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Advances in pumpable urea–silicate resin rockbolting systems: laboratory performance of hollow-core bar bolts under shear and tensile loading, coupling integrity, and productivity in modern hard rock mining

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Abstract

Pumpable 2-component urea–silicate resins have become an increasingly important component of modern rock reinforcement systems due to their compatibility with mechanised installation methods, rapid curing characteristics, and potential for improved installation quality and productivity. This paper presents the results of a laboratory investigation into the mechanical performance of dynamic and ductile hollow-core bar bolts grouted with urea–silicate resin, together with an evaluation of couplers used for extension drilling and a review of the operational advantages of pumpable resin technology in underground hard rock mining.

A series of tensile and shear tests were conducted at the NTNU Engineering Geology Laboratory using R28 and R32 dynamic and ductile hollow-core bar bolts installed in high-strength concrete blocks designed to simulate hard rock conditions. All specimens were tested one hour after installation. The results demonstrated high load-bearing capacity and excellent deformation characteristics of the bolt-resin assemblies. For dynamic bolts, the shear resistance exceeded the tensile resistance, primarily due to localised bolt bending and confinement effects developing within the borehole during loading.

No bond failure, resin failure, or bolt pull-out was observed in any test, confirming the rapid strength development and high anchorage performance of the urea–silicate resin system. Additional testing of couplers recovered from extension-drilling operations in hard granite demonstrated that the couplers consistently exceeded the strength of the connected bolts and did not constitute a weak link within the reinforcement system.

The paper also discusses the application of pumpable resin technology in mechanised and automated mining environments. The findings confirm that hollow-core bar bolts grouted with urea–silicate resin provide a robust and highly productive ground-support solution characterised by excellent mechanical performance, reliable anchorage, strong coupling integrity, and suitability for a wide range of underground mining conditions.

Keywords: *hollow-core bar bolt, shear strength, urea–silicate resin, pumpable resin, bolt coupling*

1 Introduction

The increasing demand for safer, more productive, and highly mechanised underground mining operations has accelerated the development of advanced rock reinforcement technologies. Among these developments, pumpable 2-component urea–silicate resin systems have emerged as an attractive alternative to conventional resin cartridges and cementitious grouts, offering rapid installation, improved process control,

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and compatibility with modern automated drilling equipment. At the same time, hollow-core bar bolts have gained widespread acceptance due to their versatility, suitability for mechanised installation, and capability to function both as reinforcement elements and as self-drilling anchors in difficult ground conditions.

Despite the growing adoption of pumpable resin technologies, continued validation of the performance of complete rockbolting systems remains essential. The mechanical interaction between the bolt, resin, couplings, and surrounding rock mass ultimately controls the effectiveness of ground support under both static and dynamic loading conditions. Understanding the tensile and shear behaviour of resin-grouted hollow-core bar bolts is therefore critical for evaluating their suitability in high-stress and seismically active mining environments (see for example Li 2010).

This paper presents the results of an extensive laboratory testing program conducted at the NTNU Engineering Geology Laboratory. Dynamic and ductile R28 and R32 hollow-core bar bolts grouted with urea–silicate resin were subjected to tensile and shear loading to assess their strength, deformation capacity, failure mechanisms, and anchorage performance. In addition, couplers used for extension drilling were tested to determine whether they represent a potential weak point within the reinforcement system. Finally, the paper reviews the practical application of pumpable resin technologies in underground hard rock mining, highlighting their productivity benefits, operational flexibility, and compatibility with modern mechanised and automated bolting equipment.

2 Laboratory testing of assemblies of hollow-core bar bolts grouted with urea–silicate resin and of some components of the rockbolting system

To verify the performance of modern hollow-core bar rockbolting systems, a comprehensive laboratory testing program was conducted on bolt-resin assemblies and selected system components. The work included tensile and shear testing of dynamic and ductile hollow-core bar bolts grouted with urea–silicate resin, together with strength testing of couplers used in extension-drilling applications.

2.1 Laboratory tensile and shear tests of hollow-core bar bolts grouted with mineral bolt resin

All of the tests described below were performed in the bolt test rig at NTNU Engineering Geology Laboratory. The purpose of the tests was to evaluate the mechanical performance of hollow-core bar bolts encapsulated with urea–silicate resin in concrete blocks under tensile and shear loading conditions.

The bolt test rig consists of 2 concrete blocks with size 95 x 95 x 95 cm that are placed in steel frames (Figure 1). A bolt is installed in a hole, which is drilled through both blocks. Hydraulic pressure cylinders are used to displace the blocks in 2 different directions normal to each other, allowing the bolts to be tested in tensile as well as in shear direction. The tensile and shear load capacities of the test rig are 600 and 500 kN, respectively. The displacement capacity is 250 mm in tension and 150 mm in shear (NTNU 2023).

Tensile and shear loads are measured from hydraulic pressure, and displacements of the blocks are measured with wire extensometers. Hydraulic valves are controlled manually. The blocks are made of custom cement mix, which gives very high compressive strength rated at 110 MPa. The high strength is to imitate the strength of hard rock. Casting was done at NTNU facilities several months before the testing.

The types of bolts selected for testing were dynamic and ductile versions of R28 and R32 hollow-core bar bolts. The holes were drilled with a pneumatic rockdrill with a pneumatic pusher leg and with a button drill bit of 38 mm diameter (for R28 bolts) and 42 mm diameter (for R32 bolts). The boreholes were drilled systematically in the concrete blocks with 15 cm spacing, measured from borehole centre. After drilling, the holes were thoroughly flushed with water and then dried with compressed air. The actual borehole length was 90 cm in front block (5 cm reduction because of fallouts) and 70 cm in back block (stopped drilling 25 cm from end to prevent breakthrough).

