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Improving support performances of cone bolts by a new grout additive and energy absorber

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Abstract. The cone bolts with expanded front ends supply improved anchoring performances and increase energy absorbing capacities due to ploughing in the grouted drills. Within this study, use of a novel energy absorber for the cone bolt heads were investigated to assess its design in terms of supplying high support performances. Additionally, different grout material designs were tested to investigate whether the energy absorption capacities of the rock bolts can be improved using a silicone based thermoset polymer (STP) additive. To determine load bearing and energy absorption capacities, a series of deformation controlled pull-out tests were carried out by using bolt samples grouted in rock blocks. According to the results obtained from this study, maximum load bearing capacities of cone bolts are similar and mostly depend on the steel material strength, whereas the energy absorption capacity was determined to significantly vary in accordance with the displacement limits of the shanks. As a result of using STP additive and new polyamide absorber rings, displacement limits without the steel failure increase. The STP additive was found to improve the energy absorption capacities of grouted cone bolts. The absorber rings designed within this study were also assessed to be highly effective and able to double up the energy absorption capacities of the cone bolts.

Keywords: cone bolts; energy absorption capacity; grouted rock bolts; support performances

1. Introduction

Rock bolts 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 2017, Li *et al*. 2014, 2016a, b, Wang *et al*. 2019, Ranjbarnia *et al*. 2016, Komurlu and Kesimal 2017, Skrzypkowski *et al*. 2020a).

In this study, an energy absorbing bolt type of grouted cone bolts and their support performances were investigated with a series tests. To combat rock burst problems 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 the expanding front ends for a better anchoring performance. 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 (Jager 1992, Yokota *et al*. 2020, Wang *et al*. 2021). A schematic shown of the anchor ploughing mechanisms of the cone bolts is given in

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Fig. 1.

Although typical cement grout mixes are economical and widely used in rock bolting works, their brittle material characteristics cause an immediate loose in the load bearing capacity of ordinary bolts after the maximum load is achieved. With an increase in the ductility of cement grouts, energy absorption capacities of bolts are improved under both static and dynamic conditions. The high grout material ductility property is advantageous in different rock masses like those with rock bursting, squeezing and swelling problems (Carmona *et al*. 2020, Liang *et al*. 2017, Korzeniowski *et al*. 2017). Because their anchorage performances and energy absorption capacities depend on the ploughing in the grout media, the ductility of grout mixes was also expected to be determinative for support reactions of the cone bolts as a motivation of this study.

In a study carried out by Komurlu (2020), various silicone based thermoset polymers (STPs) were investigated to assess their usability in the cement grout mixes to improve the ductility property. Because thermoset polymers are in liquid form before their polymerization processes, they are practical for homogenization in the cement grouts.

Silicones are synthetic polymers and also known as polysiloxanes. The silicone sealants which are liquid phase adhesives and have a gel form before the polymerization reactions are some well known examples of silicone based thermoset polymer (STP) products. Under both high and low temperatures, STPs keep their elasticity and stability. Furthermore, they are resistant to moisture and weathering (Zander and Peng 2018, Magalhães *et al*. 2019, Galimzyanova *et al*. 2020). Some modified silicones can polymerize and properly solidify in contact with water (Owen 2017). Therefore, it was expected to appropriately use the thermoset additive in cement grout mixes. A high strength STP type of MS Polymer product was used in this study.

Viscosity and solidification time of thermoset additives are essential for the workability of the cement grout mixes. The curing times can vary for different products. Although polymerization reactions of STPs are generally completed in a day, a remarkable solidification takes just an hour. Therefore, thermoset added cement grouts should be used in a short time after mixing in the cement grouts. According to the results obtained by Komurlu (2020), the viscosity of the cement grout mixes increases with an increase in the STP content in the mix. For a proper workability of the grout mixes, MS Polymer type STP content should not exceed to 5% in the mix by weight. As

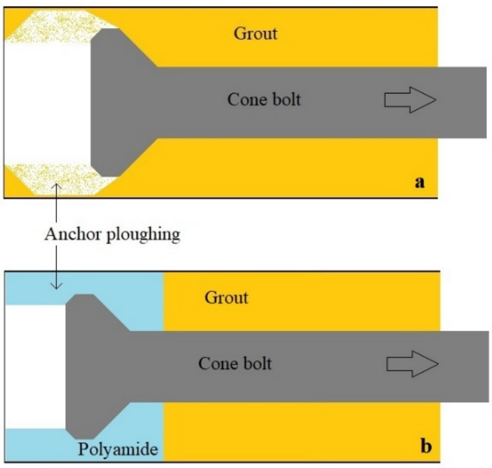

Fig. 1 Anchoring mechanism of the cone part in grout (a) and in the polyamide energy absorber ring (b)

another important outcome, the ductility and energy absorption capacities of cement grout mixes were determined to improve in consequence of the STP additive use (Komurlu 2020).

