OPTIMIZATION OF THE NEVES-CORVO MINE CABLE SUPPORT

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This research was conducted with the aim of study and analyze the optimization of the rock mass reinforcement by the use of cable support, applied in Neves-Corvo Mine, Portugal. The optimization of cable support properties is related to the introduction of new bolt types, the use of complementary elements (plates, barrels and wedges) and to the modification of water/cement ratio and the addition of admixtures to the cement grout.

The comprehension of the bond strength variation is crucial to the study of the cable support performance. In this study, through the modification of the cement grout composition, adding a plasticizer and expansive admixture (Cablejet, MAPEI) and modifying the water/cement ratio, it was possible to made uniaxial compressive strength tests and pull out tests, in order to study its geomechanical behavior and contribution in enhancement of system efficiency.

The developed study allowed concluding about the underground workability of each grouts and verify that, in laboratory, the geomechanical behavior of some of those grouts was better than the actual grout, used in Neves-Corvo Mine cable support.

1. Introduction

The cable bolt reinforcement system is made up of four components: the rock mass, the element (strands), the internal fixture (cement grout) and the external fixture (plate and anchor). The cablebolt is a flexible tendon consisting of a number of steel wires, wound into strand, which is grouted into a borehole. Normally, the borehole spacing is regular to provide a correct reinforcement and support of the walls, defining a stable zone (Hassel *et al*. 2006; Hutchinson & Diederichs, 1996) (fig.1.1).

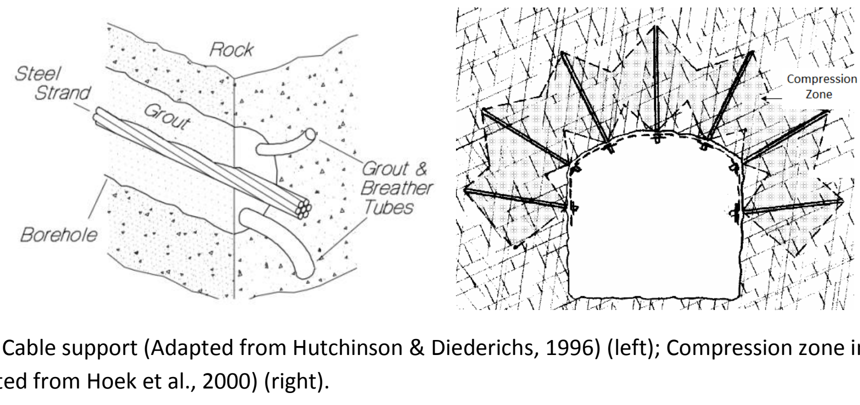

Figure 1.1 – Cable support (Adapted from Hutchinson & Diederichs, 1996) (left); Compression zone in the rock mass (Adapted from Hoek et al., 2000) (right).

Cable support was introduced in mining industry in the begining of 20th century and, since then, has been remarkably improved due to technological development and the necessity of major support capacity, associated to mining methods.

Cablebolts are choosed because they are flexible, have a larger support capacity and can reach far into the rock mass, reinforcing large volumes of rock preventing separation along planes of weakness such as joints. Cablebolts are, normally, installed in critical situations like larger spans in major intersections and large underground chambers. This increase demand requires an increase in support system capacity which can be effectively provided by cablebolts to ensure adequate safety. In addition, the dilution control, provided by cablebolts, can have a very direct and large influence on the cost of a stope ensuring the profitability of the exploitation (Hutchinson & Diederichs, 1996; Villaescusa & Potvin, 2004).

The performance of the cable support is affected by the cable and cement grout properties and by the rock mass stress state. This study pretend to analyze the behavior of the reinforcement element when submitted to an axial force. Thus, it is important to understand the contribution of the bond strength in the cable/cement grout interface by testing different cement grout compositions, with the aim of determine the best composition.

2. Cable support

Cablebolt performs a combination of reinforcement (preventing the separation and the slip of rock mass blocks) and holding (avoiding the pressure relief and the formations of rock mass fissures) functions. The discontinuities displacements are complex and are due to the combination of tensile and shear strengths with possible movements of rotation and translation. The cablebolt should be installed with an angle between 20 and 40 degrees with the sliding surface.