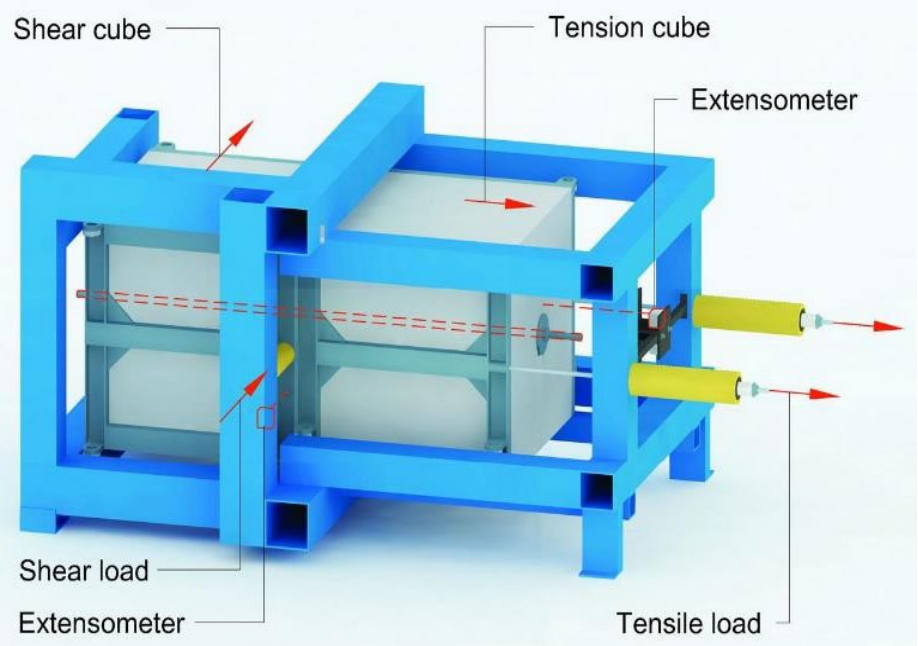


Figure 1 Sketch of the bolt test rig at NTNU/SINTEF (Source: SINTEF https://www.sintef.no/en/all-laboratories/full-scale-testing-of-rock-bolts/)

Before each bolt installation, the concrete blocks were aligned correctly with regards to the drilled hole and then pushed together with hydraulic pressure cylinders at constant load of 15–20 kN. To prevent leakage of resin, a donut rubber gasket of 3 mm thickness was placed around the hole between the blocks.

The hollow-bar bolts were encapsulated with the pumpable 2-component urea–silicate resin. The resin type chosen was Mineral Bolt MI 55. That resin is most frequently used for bolting performed with mechanised bolting equipment, MI meaning mechanised installation and set time of that resin is 55 seconds at 20°C.

The bolts were centred in the holes by 2 springs (so called pig tails) on the bolt placed at rear and front block section respectively. After the bolt was pushed to the borehole end, it was given a quick back-pull to make a small gap of approximately 5–10 mm between bolt end and borehole end. A clamp was installed temporarily to fasten the bolt to the block face to ensure that the bolt did not move during injection. The clamp was removed before the test. Injection of the 2-component resin was stopped when the resin flowed out of borehole opening, beneath the plate. Injection was done with compressed air-driven multi pump unit and mixing equipment. Curing time of the resins was set to 60 minutes, and all tests were performed exactly 1 hour after bolt installation.

In tensile tests the front concrete block was pulled in the orientation of the bolt length by 2 hydraulic cylinders in a semi-constant displacement rate so that failure occurred after a few minutes. Displacements were measured at the bolt nut and on the block, 12 cm above the bolt. A distinct difference between the displacements of the block and the bolt nut would indicate sliding of the bolt inside the front block, for example in case of resin failure.

In shear tests the back concrete block was pushed perpendicularly to the bolt length by one hydraulic cylinder in a steady displacement rate so that failure occurred after 2–3 minutes. Displacements were measured on the back block in the shear direction, and also on the bolt nut in the direction of tension to detect any possible sliding of the bolt in the front block.

Load–displacement curves of both tensile and shear testing of R32 dynamic hollow-core bar bolts are given in Figure 2.

