2008

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Publication Details

This conference paper was originally published as Moosav, M and Karimi, S, Corrosion Protection of Rock Bolts by Epoxy coating and its Effect on Reducing Bond Capacity in Aziz, N (ed), Coal 2008: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2008, 117-124.

CORROSION PROTECTION OF ROCK BOLTS BY EPOXY COATING AND ITS EFFECT ON REDUCING BOND CAPACITY

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ABSTRACT: Corrosion protection of fully grouted rock bolts has been the subject of considerable research in recent years. Corrosion protection is studied focusing on quantitatively determining how much encapsulation coating affect the bolt/resin bond capacity. Resin coating results in reduction of rib height and in turn causes a decrease in interlocking effect with the grout annulus. The laboratory tests performed have shown that there was a wide range of reduction in bonding strength (from 5 to 40 %), depending on the type of the bolt and media in which the bolt had been installed. The reduction of rib height was also responsible for lower lateral dilation during bolt pullout tests. This effect will make the confining medium become an important parameter, since higher confining medium results in higher confining pressure on the bolt surface which in turn, controls the bond capacity.

INTRODUCTION

For years, rock bolts have been a common method for ground reinforcement both at underground as well as surface rock structures. Effectiveness and ease of installation has been the main two advantages of this active support method as opposed to the usual passive ways of supporting broken rock. Most of the bolts are made out of steel which makes them good candidates for corrosion. Although fibreglass bolts have recently emerged into the market for special applications, nevertheless steel bolts have still remained the dominant type of rock bolt in daily practice.

One of the main problems about rock bolts, especially underground, is corrosion. The main causes of this problem are underground water, humidity, stray currents and chemical interaction between the surrounding media and the steel. Grounds with sulphur content, when interacts with water, can produce strong acids which quickly reduce the effective diameter of the bolt. This problem in certain circumstances becomes so severe that can cause failure of the reinforcement.

One of the temporary methods to overcome this problem is to apply a corrosion resistant coating on the surface of the bolt. Epoxy resin is one of these materials which have been widely used due to its relatively low price. Although this can be assumed only a temporary solution, but in many occasions, the lifetime of the tunnel which these reinforcements are to be used in is also short therefore their application is justifiable. For higher required life times, stronger protections are required. Double Corrosion Protection systems (DCP) utilizes a high density polyethylene tube as well as a layer of cement around the bolt as two corrosion protection layers, to ensure higher corrosion securities.
One of the causes of epoxy coating is reduction of the effective rib height in the bolts which in turn, can reduce the bond capacity due to reduced interlocking effect with the grout annulus surrounding the bolt. The present paper tries to find a quantitative answer to this general feeling about reduced bond capacity.

ROCK BOLTING IN MINES

Rock masses contain natural discontinuities which may cause stability problems, therefore most underground openings need to be stabilized to maintain their integrity during their service life. As stated by Hoek and Brown (1980), "The principal objective in the design of underground excavation support is to help the rock mass to support itself". The best way to achieve this is through the use of reinforcement (i.e. rock bolt) to help maintain the load-carrying capability of rock masses near excavation boundaries.

Beyl (1945) reported an early use of bolts in a longwall mine in 1912. The bolt was made out of wood and was used to prevent small pieces of rock from falling between the face and the main support system. Littlejohn and Bruce (1977) reported that the first use of rock anchors was in Cheurfas Dam, Algeria in 1934. Due to the success of bolting, fundamental studies on the bolting action were started by Rabcewicz (1955) and was continued by Panek (1956a, b,c,1962a,b) supported by U.S. Bureau of Mines. This research led to the concepts of suspension and beam building effects for bolts in bedded mine roofs. The arching effect of bolts was pointed out by Evans (1960). In jointed rocks, the importance of limiting displacement as the key parameter of the bolting action was explained by Palmer *et al*. (1976). This is because the opening of joints during excavation decreases the strength of rock due to the associated softening effect. This concept forms the basis of present pre-reinforcement concepts.

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It was noted that pre-placement of bolts can decrease the deterioration of the internal rock mass strength resulting from joint dilation.

Rock bolting is currently a usual practice in most of the coal mines due to the limited required length for the reinforcing rock layers and the request for high installation speed as a prerequisite for increasing production time. Most of the rock bolts use resin capsules as a bonding agent to the rock which facilitates faster process and reduces time for the whole supporting cycle.

