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A RESIN TYPE ADDITIVE USE TO IMPROVE LOAD BEARING CAPACITIES OF GROUTED ROCK BOLTS EXPOSED TO THERMAL CYCLES

Eren KÖMÜRLÜ[1*]

[1] Giresun Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Giresun, Türkiye

Keywords

Rock Bolts,
Grout Materials,
Grouts in Rock Bolting,
Thermal Resistivity,
Thermoset Polymer Additive.

Abstract

A thermoset PMS (Polyvinyl modified silicone) type polymer additive effect on load bearing capacities of cement grouted rock bolt specimens exposed to thermal cycles was investigated with a series of experimental studies. The additive used in this study was in liquid phase while adding into the fresh cement mix and started to solidify b y polymerization after being mixed well in the cement grout. The silicone based thermoset product was selected to use because of its ability of polymerization in contact with water. According to the results of this study, the load bearing capacity loss due to thermal cycles was found to be notably limited as a result of using the thermoset additive. Therefore, the additive tested in this study was assessed to improve resistivities of the cement grouted rock bolts against the thermal changes.

TERMAL ÇEVRİMLERE MARUZ KALMIŞ DOLGULU KAYA SAPLAMALARININ TAŞIMA KAPASİTELERİNİN ARTIRILMASI İÇİN REÇİNE TÜRÜ BİR KATKI KULLANIMI

Anahtar Kelimeler

Kaya Saplamaları,
Dolgu Malzemeleri,
Kaya Saplamalarında Dolgu,
Termal Direnç,
Termoset Polimer Katkı.

Öz

Termal döngülere maruz bırakılan çimento enjeksiyonlu kaya saplaması numunelerinin yük taşıma kapasiteleri üzerinde PMS tipi bir termoset polimer katkının etkisi bir dizi deneysel çalışma ile incelenmiştir. Bu çalışmada kullanılan katkı taze çimento karışımına ilave edilirken sıvı fazda olup, çimento şerbetinde iyice karıştırıldıktan sonra polimerizasyon ile katılaşmaya başlamıştır. Kullanılan termoset ürün su ile temas halinde polimerleşebilme özelliğinden dolayı tercih edilmiştir. Bu çalışmanın sonuçlarına göre, polivinil modifiyeli silikon türü termoset reçine katkısının kullanılması sonucunda termal çevrimlerden kaynaklanan yük taşıma kapasitesi kaybının oldukça azaldığı tespit edilmiştir. Bu nedenle, bu çalışmada test edilen katkı maddesinin çimento enjeksiyonlu kaya saplamalarının termal değişimlere karşı dirençlerini geliştirmek için kullanılabilir olduğu değerlendirilmiştir.

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* İlgili yazar / Corresponding author: ekomurlu@giresun.edu.tr, +90-454-3101740

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Eren KÖMÜRLÜ†
Giresun Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Giresun, Türkiye

Highlights

- Ordinary cement grouts were found to loose their bearing capacity as a result of being exposed to thermal shock cycles. The number of thermal cycles and temperature differences are decisive in this regard.
- PMS type thermoset resin additive has been investigated for its use in cement grouted rock bolt applications.
- Resistivity against thermal cycles of the cement grouts was assessed to be improved by using the PMS type thermoset polymer additive.

Purpose and Scope

The purpose of this research is to investigate the usability of a new polymer resin to improve thermal change resisitivities of cement grouts used in rock bolting applications. Thermal changes can cause cracking and strength loss of cement grout materials of bolts especially for those used in open excavations. Depending on the region, environmental affects can cause significant repairing costs for rock engineering constructions. By improving the resistivity of bolts against the thermal cycles, betterred performances and service lifetimes can be supplied as aimed in this research.

Design/methodology/approach

Three different grout mix groups with 0%, 3% and 6% resin polymer additives by weight were tested within this study. Within various tests, both strengths of cement grout mixes and their adherence to steel bolts were investigated to assess the usability of the additive. To investigate in the resistivity against thermal cycles, specimens with and without the polymer additive had totally same thermal change procedure. To speed up the effect of the thermal cycles, temperature changes were applied immediately making thermal shocks in water. Uniaxial compressive strength test was carried out to determine the strength loss property of the thermally cycled grout materials. In addition, their adherence to steel bolts was investigated by using the pull-out test equipment. The adherence performances of the bolts in different grout mixes were comparatively investigated carrying out the pull-out (anchorage) test with the aim of evaluating bearing capacities under the axial loading condition.