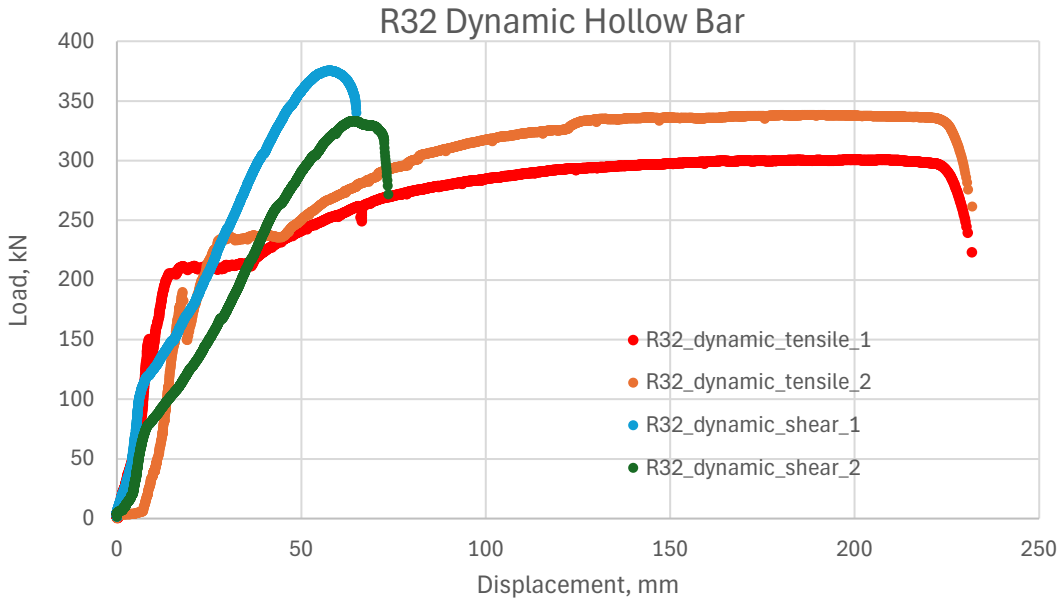


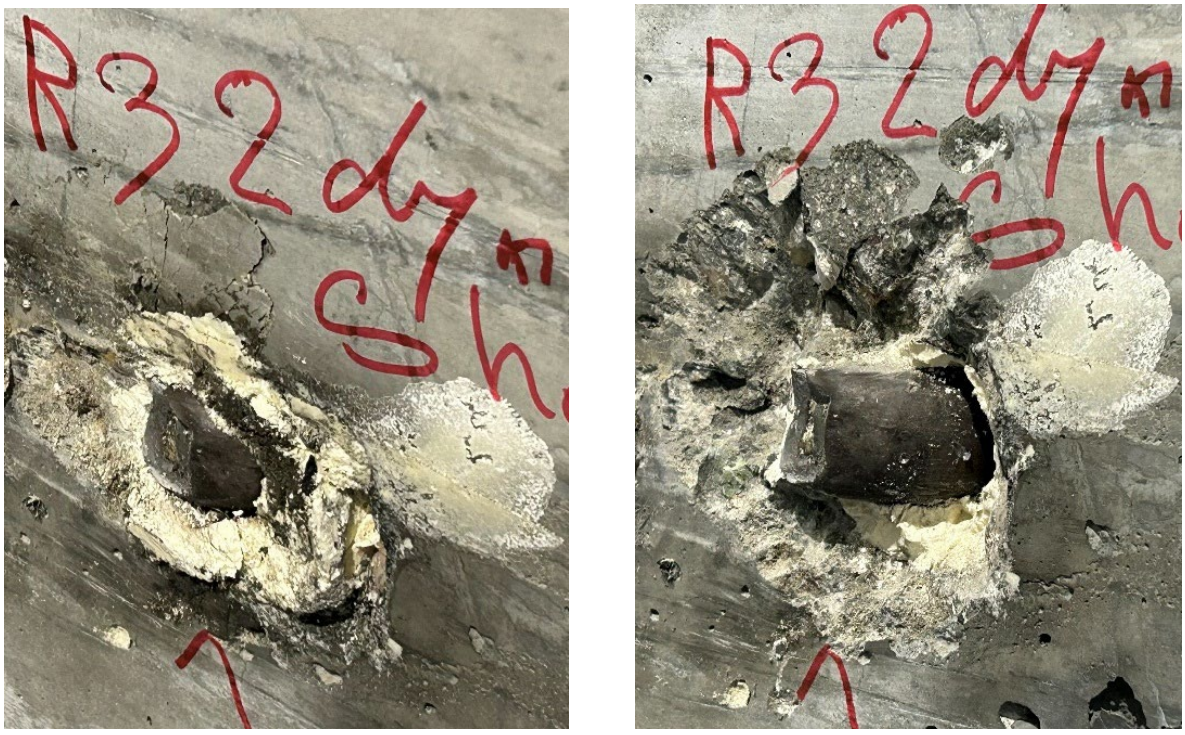
Figure 2 Load–displacement curves for R32 dynamic hollow-core bar bolts in shear and tensile loading embedded with mineral bolt resin in high-strength concrete blocks

During tensile loading, the force initially increases in a quasi-linear manner to approximately 200–240 kN, corresponding to a stiffness of about 20 kN/mm within this range. Subsequently, the bolts elongate by approximately 15–20 mm at a constant load. This is followed by a change in the deformation mechanism due to elongation of the bolt's central (smooth) section. Simultaneously, this section undergoes necking, governed by the Poisson's ratio of the bolt material (steel), resulting in significant elongation of the ductile bolt while the load continues to increase at a slower rate. Finally, when the displacement – consisting primarily of bolt deformation – reaches approximately 125 mm, the steel begins to yield and the bolt undergoes further substantial elongation at a nearly constant load, close to the maximum value. Bolt elongation exceeds 230 mm (orange and red curves in Figure 2). The maximum tensile load reaches 300–340 kN. Figure 3 shows the anchor in the final moments before failure, where significant elongation of the central section is clearly visible.



Figure 3 One of the R32 dynamic bolts during the tensile testing, just before the failure. Clear necking formation closer to rear (left) concrete block is visible as well as very significant deformation of the bolt exceeding 23 cm

Under shear loading, the bolt deformation mechanism is somewhat different. Initially, the bolts deform with a stiffness similar to that observed in tension, up to a load of about 80–120 kN. This is followed by a further quasi-linear increase in load at a somewhat lower stiffness (approximately 5 kN/mm) until a load of 335–375 kN is reached. Bolt failure occurs at displacements in the range of 65–75 mm (blue and green curves in Figure 2). Of particular interest is the fact that the shear capacity of the bolts exceeds their tensile capacity. An explanation of this phenomenon is provided in Figure 4. The Figure 4a shows a bolt after separation of the concrete blocks immediately following the test. A detailed inspection involving removal of cracked concrete fragments around the borehole and resin surrounding the bolt reveals the reasons for the high shear capacity of the R32 dynamic bolts. Figure 4b shows that the bolt experiences localised bending within the borehole. The resin is subjected to compression and local crushing, as is the surrounding concrete. The borehole walls degrade under contact with the steel bolt, and similar behaviour may be expected in rock masses.



(a) (b)

Figure 4 (a) One of the R32 dynamic bolts after the shear testing. General view of the fractured bolt after sliding away the concrete blocks, (b) closer look at the section of the bolt in a drillhole after removal of the resin and fractured concrete in its immediate vicinity

For R28 dynamic bolts, characterised by a threaded outer diameter of 28 mm and a smooth-section diameter of 26 mm, the behaviour under both tension and shear is very similar (Figure 5). The main difference is that the maximum load levels are somewhat lower. In tension, the bolt deforms with a stiffness of approximately 15 kN/mm up to a load of about 175 kN. The load then remains essentially constant while the bolt elongates by approximately 20–25 mm, after which the load gradually increases to about 250 kN.