CORROSION MECHANISM

Corrosion is defined as defect on material (usually metals) properties due to their interaction with the surrounding media. By this definition, wear, abrasion, scratch and fatigue which have mechanical cause are excluded. It is worth noting that the word "rust" is used only for Iron which is an interaction with water and Oxygen. In another words, other metals will corrode but do not rust.
The main chemical mechanism in steel corrosion is as follows:

$$Fe + H_2O + \frac{1}{2}O_2 \rightarrow Fe(OH)_2$$

So if anyone of the main three components (steel, water and oxygen) does not exist, the corrosion would not happen.
In this mechanism, some parameters can have accelerating effects which the most important ones are as follows.

- Temperature: Usually the higher the temperature, the faster the corrosion would be. The hotter points in a material are usually more anodic than the other points so cause accelerated corrosion locally.
- Difference in galvanic potential: When two metals with different galvanic potentials are close to each other, the metal with higher galvanic number acts as anode and corrodes faster so protects the other metal from corrosion.
- Surface smoothness: Metals with rough surfaces usually corrode faster than shiny surfaces.
- Stress: When a material is under tensile stress, it corrodes faster which is believed to be due to the micro cracks generation in the metal. Corrosion will accelerate if the stress level is higher, especially if it is close to the material's elastic limit.

TEST SETUP AND SAMPLE PREPARATIONS

The bolts used for tests consisted of two types, i.e. 28mm rebar and 28mm continuous thread bar from Dywidag company. The bond length in each sample was 15 cm and the water:cement ratio used for the grout annulus was 0.4. Some of the bolts were covered by epoxy resin while some others were left uncoated to enable comparison of bond reduction. The number of the bolts used in each test class is shown in Table 1.

Table 1 - The number of tests performed in each test category.

Type of bolt	Type of confining pipe		
	Steel	Aluminium	PVC
CT bar Φ28 with Epoxy	4	4	4
CT bar Φ 28 without Epoxy	3	3	3
Rebar Φ28 with Epoxy	4	4	4
Rebar Φ28 without Epoxy	3	3	3

Since the bolts are usually installed in 63.5 mm (2.5 inch) diameter borehole, the laboratory test was designed so that the bolts become surrounded by the same size mould. To confine the bolts, they were put in pipes with internal diameter of 63.5 mm (2.5 inch) and the space between the bolt and the pipe was filled with Portland Cement grout. This test was carried out "constant confining stiffness" condition, meaning that during pull test, the generated pressure at the outer surface of the grout will vary as a function of generated dilation due to ribs. These pipes were made of Steel, Aluminium and PVC, to simulate different rock mass qualities in the laboratory. To associate each pipe to a rock mass with known quality (*i.e.* E_{rm}) equation (1) can be utilized.

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

In this equation k_r is the radial stiffness of a pipe with d_i and d_o as its inner and outer diameters and E and v as the elastic properties of the pipe material. Table 2 shows the radial stiffness of the various pipes used as moulds.