Findings

Thermal shock cycles caused decreases in the strength values owing to the microcracks which are induced and grown while the immediate thermal changes. In comparision with the ordinary cement grout mixes, The PMS additive made the specimens more resistive against loosing strength under thermal cycles. To extend service life times of cement grouted rock bolts exposed to the temperature changes, the PMS resin polymer additive was found to be usable.

Practical implications (if applicable)

The liquid phase time before the solidification of the resin additive should be long enough for the application area. The resin additive product should be in the liquid phase until the bolt holes are filled. There are various PMS resin products with different gel time values in the market. For a proper application, products with enough long gel times should be preferred instead of those which polymerize early.

Originality

Cement and polymer resin type different grout materials are seperately used in rock bolt applications. The combined use of cement and resin type materials is an originality of this study for the rock bolting literature. Examination of the usability of PMS type resin additive in cement grout material is a new topic in terms of rock engineering.

† Corresponding author: ekomurlu@giresun.edu.tr, +90-454-3101740

1. Introduction

Rock bolts have been used to reinforce underground openings and open excavated rock masses for more than 100 years. Even though rock bolts did not become widespread in the 1920s and 1930s, they quickly found a place in new applications in the 1940s and 1950s. Then, rock bolts have become popular, the general details of reinforcement principles were understood and many standardizations were made in 1960s. The rock bolting system improves the competence of rock masses by preventing joint movements and forcing the rock mass to support itself. Rock bolt ground reinforcement mechanisms can be investigated under different topics such as suspension, beam effect, key effect and arching effect. Convergences can be restricted by changing the stress distributions in rock masses as a result of the anchorage effect of the rock bolts. Rock bolts are usable to prevent both structural controlled and stress controlled rock mass failures. Rock bolts which are widely used to reinforce mining and civil engineering excavations can be classified in accordance with different parameters such as grout usage (grouted or friction bolts), grout type (cement, resin, etc.), shank body material (steel, polymeric composites, etc.), pre-tensioning properties (active, passive), energy absorption capacities (energy-absorbing bolts and others) and etc. (Li et al., 2014; Wang et al., 2019; Ranjbarnia et al., 2016; Komurlu, 2021a). The widespread use of rock bolts has led to the understanding of modern tunnel support strategies in 20th century. Contemporary support applications which allow the rock mass to bear itself instead of the dead rock load occurrence, have been made possible by using rock bolts. Within the all rock bolts, the firstly patented type is the grouted rebar bolts (Komurlu and Kesimal, 2013; Kovari, 2003a, Kovari, 2003b).

Grouted rock bolts have grout bond between rock and the bolt surfaces. The strength of the grout material and its adherence to rock and steel rebar surfaces determine the bearing capacity and the reinforcement perfomances supplied by the bolts. Rock mass strength is also a determinative parameter that effect performances of the grouted rock bolts (Chen et al., 2020; Batugin et al., 2021; Kim et al., 2019). Ordinary grouted rock bolts are simple reinforcement system that consists of a ribbed rebar shank, a plate and a mechanism to fix the plate part. Generally, nuts are used to fix the plate parts. The anchorage can be supplied by both the shank and the plate parts. As a result of the rock mass deformation, rebar bodies are generally tensioned and sheared at the same time. The grout quality is an important factor for the reinforcement effectiveness of bolts against the tensile and shear loads. The plate parts supply support pressure on the wall by its anchorage owing to the rock mass deformations. To have a proper reaction from the plate part, rebars must have a good adherence capacity in the grout (Kang et al., 2020; Knox and Hadjigeorgiou, 2022; Wang et al., 2022). The grout material quality and its workmanship have great importance in providing an appropriate support pressure at the right time, by the bolt system reaction to the deformations in rock masses.

Long service times must be taken into account in geotechnical engineering designs. In the environment, there are various issues to affect the long term support performances of the grouted rock bolts. One of the issues that should be paid attention during the design stage is the time-dependent strength losses of the grout material. Also, steel corrosion is another issue that shortens the service lifetimes of the steel rock bolts. Depending on the region, environmental affects can cause significant repairing costs for rock engineering constructions to prevent undesired collapses and damages (Kahandawa et al., 2021; Lee et al., 2018; Guo et al., 2019).