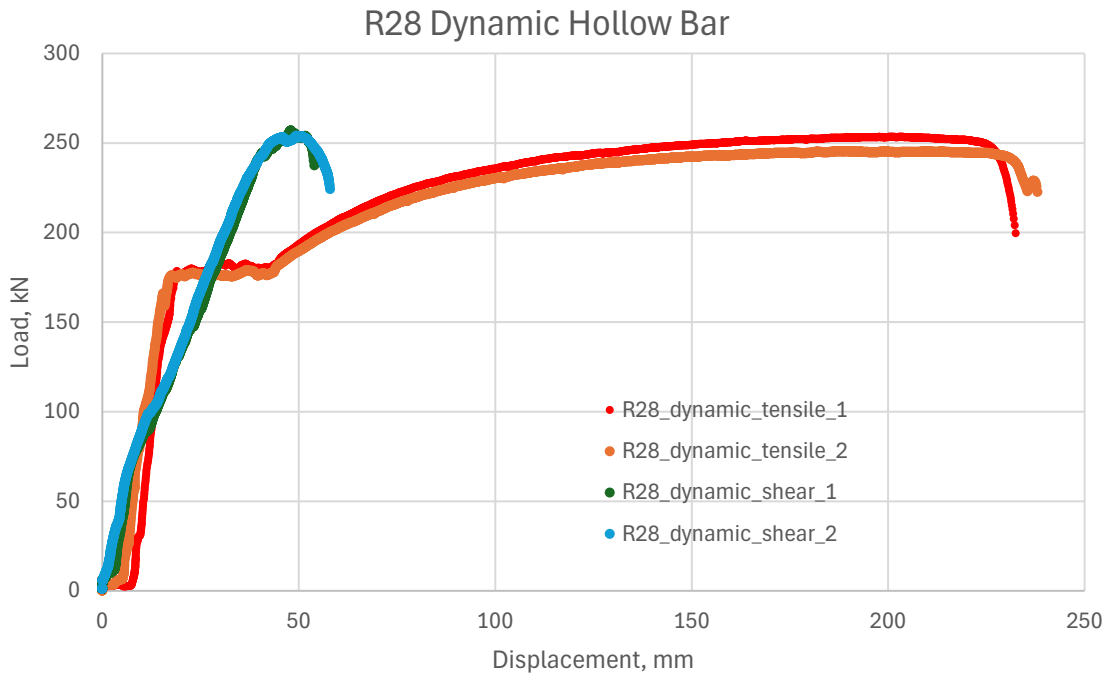


Figure 5 Load–deformation curves for R28 dynamic hollow-core bar bolts in shear and tensile loading embedded with mineral bolt resin in a high-strength concrete blocks

When the displacement (deformation) reaches approximately 150 mm, the bolt continues to deform without any further increase in load. Failure again occurs at a final displacement exceeding 230 mm. When this elongation is converted into strain – both for R32 dynamic and R28 dynamic bolts – it can be seen that failure occurs at approximately 15% strain. The shear response is similar to that observed for R32 bolts: the load increases to approximately 75 kN at a stiffness of about 11 kN/mm, after which the stiffness decreases (to approximately 5 kN/mm) and the load continues to increase linearly until a maximum value of approximately 255 kN is reached. A notable feature of testing of this bolt type is its remarkable repeatability, with both pairs of curves being almost identical in both tension and shear.

Although the length of the threaded section embedded in the rear concrete block was only about 55 cm, and the resin was very young – all tests were conducted just one hour after bolt installation – none of the tests resulted in pull-out of the bolt from the resin or failure of the resin itself.

This finding is consistent with other observations, which indicate that the critical embedment length for hollow-core bar bolts installed with mineral bolt resin is approximately 50 cm.

For fully threaded ductile bolts, which have a somewhat thinner wall thickness, the load–displacement curves – particularly in tension – are slightly different. A somewhat larger scatter, or difference between individual curves, can also be observed. This is associated with highly localised deformation occurring at the interface between the 2 concrete blocks. In general, the curves exhibit an asymmetric sigmoid shape (orange and red curves in Figures 6 and 7).

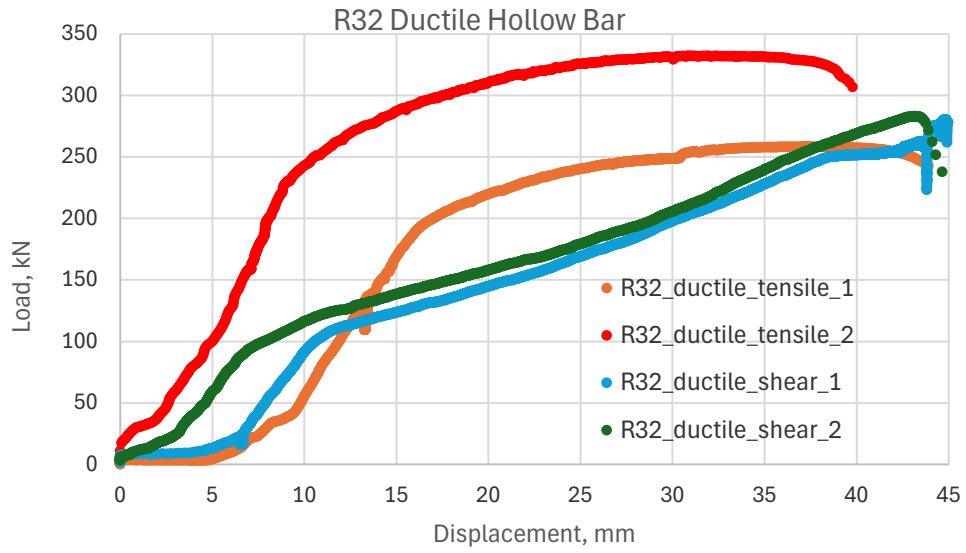


Figure 6 Load–deformation curves for R32 ductile hollow-core bar bolts in shear and tensile loading embedded with mineral bolt resin in a high-strength concrete blocks