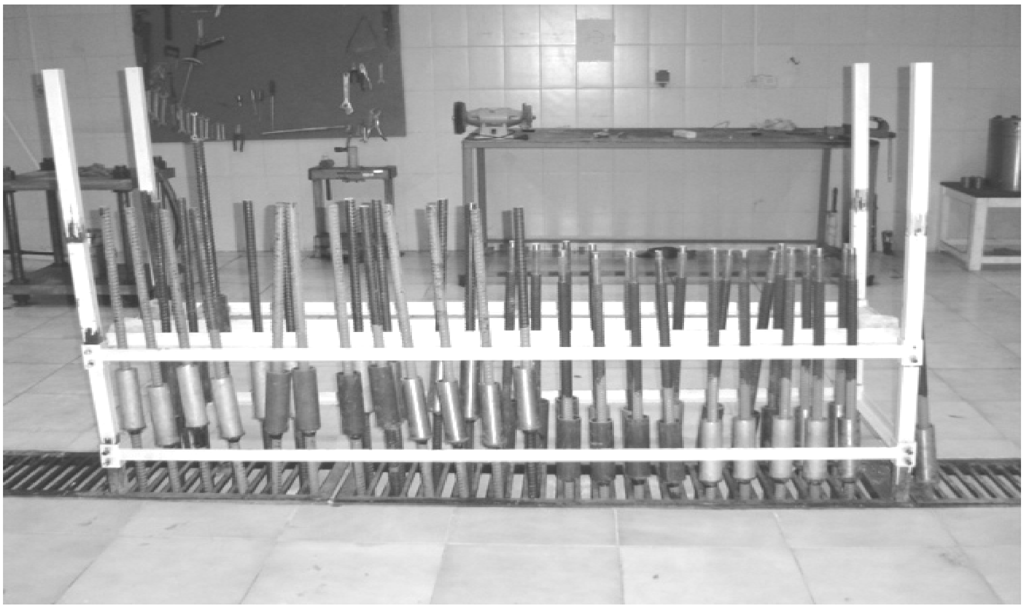

Figure 1 - Sample preparation.

Table 2 - Radial stiffness of the pipes used as mould.

	E (GPa)	v	d_o (mm)	d_i (mm)	k_r (MPa/mm)
Steel	200	.25	58.4	45.5	2110.33
Aluminium	72	.25	59.6	50.0	504.81
PVC	3	.32	62.44	53.3	19.17

For a borehole drilled with radius r in a rock mass having deformation Modulus and poison's ratio equal to E_r and v respectively, the radial stiffness is:

$$k_r = \frac{E_r}{(1+v)r} \quad (2)$$

therefore the steel pipe, for example, used in the tests is equivalent to a rock mass having deformation modulus equal to 83 GPa since;

$$2110.33 = \frac{E_r}{(1+0.25)31.5}$$ or E_r=83000 MPa.

At the time of pouring cement annulus around the bolts, cylindrical samples were taken from the grout and their mechanical properties were determined after 28 days.

After the grouted bolts were left to cure for 28 days, they were put in the testing setup and were pulled for determination of bond capacity. This consisted of a 600 kN hollow ram jack activated via a hydraulic pump. The loading force is determined using an electrical load cell and the bolt displacement during pull was measured using an electrical displacement sensor (LVDT) with 0.01 mm accuracy at the exit point of the bolt. The whole system was connected to a data acquisition system (DAS) for automatic data collection and storing.

Figure 2 - Grout samples poured for mechanical properties tests.

Figure 3 - Test setup with the hollow ram jack and DAS system for data collection.

TEST RESULTS

Figures 4 through 9 show the comparative results for pullout force for each type of bolt with and without epoxy coating. Note that each graph is the average of the number of tests in that category that was mentioned earlier in Table 1.

Table 3 has summarizes the pull force results for the above tests.

Table 3 - Comparison between the maximum pullout forces for the tested samples

Type of bolt	Type of confining pipe, peak load and pull force reduction due to epoxy coating					
	Steel		Aluminium		PVC	
	Peak Load (kN)	Reduction %	Peak Load (kN)	Reduction %	Peak Load (kN)	Reduction %
CT bar Φ28 with Epoxy	110	39	88	15	54	33
CT bar Φ 28 without Epoxy	181		104		80	
Rebar Φ28 with Epoxy	152	5.5	107	14	73	28
Rebar Φ28 without Epoxy	161		125		102	

