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Effect of mineral admixture types on the grout strength of fully-grouted rockbolts

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HIGHLIGHTS

- Bolt bond strengths and bearing capacities of grouted rockbolts were investigated.
- Mineral admixtures increased the pull-out capacities of rockbolts.
- Mineral admixtures can be used in grout to achieve higher resistance.
- The predictive models were developed for estimating bond strength of rockbolts.

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ABSTRACT

This paper represent the results of an experimental study handled with developed grouting materials for fully-cement-grouted ribbed rockbolts. These experimental studies cover the effects of some mineral admixtures (silica fume, blast furnace slag, fly ash etc.) on the bond characteristics between grout and rockbolts. The effect of mineral admixtures on the grout strength of fully-grouted rockbolts and block punch index (BPI) and compressive strength (CS) of the grout on the load bearing capacity (LBC) were investigated. Totally 150 rockbolt pull-out tests were performed using ten different grouts in order to investigate and improve the LBC of grouted rockbolts for five different curing times (1, 3, 7, 28 and 90 days). All grout types were prepared same ratios, and silica sand was used as fine aggregate. Grout mixtures that 15% of mineral admixtures replaced with cement by weight were prepared. The results showed that grouts produced with silica fume (SF) and metakaolin (MK) in all mixtures were yielded the highest CS and bond strength at all ages. The all strength tests of fly ash (FA) grout exhibited low values till 28 days of curing time in accordance with reference grout, but a sharp increase was observed after this period. Grouts with perlite (PRL) and blast furnace slag (BFS) showed the similar strength values according to reference grout. In conclusion, mineral admixtures can be used for high-strength and low cost grout in tunneling applications. In addition, the use of waste materials can contribute to the resolution of environmental problems.

1. Introduction

The rockbolts support system has often been used in the long-term stabilization of underground excavations in rock masses. Rock bolt systems can be divided into three groups, which are mechanically anchored, friction anchored and fully-grouted rockbolts (resin and cement grouted rockbolts). Developments of setting techniques and equipment, not having a disadvantage of decreasing at intersectional area of cavern, having a reinforcement effect in addition to supporting effect made rockbolts unrivalled in tunneling and slope stability.

The cement-grouted rockbolt is a fully-grouted rockbolt without mechanical anchoring. It generally consisting of a ribbed bolt inserted in a drillhole and bonded to the drillhole periphery over its embedded length. Bonding medium of rockbolts is cement mortar. The parameters controlling the LBC of cement-grouted rockbolts are shape of bolt, diameter of bolt, length of bolt, the rock and the grout strength. The major mechanism that determines the bond strength of fully-grouted rockbolts is friction. Friction depends on the shear strength at the rock-grout or bolt-grout interface. Fully grouted untensioned rockbolts have been used for many years in civil and mining engineering projects. However, only a few works have been reported on strengthening of grouting materials using mineral and chemical admixtures.

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The bolting system prevent the joint movements developing in deformed rock masses. Thus, it contributes to the self-supporting of the rock mass [1]. Fully-grouted reinforcements are popular types of reinforcement. The most common material used to bond rock masses and reinforcement agent (rockbolts) is Portland cement grout [2]. The supporting and reinforcement effects of rockbolts have been discussed by many researchers [1,3–6]. Wide applications of rockbolts have given way to invention of different types of rockbolts. Rockbolts can be divided into three main groups as regards their anchorage systems [7–11].

Moosavi et al. [2] and Kılıç et al. [11] reported that grout shearing is the key parameter controlling the LBC of rockbolts during axial pull-out movements. Bond failure mechanism of grouted rockbolts revealed this reality. Thus, any change that may occur in the rock mass-grout or grout-rockbolt interfaces will affect the LBC of rockbolts. LBC of rockbolts (cement-grouted) and their anchoring agent are a function of the cohesion of the bonding material, rockbolt and enclosing rock [7]. The LBC can be increased by increasing its strength or diameter, and the bond capacity between the interface of rock and grout material can be increased by increasing the drillhole diameter; this causes an increase of the surface area of bonding agent [12]. Increasing the shear strength of grouting materials is only possible by using high strength cement, low water/cement (w/c) ratio, superplasticizer and some mineral admixtures. A series of studies have been conducted related to optimum proportion of mineral admixtures in cement [13–21]. Lam et al. [14] studied the strength effect of SF and FA with different w/c ratios. According their findings, a 15% SF and a 25% FA replacement increased the CS of concrete considerably at the end of 28 day. Shannag [15] outlined 26% strength increasing with 15% pozzolan and 15% SF after 28-day. CS of the concretes without SF was found to be lower than the CS of the SF concrete for mixes with a w/c ratio of 0.35. Mazloom et al. [16] conducted a study on the short and long term properties of high strength concrete produced by the addition of SF. They concluded that the workability of concrete decreases, while the proportion of SF increases. Results showed that SF addition improved the short-term mechanical properties of concrete (such as secant modulus and CS) for 28 day curing time. For the determining high strength concrete properties, a series of laboratory test was conducted by Nassif et al. [17]. Experimental studies were conducted with water cement ratios ranging from 0.29 to 0.44 and FA and SF were used at different rates. FA replacement was between 10 and 30% and SF replacement was between 5 and 15%. Türkmen et al. [18] were executed a study to improve the mechanical properties of concrete and to increase the resistance of steel to corrosion. They performed their work using SF and BFS at different rates instead of Portland cement. According to experimental test results, use of 10% SF and 20% BFS increased the CS of the concrete by about 8% on the 28th day. This rate doubled in the 250th day. The 28 day CS decreased by about 22% as the water binder ratio increased from 0.35 to 0.45. Badogiannis et al. [19] were produced cement using five different types MK. The test results showed that after 2, 28 and 180 days, the increase in CS by MK addition was obtained. Researchers have discovered that the content of 10% MK has a more positive effect than the content of 20% MK, considering the physical and mechanical properties of the cement produced with MK. The effects of MK on the grout properties such as pull-out strength, CS and flow-ability were investigated by Vipulanandan and Sunder [21]. According their results, MK addition were showed remarkable variations at CS and pull-out strength of cement grouts. They also reported that the shear strength of grout increases in the mixture made with using low w/c ratio, while they decreases the workability and pourability.