2. Literature Survey

The open excavations get more harm from environmental influences than underground openings. The thermal changes must be considered for the rock bolts used to reinforce open excavations, especially for the long service lifetimes. Rock bolt parts which are close to the plate are mostly affected by outside temperature changes and freezing and thawing events. Also, it is where the highest stress occurs along the length of the rock bolts. In other words, the stress levels in the bolt and grout generally maximize just near the outside end of the drill hole as a result of the rock mass deformation (Chen, 2014; Zhao et al., 2018; Teymen and Kılıç, 2018). Therefore, it should be noted herein that the load bearing capacity of the rock bolts can be significantly reduced by the environmental affects causing deterioration of the grout material. However, some seasonal changes like those in temperature, water content and air humidity are many times neglected in rock engineering designs and analyses. In addition to the annual changes, there are also significant daily changes depending on the region climate. The daily changes can be rapid and make damages in repeating periods. In some continental climates, it is possible to see more than 30 °C temperature differences in a day. In comparison with underground ones, open rock engineering constructions are generally more resistless against environmental changes. Especially for long-term service life times of cementitious mixes, thermal differences in repeated cooling and heating cycles have an important influence on the load bearing capacity (Jena and Panda, 2018; Komurlu and Kesimal, 2015a; Cui et al., 2020). As another matter, the water saturation is also considerable in the seasonal changes affect. In particular, temperature changes causing the freezing and thawing cycles can make notable damages in case of water saturated voids of concretes and cement grouts.

There are different type grouts used in the rock bolting applications. The commonly used grout materials can be classified as cement grouts and resin grouts. Resin grouts are thermoset type polymers which are in liquid phase before their polymerization reactions. Resin grouts are advantageous due to the early curing, good bearing capacities in watery regions, high chemical durability, ductile support reactions, resistivities against the dynamic loads resulting from the blasting applications and etc (Chen et al., 2021; Liu et al., 2022; Yan et al., 2019). However, resin grouts are more expensive than the cement grout. Therefore, cement grouts are relatively more popular and common in the geotechnical engineering works. In this study, a resin material is used in the cement grout mix for the aim of improving its performance in rock bolting applications. Within the scope of this study, the thermal resistivity property was investigated to assess the composite mix of the cement and resin usability. The heating and cooling cycles and thermal shocks were applied in the experimental study to examine and compare the resistivities of the ordinary cement and resin added cement grout mixes.

Because thermoset type polymers are in liquid phase before their polymerization reactions, they are usable for good homogenization of the cement grout mixes. Effect of the water on thermoset polymerization reactions and self-strength values of the additive are important points in terms of selecting a proper polymer product. Additionally, viscosity and solidification time of thermosets are significant parameters for the workability of the fresh cement grouts. Although polymerization reactions of thermosets are typically completed within a day, a significant solidification generally happens in two hours.

Within this study, a modified silicone (MS) based thermoset polymer resin product was investigated as a cement grout additive. Silicones are synthetic polymers and also known as polysiloxanes. The thermoset MS polymers are in the liquid form and looks like a gel before their polymerization. They keep their elasticity and stability in both high and low temperatures. Furthermore, the MS resins, adhesives and sealants are resistant to moisture and weathering (Zander and Peng, 2018; Magalhães et al., 2019). Pure and some modified silicones like PMS (polyvinyl modified silicone) types can polymerize and properly solidify in contact with water (Owen, 2017). Therefore, it was expected to appropriately use the PMS based thermoset polymer additive in cement grout mixes. The aim of using a thermoset additive is to be a kind of reinforcement in cement grout mixes. To assess its usability for improving the resistivity against thermal cycles, polymer resin added cement grout mixes and their adherences to steel bolts were investigated with a series of tests.

3. Materials and Methods

In this study, CEM 1 type ordinary Portland cement was used in the grout mixes with the water to cement ratio of 0.45 by weight. There were three different grout mix groups with 0%, 3% and 6% polymer additives by weight. It should be noted herein that the percentages are ratios of the polymer additive to total mix by weights. The grout mixes were homogenized in a concrete mixer for 5 minutes. Within various tests, both strengths of cement grout mixes and their adherence to steel bolts were investigated to assess the usability of the additive in terms of improving the resistivity against thermal cycles.