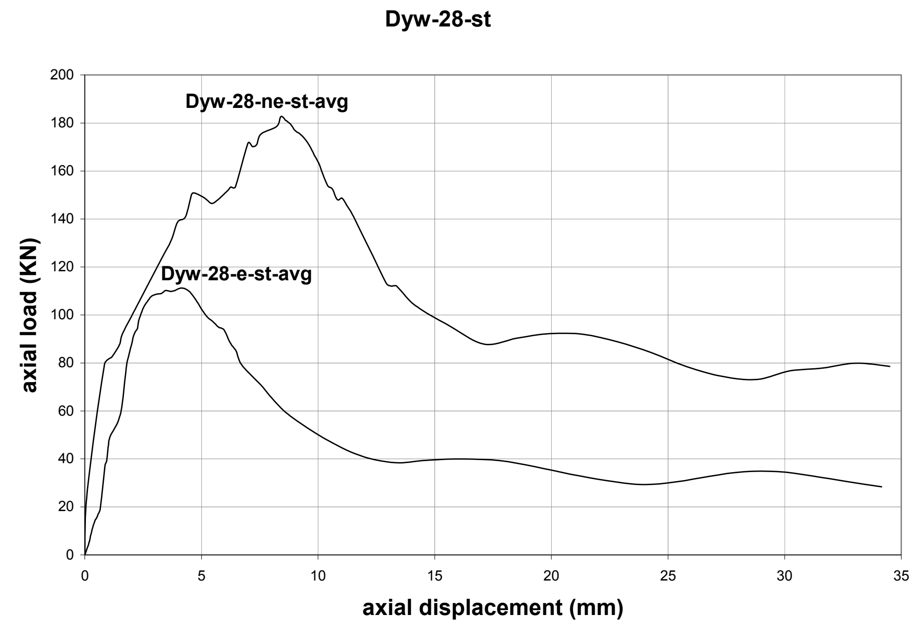

Figure 4 - 28 mm CT bar results for epoxy coated (e) and non epoxy coated (ne) when confined in a steel pipe.

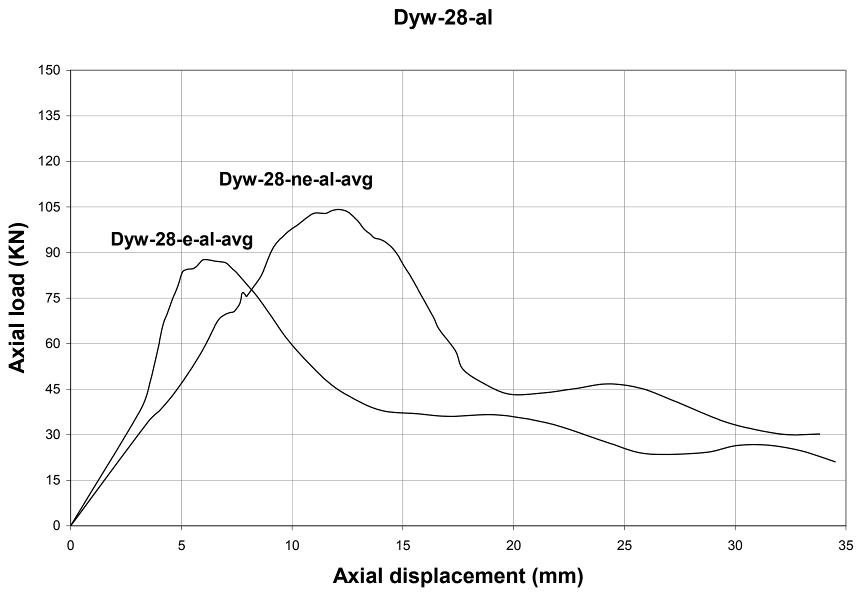

Figure 5 - 28 mm CT bar results for epoxy coated (e) and non epoxy coated (ne) when confined in an Aluminium pipe.