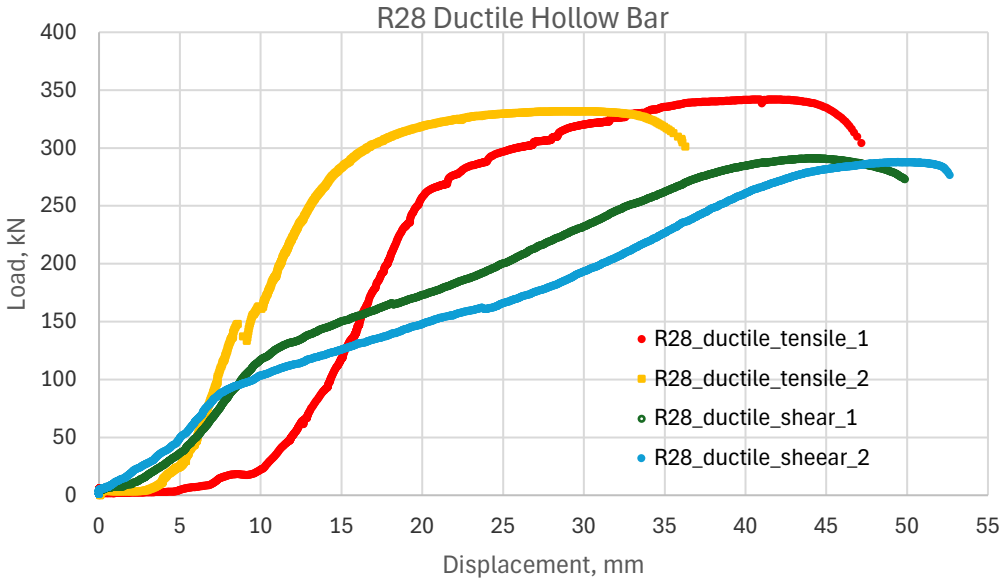


Figure 7 Load–deformation curves for R28 ductile hollow-core bar bolts in shear and tensile loading embedded with mineral bolt resin in a high-strength concrete blocks

Following an initial stage of deformation with relatively low stiffness, the load increases quasi-linearly to approximately 200 kN for R32 ductile bolts and 250 kN for R28 ductile bolts. Thereafter, with reduced stiffness and a nonlinear response, the load continues to increase until reaching approximately 260–340 kN, regardless of bolt type. Deformation at ultimate capacity is on the order of 35–45 mm for both bolt diameters.

Under shear loading, the deformation process for both types of ductile bolts is very similar. The initial deformation stage occurs at a stiffness of approximately 11 kN/mm up to a load of around 100 kN. Subsequently, the bolts continue to deform at a lower stiffness of about 3–5 kN/mm until reaching a maximum load of approximately 280–290 kN for both R32 and R28 ductile bolts. The displacement (deformation) at shear failure is only slightly greater than the ultimate deformation observed in tension and amounts to approximately 43 mm for R32 ductile bolts and 50–53 mm for R28 ductile bolts. Further insight into the deformation and failure mechanisms of ductile bolts in tension is provided by Figure 8.



(a) (b)

Figure 8 (a) One of the R32 ductile bolts after the tensile testing. View of the fractured bolt protruding from the back concrete block, (b) fractured part of the same bolt embedded in a resin in a drillhole in the front block

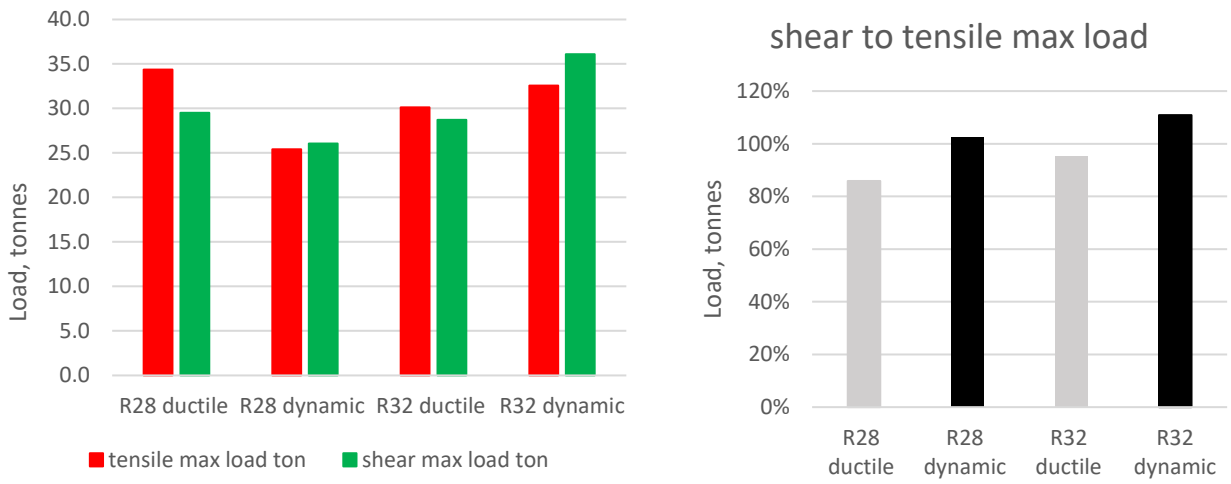
The fractured parts of R32 ductile bolts after testing are visible: the rear section on the Figure 8a and the front section on the Figure 8b. Localised deformation and elongation of the bolt in the vicinity of the opening discontinuity can be clearly observed. Understanding the shear failure mechanism of ductile bolts is facilitated by examining Figure 9. The figure illustrates localised bolt displacement within the borehole, bolt bending, and local crushing of the concrete forming the borehole walls, all occurring immediately prior to shearing of the steel bolt.

A comparison of the average ultimate tensile and shear load-bearing capacities of the tested bolts shows that, for dynamic bolts – both R28 and R32 – the shear capacity exceeds the tensile capacity. This observation applies to bolts bonded with mineral bolt resin in drilled holes in concrete blocks. This relationship is shown in Figure 10a, where the green bars are higher than the red bars for both R28 and R32 dynamic bolts. This corresponds to the height of the black bars in Figure 10b, which present the ratio of ultimate shear capacity to ultimate tensile capacity. For dynamic bolts, this ratio exceeds 100%.



(a) (b)

Figure 9 (a) One of the R28 ductile bolts after the shear testing. Remnants of the same bolt in a drillhole in a front block viewed from 2 different angles. Note clear bending of the shank of the bolt in the vicinity of the joint (discontinuity) between the concrete blocks, (b) and movement of bolt inside the drillhole prior the shear failure



(a) (b)

Figure 10 (a) Comparison of load-bearing capacities of hollow-core bar bolts in shear and tension; (b) Ratio of shear to tensile maximum load for the bolts tested

Figure 11 presents a summary of the ultimate shear capacities achieved by the tested bolts. For comparison, typical values obtained from shear tests on 20 mm diameter bar bolts – namely Versabolt dynamic bolts and conventional rebar bolts – have been included.

