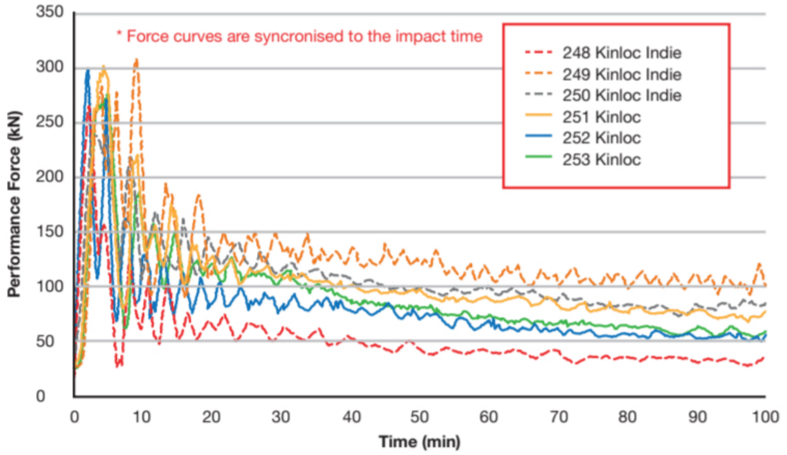

Figure 6 **Kinloc load–displacement curve of the testing conducted at Western Australian School of Mines (DSI Underground 2023)**

4 Test configuration and methodology

This investigation is part of a series of laboratory-based tests to investigate the capacity of a mechanical hybrid rockbolt under multiple loading conditions, which have been conducted in the Application Centre in Johannesburg, South Africa. Previous work investigated the performance of mechanical hybrid rockbolts in axial and shear loading (Knox & Hadjigeorgiou 2023).

4.1 Testing rig

The Dynamic Impact Tester (DIT), illustrated in Figure 7, employs the impact test method that is used at most testing sites described by Li et al. (2021). The test sample (rockbolt installed within the host tube) is instrumented and loaded through the borehole of the drop mass and affixed to the test rig. In a test, the drop mass is raised to a pre-determined drop height above the impact plate and when the mass is released, the potential energy is transferred into kinetic energy acting on the sample at impact. The load and displacement response of the sample is recorded via a series of piezoelectric load cells and line scan cameras at a rate of 10 kHz. This facilitates the calculation – with precision – of the dissipated energy prior to rupture. The rig has been in operation since 2017 and a detailed description of the testing procedures and instrumentation is available Knox & Hadjigeorgiou (2022).

A differentiating feature of the DIT to other rigs reported by Knox (2023) is the damper system which arrests the drop mass once rupture of the sample is induced, this limits the damage to the frame, foundation, and instrumentation which improves the testing frequency.

(a) (b)

Figure 7 Dynamic Impact Tester. (a) Drop mass in free fall; (b) Schematic illustration of the primary components of the rig (Knox & Hadjigeorgiou 2022)

During the direct impact continuous tube test, the impact is applied to the rockbolt accessories (face plate, spherical seat, and nut) and consequently, the impact load cell is affixed to an impact plate which is clamped between the host tube and the face plate, as illustrated in Figure. This ensures that the impact load cell is centralised, and the load is evenly distributed. During the tests, a 2,096 kg mass was released from a height of 1.5 m, thus impacting the sample with an impact energy of 30 kJ and a velocity of 5.4 m/s. This was repeated until the rupture of the sample was induced.

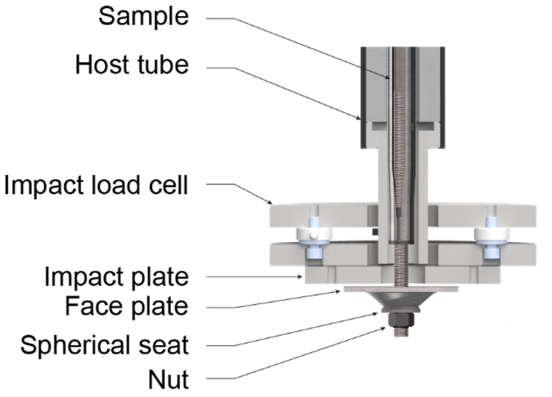

Figure 8 Sample instrumentation configuration during a direct impact test

4.2 Sample preparation

As described in Section 3, the frictional resistance between the friction unit and the borehole is integral to the activation of the mechanical anchor. The host tube was prepared using the precast concrete core method. Master flow 400, a rapid curing high strength grout, was used to cast the core which will constitute the concrete annulus. The concrete core was cast in a steel pipe with an outer diameter (d_o) of Ø95 mm and an inner diameter (d_i) of Ø83 mm (Figure 9). As part of the QA/QC for the concrete core, 50 mm square cubes of the concrete grout were cast to verify the unconfined compressive strength of the grout. Once cured, a borehole was percussively drilled through the concrete with a Ø36 mm taper 'knock-off' bit using a pneumatic rockdrill. Subsequently, the Ø39 mm Vulcan Bolts were installed into the host tube and instrumented for the direct impact continuous tube tests. The testing configuration is illustrated in Figure 10.