2.1. Load transfer mechanism

The load is transferred from the rock mass to the cable trough the shear resistance at the grout/cable and grout/rock interfaces, along the entire length of the cablebolt, if there aren't too much voids in the grout column (Hutchinson & Diederichs, 1996). The load transfer capacity of cablebolts depend, essentially, of grout annular volume, cement gout geomechanical properties, cable geometrical and mechanical properties and rock mass roughness and resistance (Jalalifar, 2011).

The failure of a cablebolt is related to: (i) cable maximum capacity; (ii) the slip at grout/rock mass interface; (iii) failure at the cable/grout interface; (iv) failure of grout; (v) failure of the rock mass; (Choo *et al*., 2008). In the third case, when the cable displacement is given, due to axial force induced in the system, the shear strength (product of the combination of the confinement pressure and friction coefficient between cable and grout) depend of the radial pressure and dilation in the system (Hyett *et al*., 1995) (fig.2.1).

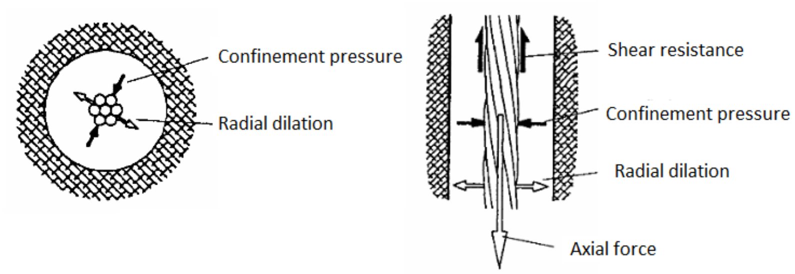

Figure 2.1 – Forces in cable support: a) Transversal section; b) Longitudinal section (Adapted from Hutchinson & Diederichs, 1996).

The bond strength of a cable is defined as the resistance to slip (at the cable/grout interface) along a unit or a unit surface area of a cable and the convenient units are kN/m or ton/m. While the actual relationship between ultimate capacity and grouted length is not always linear, the concept of normalized bond strength serves to simplify analysis and design. This property depends, essentially, of the chemical adhesion, the friction and the mechanical interlock component between cable and grout (Satola, 2007; Jalalifar, 2011).

2.2. Axial laboratory tests

The axial laboratory test (pull-out test) allow the study of the reinforce system maximum capacity and the study of the each component contribution. There are two types of axial test: (i) rotating tests (allow the cable rotation and tend to give a lower bond strength) ; (ii) non-rotating tests (can be done by constrained test or double pipe tests) (Satola, 2007).

In the laboratory, the total length of the system is equivalent to the embedment length (EL). If embedment length is smaller than critical embedment length (CEL), which means the minimum length at which cable rupture, the failure of the system is reached by the break of the grout. In other hand, if EL is bigger than CEL the system failure is due to cable rupture. In general, CEL corresponds to fifteen or twenty times the cable diameter. The system capacity increase with embedment length until a limit, defined by the capacity of the strand (Hyett *et al*., 1992; Kaiser & McCreath, 1992).

3. Cement grout

The capacity of the cablebolt is transferred to the rock mass through grout. Grout used in this type of support is usually composed by Portland cement and water in different quantities. Sometimes, additives area added to the mix to improve the physical and chemical properties of the grout. Any variation in the components quality and quantity will affect the mechanical properties in the fresh or hard state of the grout (Villaescusa & Potvin, 2004).

The water/cement ratio (w/c) is the most important property of cement grout or paste. It affects all the properties of the grout and is non-proportional to grout resistance. To cablebolting applications, a good water/cement grout is between 0,35 and 0,4. Values under 0,3, promote a large variety of grout resistance with a decrease of workability in pumping process due to higher viscosity. In other hand, values of water/cement above 0,4 can compromise the efficiency of reinforce system because of the decrease in gout geomechanical properties and the creation of voids in the grout column (reduce the load transfer of the system and the bond strength of the system) (fig.3.1). Therefore, a balance between the grout consistency, viscosity and fluidity is required (Hutchinson & Diederichs, 1996; Hyett *et al.*, 1992; Goris, 1990).