The focus of this paper is to determine the effects of different grout types on the pull-out capacity of grouted rockbolts. In order to improve applicable grout mixtures, a series of laboratory study was undertaken by taking into consideration technical and environmental reasons. In addition, some empirical formulas were determined for estimating the bolt bond strength (τ_b) and pull-out resistance using CS of grout and grout shear strength.

2. Experimental study

In this study, an experimental study was undertaken to investigate the effects of mineral admixtures on the pull-out capacity of grouted rockbolts and strength of grouting materials. The mineral admixtures used grout mixes were collected from different factory and processing plants in Turkey. Type of admixtures and origins were summarized in Table 1.

The diameter of ribbed rockbolts used in the tests was 14 mm, and the diameter of boreholes was 24.8 mm. The yielding strength and the ultimate strength of the rockbolts, which used in the study, were determined as 97 kN and 113 kN, respectively. Pre-investigation studies were carried out before the experimental studies were planned. Pre-investigation results showed that the bolts longer than 25 cm failed from bolt shank unless slippage occurred after 7 days of curing time. Therefore, 20 cm-rockbolts were used in this study.

Pull-out tests were carried out on rockbolts placed in six basalt blocks prepared by cutting and smoothing in a natural stone factory in Osmaniye/Turkey. Basalt blocks were prepared in $15 \times 20 \times 60$ cm dimensions and ten rockbolts were placed in each. When determining the sizes of the basalt blocks, the anchor length of the rockbolts and the dimensions of the boltmeter were taken into consideration. Ten different types of grouting mixtures were prepared to examine the effect of mineral admixtures on the pull-out capacity of grouted rockbolts. One of them was prepared as a reference grout and no mineral admixture was used in this grout. The composition of grouting mortars and fresh unit weight of grouts has been summarized in Table 2. During the planning stage, a series of trial tests were carried out with different mixing ratios. The grouts were prepared by using mineral admixtures at the range of 5%–25% of the cement weight. In practice, the grout must be resistant to stress and easily pumpable to the boreholes. Considering these two parameters, the substitution of mineral admixtures rate determined as 15%.

All mixture types were prepared under the same mixing conditions to determine the effects of different mineral admixtures on the grout properties. Silica sand to binder (cement + mineral admixture) ratio was 0.10, and water to binder ratios was 0.36. The ratio of superplasticizer to binder was 0.85%. With ten different types of grouting materials and five different curing times (1, 3, 7, 28, 90 days), pull-out tests have been executed in order to investigate and improve the LBC of grouted rockbolts (fully-cement). In the tests, 150 rockbolts were used. In order to obtain different grouting materials, grout mixtures were prepared

Table 1
Type-origins of mineral admixtures.

Admixture names	Codes	Admixture origins
Silica fume	SF	Antalya-Etibank Ferro – Chrome Factory
Blast furnace slag	BFS	Iskenderun – Iron and Steel Factory
Fly ash	FA	Adana – Sugözü Thermal Power Reactor
Colemanite	CLM	Kütahya (Emet-Espey) – Colemanite Quarry
Simektit	SMT	Ankara (İmrahor) – Clay Quarry
Perlite	PRL	İzmir (Cumaovası) – Etibank Perlite Quarry
Basalt dust	BD	Osmaniye
Coal dust	CD	Zonguldak
Metakaolin	MK	Niğde (Fesleğen) Kaolinite Quarry
Reference grout	RF	–