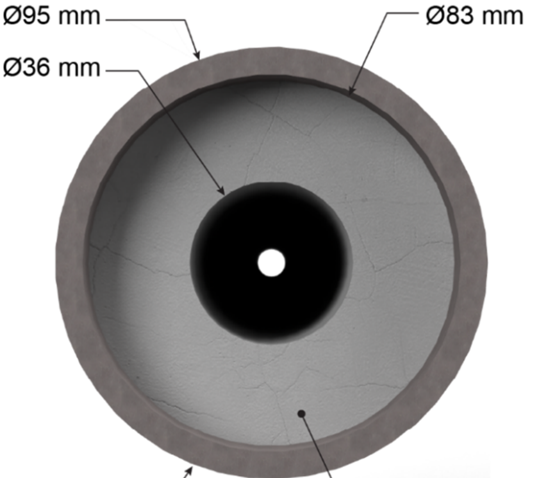

Figure 9 Profile of the host tube

The radial stiffness (K_r) of the host tube was calculated to be 705 MPa/mm using Equation 1. This was based on the mechanical properties of the steel from which the host tube was fabricated (Young's modulus (E) of 210 GPa and a Poisson's ratio (v) of 0.3).

$$K_r = \frac{2E}{(1+v)}\left\{\frac{d_o^2-d_i^2}{d_i\left[(1-2v)d_i^2+d_o^2\right]}\right\} \tag{1}$$

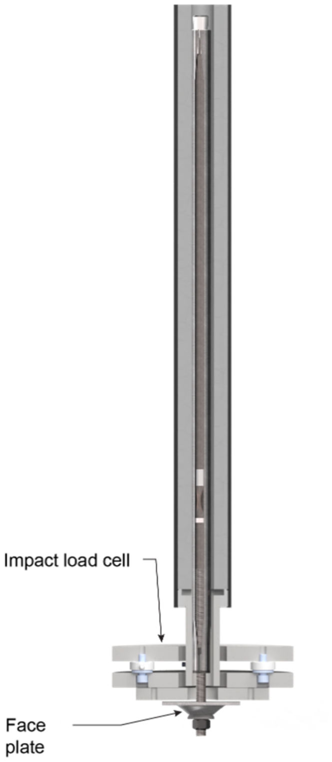

Figure 10 Direct impact continuous tube test configuration

Consistent with previous work by Knox & Hadjigeorgiou (2022) on other rockbolts, the mechanical properties of the bar were determined based on ISO6892 (International Standards Organisation 2009). The capacity of the thread and nut interface was determined by an axial destructive tensile test. Finally, the dome collapse load was determined as the peak load recorded during a compression test when loaded on a plate with a 101 mm hole.

5 Results

The mechanical properties of the rockbolt and host tube were verified prior to conducting the impact testing and are summarised in Table 1. During the tensile loading of the thread and nut interface, the observed failure mode in all threaded samples was rupture of the thread for all three samples, no stripping of the thread-nut interface was observed.

Table 1 Verification of mechanical properties

Component	Parameter	Value
Grout	Ultimate compressive strength (UCS)	92 MPa
Bar	Yielding load (YL)	186 kN
Bar	Ultimate tensile load (UTL)	235 kN
Bar	Elongation at ultimate load (A_ut)	12%
Bar	Elongation at rupture (A_5t)	24%
Thread	Ultimate tensile load (UTL)	226 kN
Face plate	Dome collapse load	309 kN

The consistency of the cumulative load-deformation response during the impact is represented by Figure. No indication of wedge slip was observed in the first sample, however, a single saw tool profile was reported for both the first and second impact on samples (MHR-CT02). The welding on the third host tube failed and consquently there is no data reported. The results of the individual impact tests are reported in Table 2.