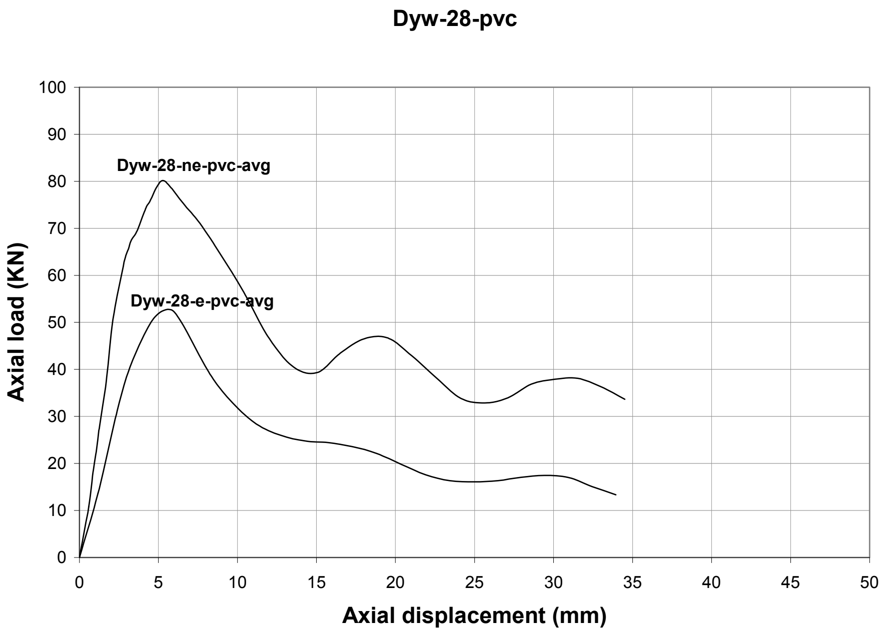

Figure 6 - 28 mm CT bar results for epoxy coated (e) and non epoxy coated (ne) when confined in a PVC pipe

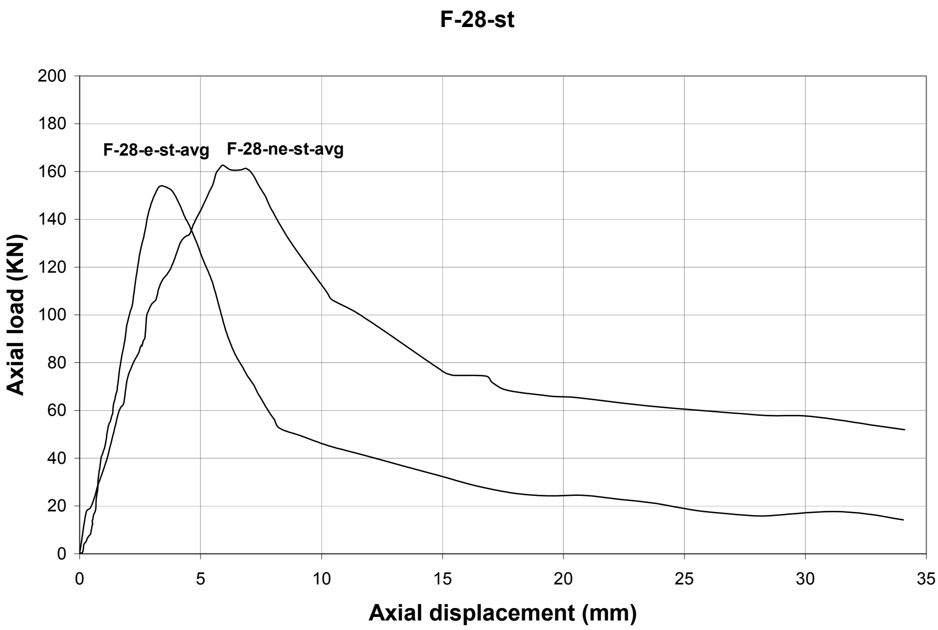

Figure 7 - 28 mm rebar results for epoxy coated (e) and non epoxy coated (ne) when confined in a steel pipe