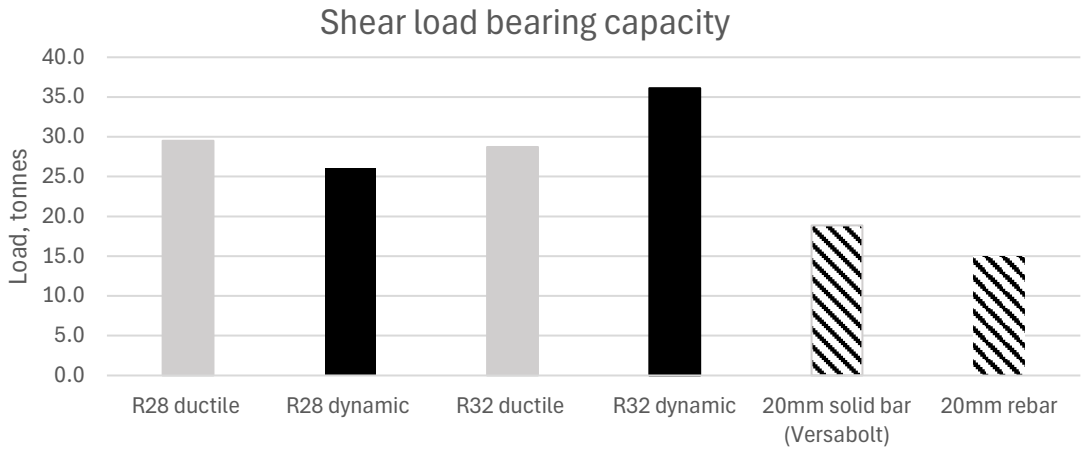


Figure 11 Comparison of the load-bearing capacities in shear of hollow-core bar bolts and 2 different solid bar bolts

As can be seen, the capacities of these bolt types are significantly lower and may reach only about 50%, or even less than 50%, of the ultimate shear capacity achieved by the strongest R32 dynamic bolts.

2.2 Performance and strength of couplings used for extension drilling with hollow-core bar bolts

One of the advantages of hollow-core bar bolts, apart from the fact that they can be – and are often used as – so-called self-drilling bolts, is their flexibility in allowing a seamless transition from single-bolt installation to so-called extension drilling, where 2, 3, 4, or even more bolts are connected using couplers to increase the bolting horizon in demanding ground conditions.

To ensure high-quality of the whole rockbolting process, the couplers themselves were also tested as part of this research campaign. Questions are sometimes raised, or doubts expressed, as to whether the coupler might represent the weakest link in the bolting system.

To eliminate these concerns, the couplers were tested in 2 configurations. First, brand-new couplers obtained directly from the factory were tested. In addition, another test was carried out involving the drilling of boreholes at Sandvik's test mine in Tampere, Finland, using ductile and dynamic hollow-core bar bolts connected by couplers. After drilling in the hard Scandinavian granites, the bolts were not grouted with resin; instead, they were withdrawn from the boreholes. The couplers that had connected the bolts during drilling – and had therefore been subjected to bending and loading generated by drilling at the full power of the drilling rig – were then removed from the bolts and used in tensile testing.

Testing of couplers used to connect both dynamic and ductile bolts was conducted at a specialised testing facility in Finland. A total of 15 tests were performed on couplers obtained from 4 sets of ductile bolts and one set of dynamic bolts. The consolidated results are presented in Figure 12.

The individual bars represent the average maximum force recorded in each test for the 3 couplers connecting bolts from a single borehole. Two observations are particularly noteworthy. First, the results for the ductile bolts were highly consistent, with the load-bearing capacity of the tested assemblies reaching approximately 320 kN in every case (the couplers themselves were capable of carrying higher loads).

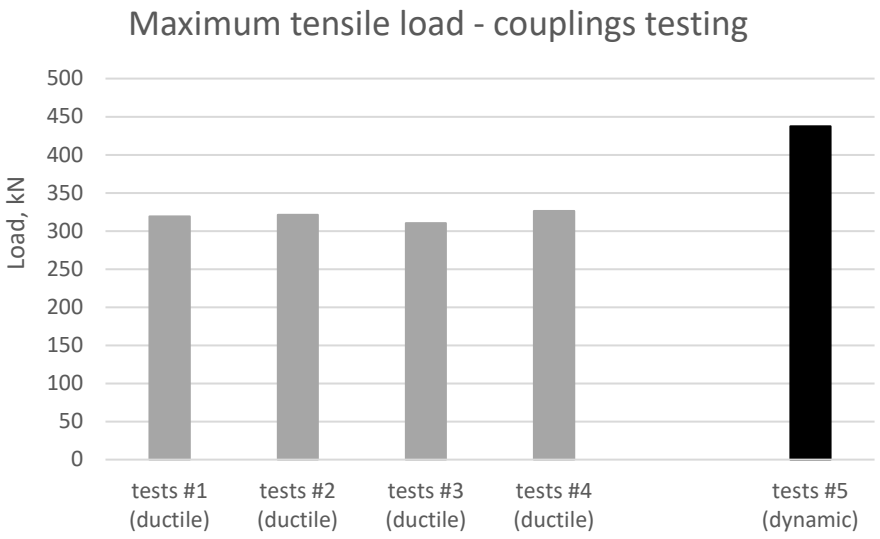


Figure 12 Summary of the results of tensile testing of couplings retrieved from drillholes. Each bar gives a mean value of 3 coupling tests

For the couplers connecting dynamic bolts, the average maximum load reached nearly 440 kN and again couplers did not fail at that load level.

Representative photographs of bolt sections and the couplers connecting them after testing are shown in Figure 13.



(a) (b)

Figure 13 (a) Couplings retrieved from drill-holes after tensile testing, broken one of the R32 ductile bolt with intact coupling; (b)Fractured R32 dynamic bolt with intact coupling

The tests confirmed that the couplers possess a higher load-bearing capacity than the bolts themselves. Not a single case of coupler failure or shearing of the bolt thread within the coupler was observed. In every test, either the ultimate load capacity of the bolt was reached, resulting in bolt fracture, or – in a few isolated cases – the thread beneath a single nut used to secure the assembly in the testing machine was sheared.