The uniaxial compressive strength (UCS) test was carried out to make an idea for understanding the thermoset additive effect on the weathering and strength loss resistivity of grout mixes against thermal cycles. The UCS test specimens were casted into cylindrical moulds with the inner diameter of 46 mm, compacted using tamping rods, and put on the vibration table to remove air in fresh mix. The UCS test specimens were casted into the moulds with the ratio of length to diameter of 2 in two steps for making them well compacted and removing air in the mix properly by using tamping rods after each casting steps. The geometry of the UCS test specimens is suited to that stated in the ASTM C780-19 coded standard for cement mortar mixes (ASTM, 2019). Specimens with the curing time of 11 days were tested with a loading rate of 0.5 mm/min in the UCS test (Figure 1).

In addition to the strength test applied on the cement grout mixes, their adherence to steel bolt surfaces was also investigated by using the pull-out test equipment. Ribbed steel rock bolts with the diameter of 12 mm and length of 500 mm were used in the pull-out test. Cement grouts were casted into the plastic moulds with the inner diameter of 96 mm. The bolts were slowly immersed after the moulds were filled to the height of 120 mm by the grout mixes. To make the bolts for standing vertical in fresh grout mixes, drilled steel plates were used on the moulds (Figure 2). Before using the steel plates to hold bolts, grout mixes were compacted by tamping rods. In addition, bolts were gently rotated in the grout mix to supply a well contact at their surfaces. Use of the holding plate devices supplied vertical alignment of the bolts in the fresh mix. Pull-out test specimens were remolded after a day of curing period. The pull-out test was performed using the rock bolt samples in 11 days cured cement grouts. A photograph from the pull-out test is given in Figure 3.

The aim of the pull out test is to determine the bearing capacities of rock bolts under the axial loading condition. The portable test equipment is usable in both laboratory and site investigations. The adherence performances of the bolts in different grout mixes were comparatively investigated carrying out the pull-out (anchorage) test. The bolt shanks were gripped and held by the jaw of the equipment and the axial loading was applied till the maximum level of the anchorage capacity is reached. Grout materials were cracked at the maximum load level, and the pull-out tests were finalized after reaching the peak load level which is recorded by the test equipment.

Within this study, the slump test was also performed to investigate the workability of fresh grout mixes with different amounts of the polymeric additive. According to ASTM C143 coded standard, the slump cone with a height of 300 millimeters, an internal diameter of 100 millimetres at the top and of 200 millimetres at the bottom was filled with fresh cement grout mixes in three stages. Each layer is tamped for 25 times by using a bullet-nosed metal rod. Then, the cone mould was carefully lifted and slump values of the mixes were measured in accordance with the methodology stated in the ASTM C143 coded standard (ASTM, 2020).

To investigate thermal changes effect on results of the UCS and pull-out tests, a refrigerator at 4 °C and a stove at 90 °C were respectively used for 16 cycles (Figure 4). There were water tanks in the refrigerator and the stove. Specimens with and without the polymer additive were immersed in the water tanks and had totally same thermal change procedure in water. To speed up the effect of the thermal cycles, temperature changes were applied immediately making a thermal shock in water. As 2 days cured specimens were remolded, heating at 90 °C (150 minutes) and cooling at 4 ° C (150 minutes) were carried out twice a day. Specimens were kept out of water at the end of the daily thermal cycles. At the end of 16 thermal cycles, 10 days cured wet specimen surfaces were wiped before the tests. Specimens which were not exposed to the thermal cycles were cured in the room temperature and not kept in water. The pull-out test was applied in the 11th day of curing. The experimental study was carried out in geotechnical engineering laboratories of Giresun University department of civil engineering.