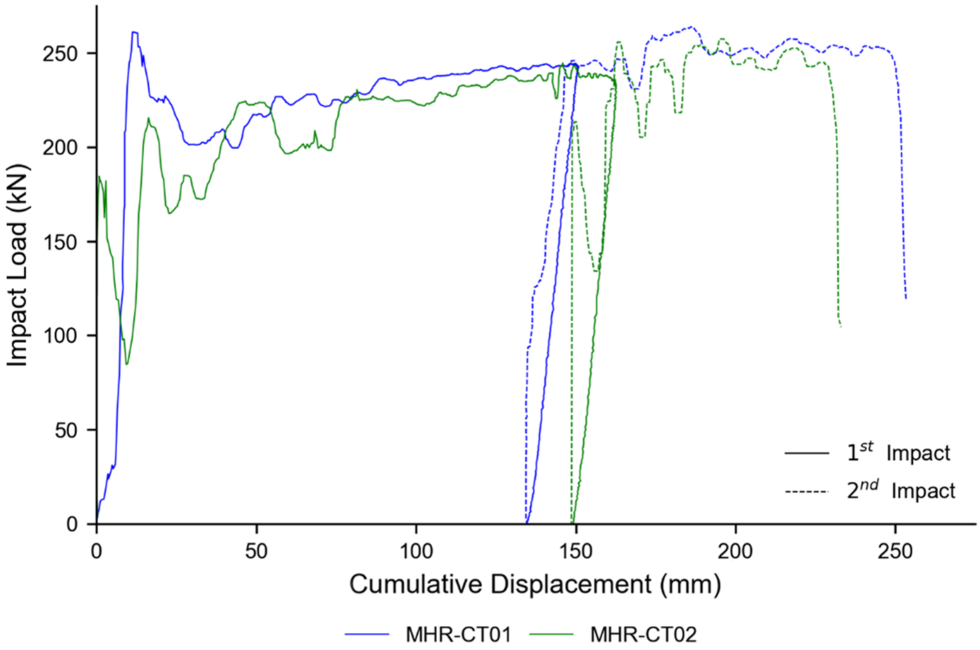

Figure 11 Cumulative load-displacement plot of the multiple impact test results

Table 2 Continuous tube impact testing results

Sample Ref	1st Impact			2nd Impact			Total	
	$\overline{F}_{IMP}$ (kN)	δ_{PF} (mm)	PE (kJ)	$\overline{F}_{IMP}$ (kN)	δ_{PF} (mm)	PE (kJ)	δ_{PF} (mm)	PE (kJ)
MHR-CT01	234	135	31	243	119	29	254	60
MHR-CT02	221	148	33	230	84	19	232	52

In addition to the instrumentation data, a visual inspection did not identify any deformation of the plate following the tests. The only indication that the plate had been loaded was a minor plastic deformation of the surface against which the spherical seat interacts. The axial load generated by the bar is transferred through the thread-nut-spherical seat-plate interface and consquently, failure of this interface could result in premature failure of the rock reinforcement element.

6 Discussion and future work

Mechanical hybrid rockbolts are typically installed in fractured or friable rock masses where the intent is to avoid the use of a chemical anchor. The reinforcement mechanism of a mechanical hybrid rockbolt is achieved by two anchor points through which the load is transferred to the rock mass; the mechanical anchor at the distal end of the rockbolt and a face plate at the proximal end of the rockbolt.

During the impact loading of the rockbolts tested, minimal load shedding (represented by a saw-tooth profie in the impact load response) was observed. This demonstrates that the capacity of the mechanical anchor exceeded the capacity of the tendon. The capacity of the proximal anchor is governed by the thread-nut-spherical seat-plate interface. The component verification testing determined that the capacity of the plate exceeded the capacity of both the bar and the thread-nut interface. Therefore, the plate is compatible with the rockbolt which was verified by the limited deformantion of the plate observed during impact testing.

During the capacity verification of the thread-nut interface no stripping of the thread was recorded. The test was terminated based on the rupture of the thread at a load (225 kN), which was approxiamtely 10 kN less than the ultimate tensile load of the bar (235 kN). Consquently, during impact testing the capacity of the thread governed the ultimate performance of the rockbolt. Based on the elongation properties of the bar, a record displacement of ≈276 mm would be anticapted. As the thread ruptures prior to the full plastic potential of the bar being realised, the average displacement of 243 mm was recorded, highlighting the importance of the thread capacity in a rockbolt such as a mechanical hybrid rockbolt.

7 Conclusion

Mechanical hybrid rockbolts offer the ability to effectively install energy-absorbing rock reinforcement in fractured and friable rock masses using specialised and platform bolters or twin boom drill rigs.

A full-scale laboratory study was conducted on a 2.4 m mechanical hybrid rockbolt. The mechanical properties of each critical component in the sample configuration were verified. It was determined that the ultimate tensile capacity of the bar (235 kN), exceed that of the thread (225 kN). The capacity of the face plate (309 kN) exceeds that of both the bar and the thread.

The mechanical hybrid rockbolts arrested the mass on the first 30 kJ impulse and rupture on the second impulse. In total an average displacement of 243 mm and an energy dissipation of 56 kJ was recorded.

Acknowledgement

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