These investigations confirmed the quality of the couplers and demonstrated that, even after being exposed to demanding drilling conditions, they do not constitute the weakest link in the bolting system.

3 Performance, efficiency and productivity of rockbolting with pumpable resin under varying hard rock mining conditions

Pumpable resin has been used in various hard rock mining applications for several years (Bray et al. 2019). Semi-mechanised, mechanised, and, more recently, fully automated installation cycles have improved both installation quality and working conditions for operators. Studies have also shown that bolt installation productivity has improved compared with conventional methods (Osinga 2018). The use of pumpable resin in underground hard rock mines now faces very few limitations. A wide range of temperatures, varying rock conditions, seismicity, and other factors do not significantly restrict its application.

Pumpable resin can currently be used in a wide range of underground mining applications. Unlike a few years ago, its use is no longer limited to mechanised rock bolters. Pumpable resin can also be applied using mechanised cable bolters and face-drilling jumbos. In addition, bolt selection is no longer restricted to hollow-core bars or self-drilling bolts. Pumpable resin can be used with rebar bolts and similar dynamic versions such as Versabolt (Kouhia et al. 2024). Results of extensive dynamic testing performed on different bolt types such as Versabolt and hollow-core bar bolts grouted with mineral bolt resin and the energy absorption capacity of those assemblies can be found for instance in Smolnik & Penczek (2025). Both injection methods – pre-injection and post-injection (pre- and post-grouting) – are available for different bolt types. Current application categories and installation methods are presented in Table 1.

Table 1 Different installation methods per application

Application	Installation method and description
Two boom face-drilling jumbos	Semi-mechanised. Bolts need to be reloaded one by one to drilling feed. Drilling, injection and bolt installations are mechanised.
Rock bolter	Mechanised or fully automated. Bolts are in a bolt cassette. Typical cassette capacity 8–12 bolts. Operator assistant is needed to operate bolter in mechanised installation method.
Cable bolter	Mechanised. Modern cable bolter doesn’t need consumables manual handling. Drilling, injection and bolt installation are fully mechanised.

Several original equipment manufacturers currently offer the capability to integrate pumpable resin systems into underground drilling equipment. In addition, field experience has demonstrated that hollow-core bar bolts can replace traditional rebar bolts installed with resin capsules in certain applications (Bergman et al. 2023).

Numerous studies have highlighted the advantages of pumpable resin, particularly 2-component urea–silicate resin systems. Reported benefits include productivity improvements of up to 20% and, in some cases, an overall increase in mine production of approximately 8% (see, for example, Osinga 2018). However, productivity gains are not the only advantage. Pumpable resin can also improve installation quality, process consistency, and operator safety.

These improvements are achieved because the drilling rig control system manages both resin injection and bolt installation throughout the entire installation cycle. The operator maintains full visibility of the process,

while advanced user interfaces available on modern underground drilling equipment provide comprehensive monitoring and control of all installation parameters.

Figure 14a presents a modern user interface together with accessories designed to improve installation quality, enhance workplace safety, and enable the use of hollow-core bar bolts for extension drilling (Figure 14b and c).

The resin pumping system is self-calibrating and maintains a mixing ratio of 1:1 between the 2 resin components. If the required ratio cannot be achieved, the control system automatically stops the pumping process. This ensures that the components are always mixed correctly before being injected into the borehole.

Traditionally, mechanised rock bolters have been the primary equipment used for both primary and secondary ground support installation. However, the Australian practice of utilising face-drilling jumbos for ground-support installation has since been adopted in several mining regions worldwide.

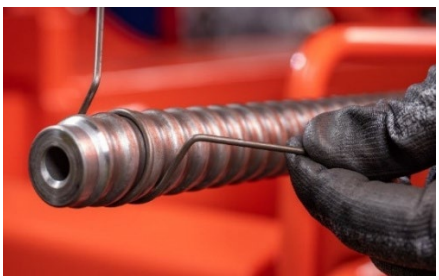
Today, face-drilling jumbos are routinely used for face drilling, scaling, and ground-support installation. While friction bolts were historically the most common support element installed using jumbos, modern equipment is capable of installing a wide range of reinforcement products, including hollow-core bar bolts with pumpable resin systems.



(a)



(b)



(c)

Figure 14 (a) Modern user interface providing a clear overview of the complete process, (b) bolt holder which is suitable for percussive drilling, (c) 'pig-tail' bolt holder to keep bolt in the hole after installation

Urea–silicate resin was introduced for use with mechanised cable bolters several years ago. The installation method is similar to that used for pre-grouted cemented cable holes. Compared with conventional cement grouting, urea–silicate resin eliminates the need for cement mixing and end-of-shift equipment cleaning, resulting in significant time savings. The injection process is cleaner, and refilling resin tanks is simpler and more efficient. Progress achieved in the development of a novel helical spirally indented cable bolt, together with the results of static and dynamic testing of cables grouted with mineral bolt resin and case studies demonstrating increased productivity on mechanised cable bolters, are described in Smolnik et al. (2026).

The use of integrated solutions based on injectable bulk resin enables fast, safe, and efficient rockbolting operations. Numerous studies and field applications have demonstrated the benefits of adopting hollow-core bar bolts in combination with pumpable resin systems.

Modern face-drilling jumbos can install several types of rock reinforcement, including hollow-core bar and self-drilling bolts. Self-drilling bolts are particularly suitable for poor ground conditions where boreholes collapse immediately after drilling. However, hollow-core bar bolts installed with pumpable resin can also be successfully used in many challenging ground conditions.

One of the key productivity advantages of face-drilling jumbos is their ability to perform simultaneous operations. On two-boom jumbos, drilling and bolt installation can be carried out concurrently. The use of bolt holders (‘pig-tails’) can further improve productivity by allowing bolts to remain securely positioned in the borehole without immediate resin injection.

As a result, resin injection and bolt tensioning can be completed after one or more bolt rings have been installed, minimising interruptions to the installation cycle.