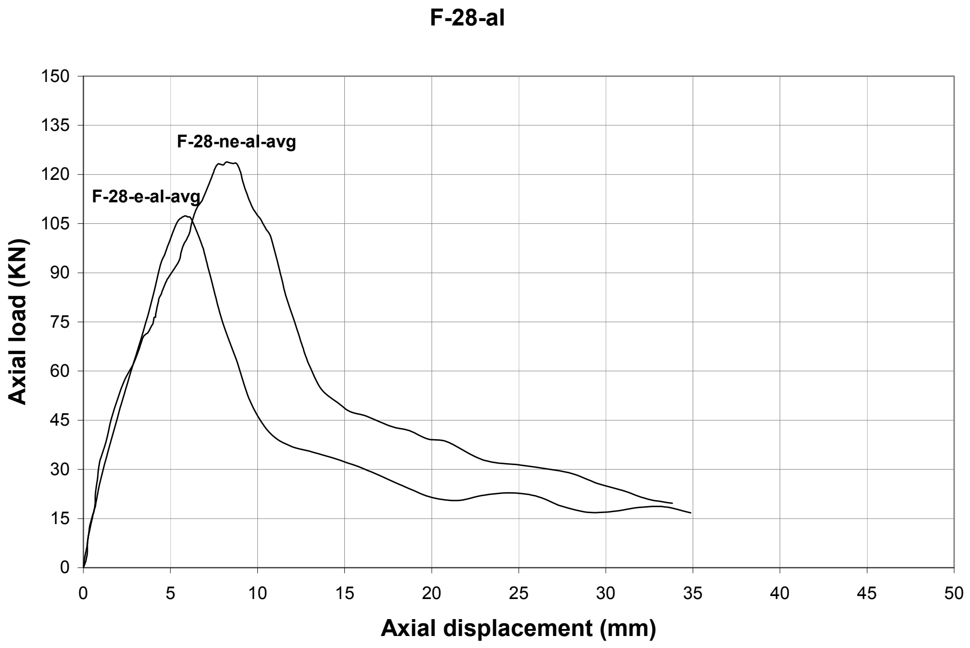

Figure 8 - 28 mm rebar results for epoxy coated (e) and non epoxy coated (ne) when confined in aluminium pipe.

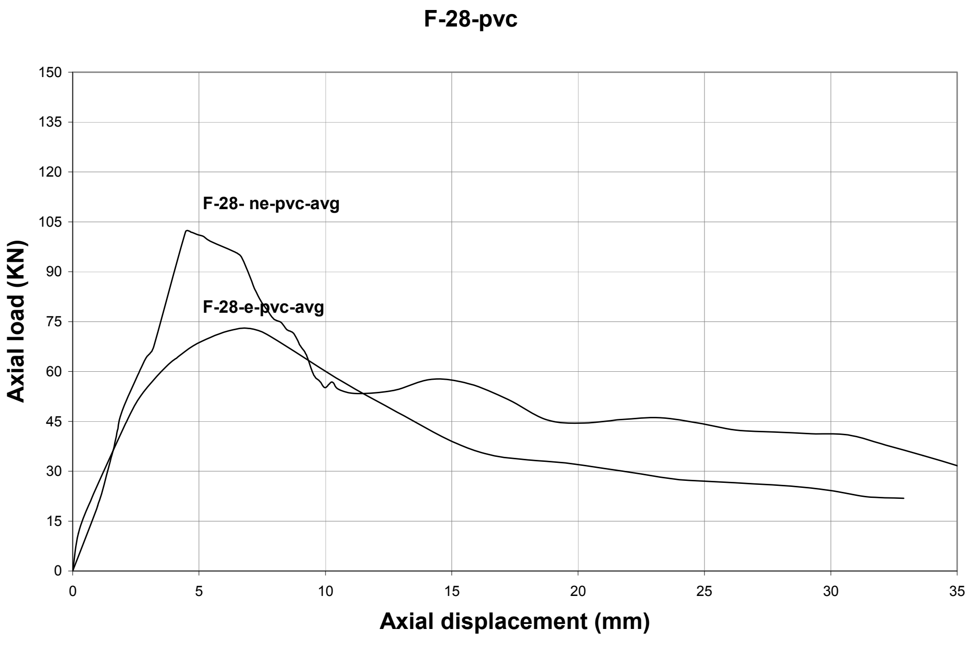

Figure 9 - 28 mm rebar results for epoxy coated (e) and non epoxy coated (ne) when confined in a PVC pipe.

DISCUSSIONS AND CONCLUSIONS

According to the obtained results, the following conclusions can be made:

1. In all results, higher bond capacities are obtained from bolts without epoxy coatings regardless of the bolt type. This reduction is ranging from 5 to almost 40 percent in different bolts.
2. Reduction of bond capacity due to epoxy coating is believed to be due to reduction in effective rib height and creation of a more smooth bolt so the frictional properties of the bolt-cement interface is reduced.
3. Higher bond capacities are obtained from pipes with higher radial stiffness i.e. Steel, Aluminium and PVC respectively.
4. The wavy form of pull curves is notable in these tests and is believed to be from the passage of ribs through the sound and crushed cement regions. Correlation of wave lengths and rib spacing confirms this finding.
5. After increasing shear displacement, the shear face becomes more and more smooth which explains the decaying trend of each load peak.
6. Lower bond results are obtained from CT bars compared to rebar which are explainable by existence of two smooth sides on the CT bolts. These area has no ribs hence reduces the frictional properties of the bolt surface during pullout.

ACKNOWLEDGEMENT

This research was funded by the Research deputy of The University of Tehran and tests were performed at Rock Mechanics laboratory which both supports are highly appreciated and acknowledged.

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