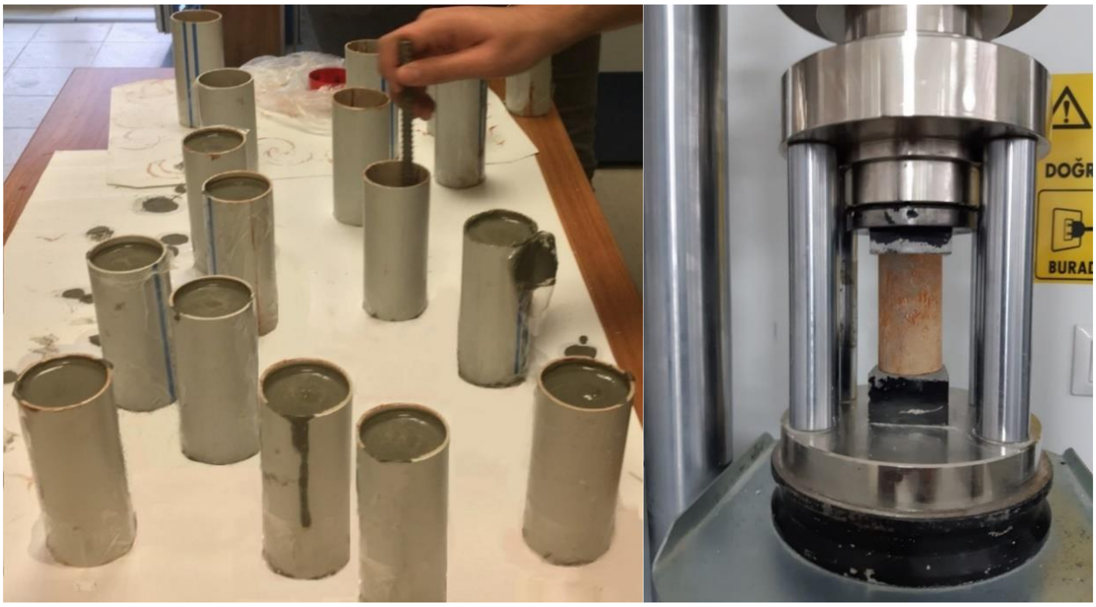

Figure 1. Preparation of UCS test specimens (left), The UCS test (right)

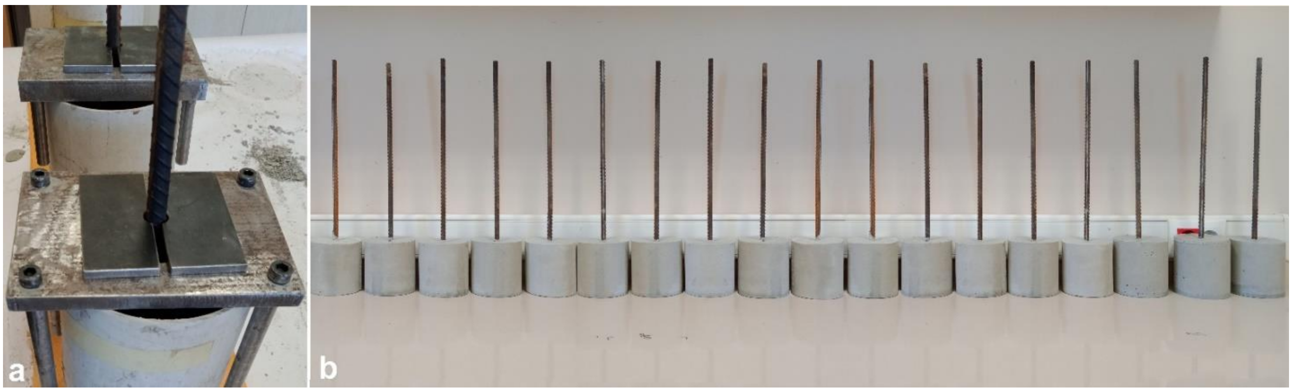

Figure 2. a) Plates for keeping bolt specimens stood vertical in grout mixes, b) grouted bolt specimens used in this study

Figure 3. The pull-out test

Figure 4. Stove (a) and refrigerator (b and c) used in this study

4. Experimental Results

Results obtained from the UCS test are given in Table 1. According to results of this study, UCS values of cement grouts kept under constant temperature were found to decrease with an increase in the amount of the thermoset modified silicone based additive in the mix. On the other hand, it made the specimens more resistive against loosing strength under thermal changes. It is a remarkable outcome of this study to obtain nonignorably higher strength values from 3% polymer added specimens in comparison with the case of no polymer additive use. As seen from SR (Ratio of UCS test results of specimens exposed to thermal cycles to those of specimens kept under no temperature change) values given in Table 1, the grout specimens with 6% polymer additive content were the most resistive against strength loss due to the thermal cycles.

The slump values of grout mixes were found to decrease with increasing polymer contents. Grout mixes with 0%, 3% and 6% PMS additives had 12 cm, 10 cm and 7 cm slump values, respectively. Considering the slump test results, it can be noted that the PMS content decreases the workability of grout mixes. Although the 3% PMS content can be assessed to cause not a big change, use of 6% additive was found to make a notable decrease in the workability of fresh cement grout mixes.