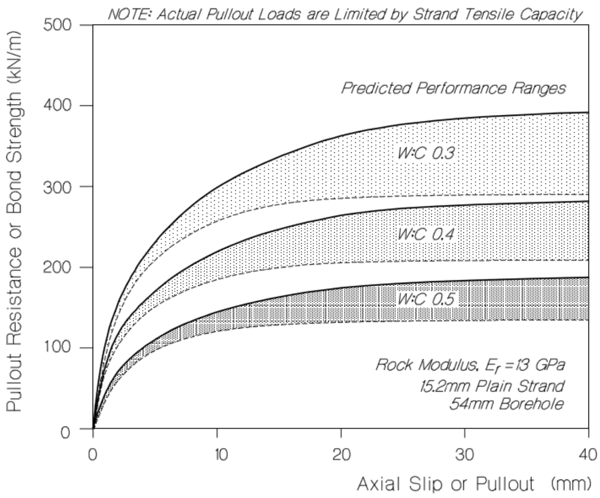

Figure 3.1 - Influence of water/cement ratio in the bond strength (Adapted from Hutchinson & Diederichs, 1996).

The compressive strength is the capacity of a grout to support (without damages) a compression force. It depends, essentially, of the grout type and composition, the setting conditions and the porosity (related with the voids quantity, dimension and shape). The compressive strength is a important parameter to grout geomechanical characterization. It is crucial that exists, a balance between a higher resistance (lower water/cement ratio) and a good fluidity (higher water/cement ratio) of the grout (Neno, 2010) (fig.3.2).

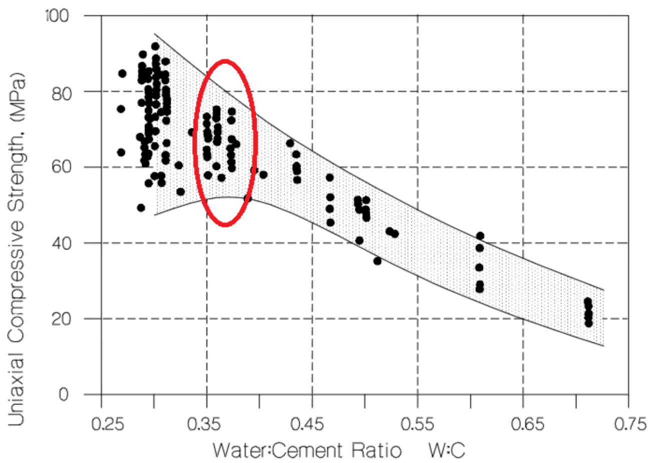

Figura 3.2 – Relation between the comprisse strength and water/cement ratio (Adapted from Hutchinson & Diederichs, 1996).

The admixtures are chemical substances that have organic or inorganic origin, which modify the physic-chemical properties of cement grout depending on the amount applied. In cablebolting, the application of these products is made whit the aim of improve the pumping process, accelerate the development of resistance as well as increase the breaking strength of the grout and increase corrosion resistance of cables.

4. Neves-Corvo Mine – Practical case

Neves-Corvo mine, located in Portugal on the southern edge f the Iberian Pyrite Belt, is actually, the most important and bigger (one of the biggest copper mines in Europe) Portuguese mining project and it is owns to SOMINCOR, S.A which belongs to LUNDIN group.

The production increase, associated with the decrease of actual ore grades lead to the need for introduction of new processes and technologies. Actually, the applied mining methods are based in the principle of Cut & fill, like: drift & fill, bench & fill, mini-bench & fill and sill pillars.