Face-drilling jumbos are generally considered capable of achieving higher overall bolting productivity than dedicated mechanised rock bolters. Conventional friction-bolt installation combined with simultaneous drilling enables highly productive support installation. Although hollow-core bar and self-drilling bolts typically require additional time for resin injection and bolt tensioning, they can still provide competitive productivity while delivering superior ground-support performance.

The following productivity levels can typically be achieved with hollow-core bar bolts and pumpable resin:

- up to 100 installed bolts per 12-hour shift, with an effective bolting time of 6–8 hours (excluding mesh installation)
- on average, 12–17 bolts per hour can be installed, with rates of up to 20–25 bolts per hour achievable under favourable conditions (excluding mesh installation).

Some underground mines have partially replaced conventional Prestressed Concrete-strand cable bolts with self-drilling bolt systems. Face-drilling jumbos can also be used for drilling and installing longer reinforcement holes.

For these applications, specialised bolt holders are required to secure the bolt in the borehole while additional bolt sections are connected to the drill feed. These holders must be more robust than those used for standard hollow-core bar installation, as conventional hollow-core bar bolt holders are generally not designed to withstand drilling loads. Standard self-drilling bolts may not be the optimal solution for longer holes. Dynamic and ductile hollow-core bar bolts are often a better alternative due to their greater wall thickness, which allows higher feed forces and improved drilling penetration rates.

Urea–silicate resin offers a wide operating temperature range. Underground application temperatures can vary from approximately 5 to 45°C, while recommended storage temperatures typically range from 5 to 30°C. The primary storage limitation is exposure to direct sunlight; therefore, resin tanks should not be stored outdoors without protection from solar radiation.

The availability of resins with different curing times enables their use even in high-temperature underground environments and for longer reinforcement holes. Since curing time is strongly influenced by temperature, higher temperatures result in faster resin curing, while lower temperatures extend the curing period.

4 Conclusion

The paper presents laboratory investigations of hollow-core bar bolt assemblies installed with mineral bolt urea–silicate resin and evaluates key components of the rockbolting system.

Tensile and shear testing of R28 and R32 dynamic and ductile hollow-core bar bolts demonstrated excellent mechanical performance. Dynamic bolts exhibited exceptionally high deformation capacity, reaching failure strains of approximately 15% and elongations exceeding 230 mm in tension. A particularly significant finding was that the shear capacity of dynamic bolts exceeded their tensile capacity, primarily due to localised bolt bending and confinement effects within the borehole.

Ductile bolts also showed high load-bearing capacity, their behaviour was characterised by controlled localised deformation near the discontinuity between the concrete blocks prior to failure.

A notable outcome of the testing program was the complete absence of resin bond failure or bolt pull-out, despite all tests being performed only one hour after installation. Even with relatively short embedment lengths, the urea–silicate resin developed sufficient bond strength to fully mobilise bolt capacity, confirming the effectiveness of the mineral bolt resin system.

The study also investigated couplers used in extension drilling applications. Tensile testing of both new couplers and couplers recovered after drilling in hard Scandinavian granite demonstrated that their strength exceeded that of the connected bolts. In all tests, bolt failure occurred before coupler failure, confirming that the couplers do not constitute the weakest component of the rockbolting system.

The paper further examines the practical application of pumpable resin technology in underground mining. The results highlight the compatibility of urea–silicate resin with face-drilling jumbos, rock bolters, and cable bolters, enabling semi-mechanised, mechanised, and fully automated installation methods. Benefits include improved installation quality, enhanced safety, reliable process control, reduced manual handling, and productivity gains of up to 20% compared with conventional installation methods.

Overall, the findings confirm that hollow-core bar bolts grouted with pumpable urea–silicate resin provide a high-performance ground support solution characterised by strong anchorage, high tensile and shear resistance, excellent ductility, reliable coupler performance, and suitability for modern productive underground mining operations.

References

Bergman, A, Fjellner, E, Hallén, P, Penczek, R, Pérez Hidalgo, K, Scolari, F & Svanberg, M, 2023, 'Adopting hollow bar: lessons learned', in J Wesseloo (ed.), *Ground Support 2023: Proceedings of the 10th International Conference on Ground Support in Mining*, Australian Centre for Geomechanics, Perth, pp. 301–316, https://doi.org/10.36487/ACG_repo/2325_20

Bray, P, Johnsson, A & Schunnesson, H 2019, 'Rock reinforcement solutions case study: Malmberget iron ore mine, Sweden', in W Joughin (ed.), *Deep Mining 2019: Proceedings of the Ninth International Conference on Deep and High Stress Mining*, The Southern African Institute of Mining and Metallurgy, Johannesburg, pp. 191–204, https://doi.org/10.36487/ACG_rep/1952_15_Bray

Kouhia, A, Penczek, R & Scolari, F 2024, 'Integrated solutions based on injectable bulk resin for fast and safe rockbolting', in P Andrieux & D Cumming-Potvin (eds), *Deep Mining 2024: Proceedings of the 10th International Conference on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 607–620, https://doi.org/10.36487/ACG_repo/2465_36

Li, Ch 2010, 'Field Observations of Rock Bolts in High Stress Rock Masses.', *Rock Mechanics and Rock Engineering*, vol. 43, pp. 491–496, https://doi.org/10.1007/s00603-009-0067-8

NTNU 2023, *Tensile and shear tests for hollow bar bolts in rock bolt test rig – Phase 2*, Trondheim.

Osinga, DJA 2018, *A Review of the High-Performance Rockbolting Method and its Application in a Nordic Mine*, Master thesis, Aalto University, Espoo.

Smolnik, G & Penczek, R 2025, 'Styrene-free Polyester Resin and Urea-Silicate Resin Behaviour Under Dynamic Loading Conditions', in Savka Dineva (ed.), *Proceedings of the 11th International Symposium on Rockbursts and Seismicity in Mines,* Mining and Rock Engineering, Luleå University of Technology, Luleå, pp. 795–811.

Smolnik, G, Penczek, R & Guenette, A 2026, 'Innovations in cable bolting in a hot and seismic mining areas', in L Lorig (ed.), *60th US Rock Mechanics / Geomechanics Symposium*, American Rock Mechanics Association, Tucson.