Load bearing capacities of the grouted rock bolts kept under the constant temperature were determined to slightly decrease with an increase in the amount of the PMS additive. In contrast, the additive made the grouted rock bolt specimens more resistive against loosing axial load bearing capacity due to the thermal cycles. Among all the tested specimen types, the highest pull-out test loads were measured from the grouts with 3% PMS additive after thermal cycles. Considering the ratio of pull-out test results of specimens exposed to thermal cycles to those of specimens kept under no temperature change (LR) values, the grout specimens with 6% silicone content were found to be the most resistive type against load bearing capacity loss due to the thermal cycles. Bolt specimens in the grouts without the polymer additive were determined to have a notable decrease of 33% (LR: 0.67) in the load bearing capacity after thermal cycles, whereas it was only 11% (LR: 0.89) decrease for 6% polymer added grout specimens (Table 2).

The PMS type thermoset polymer additive amount effect on uniaxial compressive strength test and pull-out test (axial load bearing capacity test) results are also shown in Figure 5. According to the results obtained from this study, the resistivity against the thermal cycles was assessed to be notably improved by use of the PMS type polymer resin additive. It should be noted herein that the results are quite promising for the in-situ thermal change resistivities of rock bolts. Because this experimental study was carried out in a laboratory environment, it will be beneficial to test the promising results of this study with further in-situ investigations to better understand the effect of the PMS additive in the field conditions.

Table 1. Results of the UCS test (G0: grout mix with 0% polymer additive, G3: grout mix with 3% polymer additive, G6: grout mix with 6% polymer additive, SN: Specimen number, T: thermally cycled, SD: standard deviation, SR: Ratio of UCS values of specimens exposed to thermal cycles to those of specimens kept under no temperature change for a same polymer content)

Specimen type	SN	UCS (MPa)	SD for UCS (MPa)	SR for UCS (MPa)
G0	3	28.1	0.6	-
G3	3	25.9	0.6	-
G6	3	22.7	0.5	-
G0-T	3	18.5	0.7	0.66
G3-T	3	19.4	0.8	0.75
G6-T	3	18.8	0.7	0.83

Table 2. Results of the pull-out test (B0: bolts in the G0 type grout mix, B3: bolts in the G3 type grout mix, B6: bolts in the G6 type grout mix, F_{max}: Maksimum load bearing capacity, LR: Ratio of F_{max} values of specimens exposed to thermal cycles to those of specimens kept under no temperature change, which is for a same polymer content).

Specimen type	SN	F_{max} (kN)	SD for F_{max} (kN)	LR for F_{max} (kN)
B0	3	26.0	2.0	-
B3	3	23.7	1.5	-
B6	3	20.3	1.2	-
B0-T	3	17.3	2.5	0.67
B3-T	3	18.7	2.1	0.79
B6-T	3	18.0	1.7	0.89

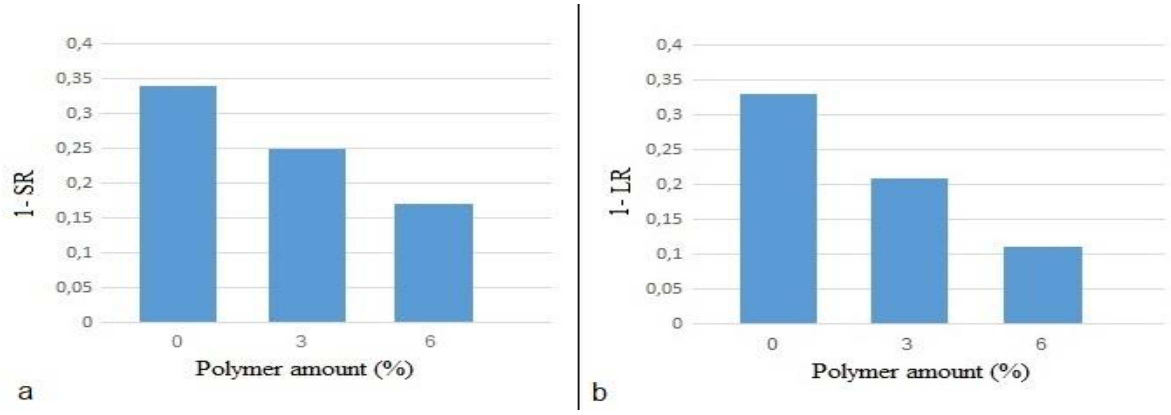

Figure 5. a) UCS losses after thermal cycles, b) decreases in the pull-out test results after thermal cycles