In Neves-Corvo Mine, the cable support is made by the introduction of two separated plane cables of 15,2 mm in a borehole of 51 mm (standard situations) or 64 (critical situations, when is needed major reinforce). The introduction of two single cables and the tensile of just one, allow that exists, in one hand, a rock mass deformation and, in other hand, the support of the rock mass, giving the necessary stability to the underground operations.

In order to understand all the process of cable support, were follow several operations in mine. The borehole marks (in the roof and side walls) are made by one team, of Rock Mechanic Department, using a fluorescent spray. The drilling operation requires a great knowledge of the equipment and great skill by the operator because it can decrease the execution time of the process. In the process of cables application was observed, in some situations, the difficulty of introducing the grout tube and cables into the boreholes and the production of grout waste. The grout wastes are created by the adhesion (between the grout and injection tube) and the retraction of the tube, provoking the drag of the grout to outside (fig.4.1).

Figure 4.1. – Drilling operation (left); Cables application (right).

4.1. Experimental work

In this study, was not possible to test different types of cables. Thus, were made several cement grouts with different water/cement ratios, a plasticizer and expansive admixture (Cablejet, MAPEI) or by the substitution of cement for a specific mortar for injection and anchoring (Stabilcem T, MAPEI).

4.1.1. Types of grouts tested

The types of tested grout were:

Table 4.1 – Types of tested grouts.

Grout		Observation
Type	**water/cement ratio**	
1	w/c = 0,3	Normal grout; Already applied in the mine
2	w/c = 0,3 + 3% Cablejet	3 % of the cement weight
3	w/c = 0,2 Stabilcem T	20% or 22% of water accordingly to the Stabilcem T specifications
4	w/c = 0,25 +3% Cablejet	3 % of the cement weight
5	w/c = 0,26 +3% Cablejet	3 % of the cement weight

It is important to refer that, to minimize the differences between the environments (laboratory or mine), the applied water in the mixes was recycled water from the mine, only applied in mining operations and not potable.

4.1.2 – Uniaxial Compressive Strength tests

The compressive tests were made in the first, third, seventh and twenty-eighth days after the production of the grouts. The specimens dimensions are normalized (NP EN 12390-1 2010) with edges of 100 mm and were made a total of eighty-four normalized tests (NP EN 12390-3 2009). The figure 4.2 show the average values for each grout and the standard defined by the Somincor “Ground Control Management Plan”.

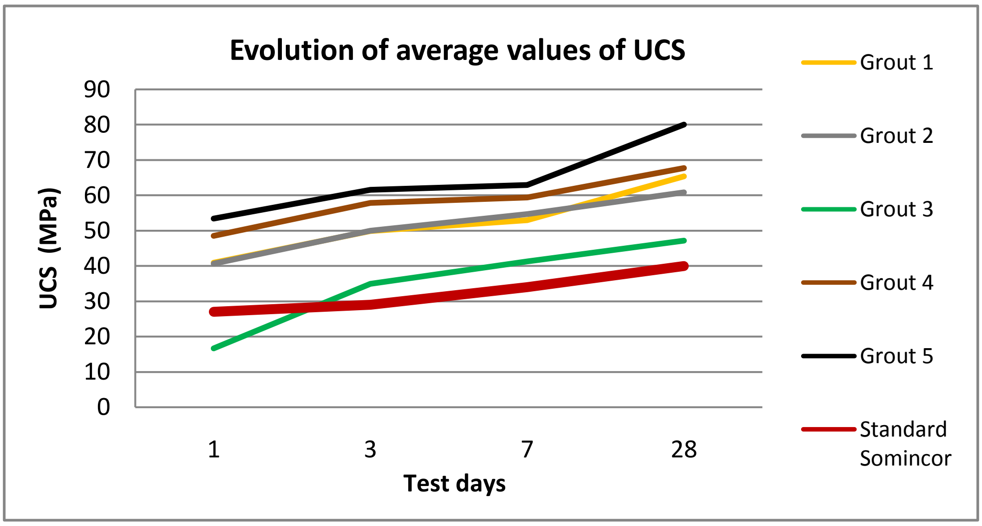

Figure 4.2 – Evolution of average values of uniaxial compressive strength.

4.1.3. Pull-out tests

The type of pull-out test adopted was the rotating test, with 1 m of embedment length (in a steel pipe with an external diameter of 51 mm) and cables with a 1,7 m length. Were made about 60 pull out tests.

The tensile strength is made in the most centralized cable, like in the mine. The tensile equipment (jack) is manual with a pressure gauge (lecture made in kN). The measuring deformation or displacement (d) was carried out in the zone between the hydraulic cylinder (allows a maximum displacement 7 cm) and the auxiliary plates (fig. 4.3).

Figure 4.3 – Pull-out test (left); Hidraulics cylinder pulling the cable (right).

In this study, the axial test can be divided in two, each one with different time intervals: (i) horary tests (4, 8, 12 and 24 hours after produce the grouts) with the objective of reduce the time interval between the application of the cables and their traction, in the underground (actually is about 3 shifts, 8 hours each); (ii) diary tests at first, third, seventh and twenty-eighth days. For each test was noted the force values (kN), the displacement of the cable (cm) and the force associated to the first displacement of the cable.

Only the grouts 1 (w/c = 0,3) and 4 (w/c = 0,25 + 3% Cablejet) were submitted to horary test due to questions of time of these study. The tested grouts in diary tests were the first, fourth and the fifth (w/c = 0,26 + 3% Cablejet). The selection of these grouts was made considering the workability and the geomechanical behavior of each grout.

During the pull-out tests was possible to verify different behaviors of the specimens. Some tests reach the rupture of the cable strand (when the tensile strength was bigger than the tensile capacity of the cable,223 kN) other tests result in a large deformation in the steel pipe (which indicates that, neither cable neither grout ceded) and, finally, in some test the cable just slip along the grout annulus (fig.4.4).

Figure 4.4 – Cable strand rupture (left); Steel pipe deformation (centre); Displacements: 1- displacement of the pulled cable, 2- displacement of the other cable (right).

5. Conclusions

There is an optimum grout mixture for each cablebolt type and method which represents a compromise between high grout strength (lower w/c ratio) and good grout flowability (higher w/c ratio). In the Neves-Corvo case, the grout 1 (w/c ratio) is appropriated. However, after this the laboratory work, was possible to produce cement grout with higher resistant behavior.

The consistency of the different cement grout is shown in the next table:

Table 5.1 –Consistency of tested grouts.

Grout		Consistency
Type	**w/c ratio**	
1	w/c = 0,3	Adequated to the cable support in Neves-Corvo Mine
2	w/c = 0,3 +3% Cablejet	Higher fluidity
3	w/c =0,2 Stabilcem T	Similar to grout 1
4	w/c = 0,25 +3% Cablejet	Lower workability, fast setting
5	w/c = 0,26 +3% Cablejet	Similar to grout 1

The variation in the consistency between grout 4 and 5 show the admixture sensibility to the quantity of water in the composition of the grout. Therefore, the quantity of mixing water should be highly controlled to product a grout with good workability, without compromising the performance of cable support.

In the uniaxial compressive strength tests, the grouts 4 and 5 had higher values than the other cement grouts. However, grout 5 achieved the best results, with even a 22% increase in the twenty-eighth day regarding grout 1.

In the horary pull-out test, with the grout 4, the deformation of the steel pipe and the rupture of the cable strand were achieved after 12 hours. These facts show that the bond strength in the grout/cable interface is good after this time interval. Thus, it is possible to reduce a shift in the operation of cables traction in the underground.

In the diary pull-out tests, the influence of the admixture (Cablejet) is demonstrated by the increase of the bond between the cable and grout. This influence is mainly noted in the first, third and seventh days, where grout 5 achieved great results, especially in the 7th day. However, it is important for future studies, the total knowledge of the grout 5 behavior at 28th day, since the shown unusual results at that day (fig. 5.1). In this study, was defined a factor of bond strength (R) determined by the relation between the force associated at cable first displacement and the maximum load achieved in the tests. This factor allows comparing different pull-out tests results because is expressed in percentage.