5. Discussion

From the various point of views, their high brittleness can be assessed as the most important disadvantage of ordinary cement grout mixes. The brittle characteristics causes an immediate loss of the bearing capacity as the maximum load is achieved. With an increase in the cement grout material ductility, energy absorption capacities of rock bolts increase under both static and dynamic load conditions (Li, 2017; Komurlu et al. 2017; Komurlu and Kesimal, 2017; An and Lee, 2016). Their high brittleness property also causes the poor thermal resistivity of ordinary cement grout materials. Because the crack propagation resistivities of the brittle materials are quite poor, they are easily disintegrated owing to the thermal strain cycles. Polymeric additives are popular to improve crack propagation resistivity, ductility and energy absorption capacity of cementitious materials. Use of polymer additives can also improve the resistivity of cementitious mixes against thermal strains (Yaragal and Ramanjaneyulu, 2016; Yaragal et al., 2015; Marthong, 2019).

As confirmed by results of this study, thermal cycles caused decreases in the strength values owing to the microcracks which are induced and grown while the thermal cycles. The thermal strains can make significant damages as it is a well-known property of the brittle cementitious materials (Heidari-Rarani et al., 2014; Khan et al., 2020; Shang and Lu, 2014; Kaya et al., 2016; Keskin et al., 2017). Since the main reason for the increase in the ductility is the improvement in the crack propagation resistivity, it is an estimated result to have an improvement against the repeated strains of thermal cycles with an increase in the ductility (Groeneveld et al. 2018; Das et al., 2020; Komurlu, 2018). In a study carried out by Komurlu (2020), the same thermoset polymer additive with that used in this study was investigated to determine its effect on the ductility of the cement grouts and it was reported that the additive notably improves the ductility and the energy absorption capacities of the grout mixes.

Because mechanical properties of polymer materials vary within a high range, a product should be individually and carefully investigated to assess about its usability (Korey et al., 2020; Komurlu and Kesimal, 2015b; Komurlu and Kesimal, 2016). Depending on the production details, same type polymer materials can exhibit significant variations in their strength values. Therefore, self-properties of a product should be examined instead of considering typical mechanical property values of a polymer material. Within further analyses, different thermosets can be investigated for the aim of making better strength properties of cement grouts. The material properties of candidate thermosets should be known before the investigation of usage to foresee an undesired result. For instance, some of the sealants like acrylic based thermoset products have a disadvantage of deterioration in contact with water during polymerization reactions (Jiang et al., 2019).

The resin product to be added into the grout must have the ability to polymerize in contact with water. There are various thermoset materials that require water for polymerization, such materials can be preferred in rock bolt grouting works. The polymerization time should also be preferred in accordance with the application details. Before injection into the hole, products that solidify very early should not be preferred.

The liquid phase time can be chosen according to the type of product. The thermoset resin materials used in this study are activated within 5 minutes. As a result of polymerization, the liquid ingredient(s) become(s) a solid phase polymer. There are three stages of the resin polymerization. The first one is cream time; at this stage, polymerization does not start to work, and the mixture is in liquid form. The liquid additive should be mixed well in the cement grout before the end of the cream time. By the end of this time, the gel time and polymerization start. In the gel time, the polymerization starts and the mix is still groutable into the drill holes. However, the viscosity increases as the duration passes in the gel time. The third stage is called as the tack free time. In that time, the material completely solidifies and the polymerization ends. Therefore, the maximum mechanical strength is reached at the end of the tack free time varying between 18 h and 24 h for most of the thermosets (Tsangouri et al., 2015; Komurlu, 2021b). The longest polymerization stage is the tack-free time.

The viscosity of the cement grout materials is another important point for the assessment of the usability for a relevant engineering work. The viscosity of the fresh cement grout mixes was found to increase with an increase in the amount of the polymer additive used in this study. In a work carried out by Komurlu (2020), various tests were performed to determine effect of 3.5% and 7.0% same modified silicone type thermoset additive on the workability of the cement grout mixes in detail. Although it was reported that the polymer additive makes increases in the viscosity of cement grouts, 3.5% PMS additive was assessed not enough high to prevent the grouting applications by standard equipments used in a mine. On the other hand, 7% additive amount was found to need modified equipments for its systematic use and not practical for grouting in the study by Komurlu (Komurlu, 2020). In case of having a tolerable increase in the viscosity, an advantage to prevent the grout to flow down especially from the holes drilled at the roof can be supplied by the use of the polymer additive. Generally, relatively low water contents are used to prevent the grout flowing out of the hole. When it is necessary to reduce the water/cement ratio below 0.35 by mass to increase the viscosity, strength losses occur in the grout applications. In such cases, it may be possible to increase the water content to make no strength decrease resulting from the low water content, by using a resin thermoset additive. In other words, it is not necessary to excessively reduce the water-cement ratio to increase the viscosity by the use of the PMS resin.