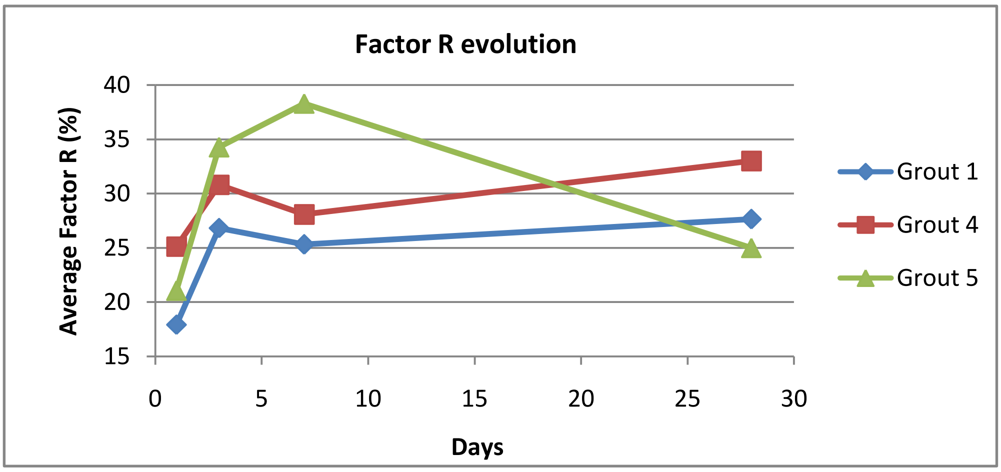

Figure 5.1 – Factor R evolution in the test days.

The figure 5.2 shows the relation between the uniaxial compressive strength and the factor of bond strength. Through the trend lines it is possible to see that the relation between these two parameters varies in an interval between 67% and 99%. In the case of grout 5 (w/c = 0,26 +3% Cablejet), only the first days of test count to this relation because the value of the last day is clearly unusual.

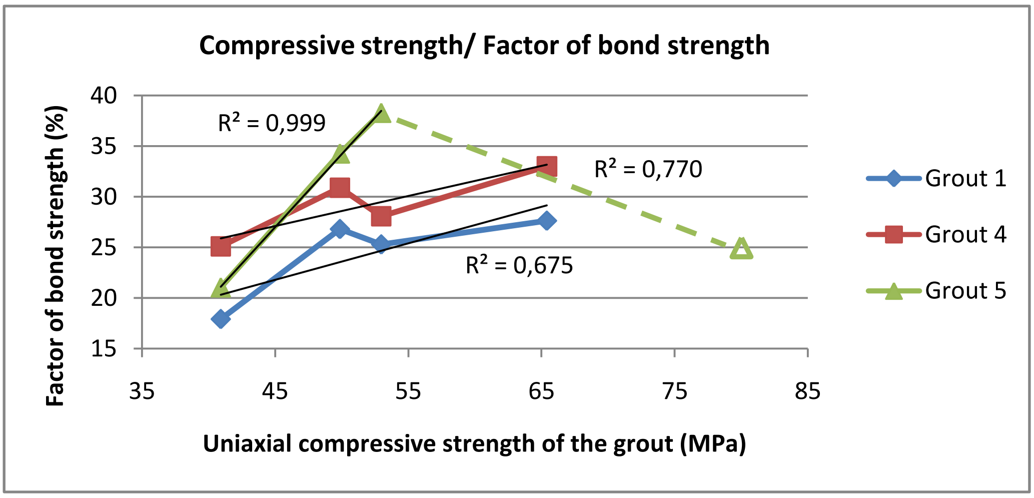

Figure 5.2 – Relation between compressive strength of the grout and factor R.

The failure of the reinforce system tested, due to the cable rupture means that, embedment length is higher than critical embedment length (EL>CEL). For the embedment length of 1 meter, the CEL as to be between 22,8 cm and 30,4 cm. Therefore, the pull-out tests were made into the domain of system failure by the cable strand rupture, showed by the results.

6. References

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