In this study, repeated thermal shocks in water were applied to investigate whether the thermoset type PMS polymer additive improves the load bearing capacities of grouted bolt specimens exposed to the temperature changes. Because the heating-cooling cycles in water are more affective instead of those in air, the water medium was preferred to speed up the influence of the thermal cycles (Komurlu, 2019; Lee et al., 2008). The PMS polymer added cement mixes were assessed to have higher load bearing capacities than those without the polymeric additive. Although it is not effective in case of no temperature change, the thermal resistivity was found to be notably bettered by using PMS polymer additive in the mix. Since the loss in the strength values is significantly limited by the increase in the polymer additive amount, it is possible to obtain higher load bearing capacity values from pull-out tests of 6% polymer added specimens compared to those with 3% additive under further thermal cycles.

To deal about costs, it can be noted that the price of the additive used in this study is about 4 USD/kg. As an example for its cost, approximately 4.5 kg grout is filled in a typical drill hole of a rock bolt with a length of 3 m. The polymer additive cost is about 0.54 USD per a bolt in case of using 3% polymer additive. In first, the cost may seem a bit high considering the rock bolts number in a project. However, the additive can be usable depending on the engineering aims. The thermal resistivity is a quite important property for long-term service life times of various engineering constructions and mining openings. Economy and safety should be considered together in engineering designs. However, when a choice has to be made between them, the most important consideration in engineering designs is the safety. For this reason, the use of special materials is beneficial when it is necessary. Choosing right materials supply economical solutions by eliminating the need for repair costs.

Although ordinary cement grouts are widely used in rock bolt applications, it has some lacks to be improved by using new additives. In addition to thermoset polymers, other extra additives that can be used in the cement grout can be investigated in further analyses on the use of various hybrid grout mixes. To have novel solutions in support practices, new polymeric materials and their composites should be investigated in comparison with other engineering polymers in use for making even better effects on support performances. The success in today's rock bolting applications is a result of many developments in different scientific disciplines and material technology. Therefore, rock engineers should follow the developments in the polymeric materials which are candidates to be used in civil and mining engineering practices.

This study investigated the thermal resisitivty property. Other issues like creep effect, fatigue effect and etc. can be investigated for further studies on the PMS additive usability. As previously stated, the PMS additive is known to improve the ductility and crack propagation resistivity of the grout mixes. New studies on different issues will be highly beneficial to better understand the PMS added grout performances in the rock bolting applications. For instance, the ductility property in the support reactions is a key factor to combat different problems like clay swelling, rock squeezing or rock bursting (Hao et al., 2020; Dai et al., 2020; Wu et al., 2019). Because of increasing ductility, energy absorption capacity of the rock bolts can be improved. Resin added cement grouts can be used for special bolts like those designed for the rock burst. In deep mining applications, many challenges have been faced concerning the use of new rock bolts. The cone bolt developed to combat rock burst problems in deep mines is a bolt type with expanding front ends for a better anchoring performance in the grout. The cone bolts used since 1990s have a simple design with an expanded front end which can make ploughing in the grout and improve deformation limits while supplying significant load bearing capacities. In a study carried by Komurlu (2022), a similar resin polymer was investigated to assess its usability in the cement grout mixes to improve the energy absorption capacities of the cone bolts, and a notable increase in the energy absorption capacity was obtained due to the new additive use. It should be reminded herein that new materials supply new solutions in engineering, and many progressions in the rock engineering have been reached as a result of new material choices.

6. Conclusion

In this study, a new grout mix with the PMS type thermoset resin additive has been investigated for its use in rock bolt applications. To make a conclusion, it can be noted that the thermal resistivity of the cement grouts was assessed to be improved by using the PMS type thermoset polymer additive. To extend service life times of cement grouted rock bolts exposed to the temperature changes, the PMS resin polymer additive was found to be usable according to the results of this study. The new grout additive was found to have a good potential to become more popular in rock bolting practices of civil and mining engineering works. Especially, it is recommended to use PMS additives for rock bolts where daily temperature changes are high.

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Conflict of Interest

No conflict of interest was declared by the authors.

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