As a novelty of this study, the STP additive effect on the support performances of cone bolts was investigated to assess whether significant improvements in load bearing and energy absorption capacities can be supplied by its usage. As another novelty, a new method of using plastic absorber rings was tested within this study. The absorber rings made of the Polyamide-6 type engineering polymer material were contacted to the cone parts to supply a full polymeric and ductile ploughed media instead of the cement grout.

Because of their mechanical properties, the Polyamide-6 polymers are used as machine element materials and popular in the machinery manufacture. Engineering polymers are a group of plastic materials with improved mechanical properties which make them ideal for use in engineering applications. Polyamide-6 type thermoplastics with typical tensile strength values between 75 MPa and 100 MPa are widely used engineering polymers. The polyamide materials which are more deformable in comparison with the cement grout mixes have a typical modulus of elasticity values interval from 2 GPa to 3 GPa. The polyamides are quite ductile materials which can have over 60% strain without failure (Komurlu *et al*. 2017, Abdelbary and Nasr 2016, Obeid *et al*. 2018). Design details of new cone bolts with polyamide absorber rings are given in the following title.

2. Materials and methods

The steps in this experimental study can be summarized as follows: specimen preparation (manufacturing rock bolt specimens → getting rock blocks → rock block drilling → preparation of grout mixes → insertion of rock bolts into the blocks → grouting rock bolts in drill holes → grout curing) → pull-out testing → obtaining data of results.

In the specimen preparation step, andesite blocks with 300 mm × 150 mm × 150 mm sizes were drilled by a stand driller machine (Fig. 2). A bit with the diameter of 24 mm was used to drill holes

Fig. 2 Drilling rock blocks

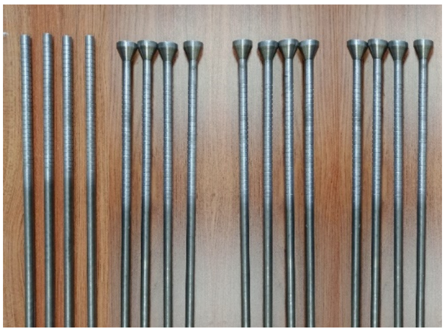

Fig. 3 Rock bolts used in this study

with the length of 250 mm. The inside of the holes was carefully cleaned to remove dust from the drilling process. Cone bolt samples with the cone angle of 25° and ordinary ribbed rebars without a conic head part were used in experiments (Fig. 3). Various ploughed media materials were tested to investigate their effect on load bearing and energy absorption capacities of the bolts. All the samples with and without cone heads had 220 mm long parts with same rib design.

A CEM 1 type ordinary Portland cement and the tap water were used in the grout mixes. The water to cement ratio was 0.45 by weight. In rock bolting applications, water to cement ratios of grouts generally vary between 0.35 and 0.45 by weight (Kim *et al*. 2019, Zhang *et al*. 2020a, Teymen 2017). To investigate the effect of STP additive on the support performances of cone bolts, grouts with and without STP content were tested in this study. Considering the workability property of cement grouts, STP amount in the grout mix was chosen to be 4% by weight. It should be noted herein that this percentage is the ratio of STP to total grout mix weights. The grout mixes were homogenized in a cement mixer for 8 minutes and poured into the holes after insertion of bolt samples. Bolt inserted holes were fully filled with the grout materials. Bolts were gently rotated in the holes to make a well contact to grout mixes. Because of its geometry cone bolts can be easily stood in vertical in the grout mix. For standing bolts without cone ends vertical in the fresh grout, drilled cups were passed through the bolt shanks and taped on the blocks (Fig. 4). The bolt shanks with the length of 80 cm were sensitively checked to be aligned vertically.

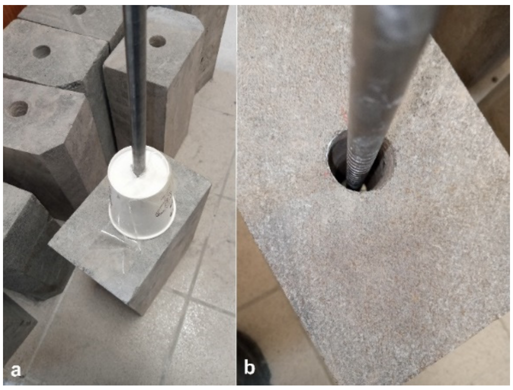

Fig. 4 (a) Use of drilled cup to hold bolts without expanded (cone) end; (b) ability of cone bolts to stand by itself

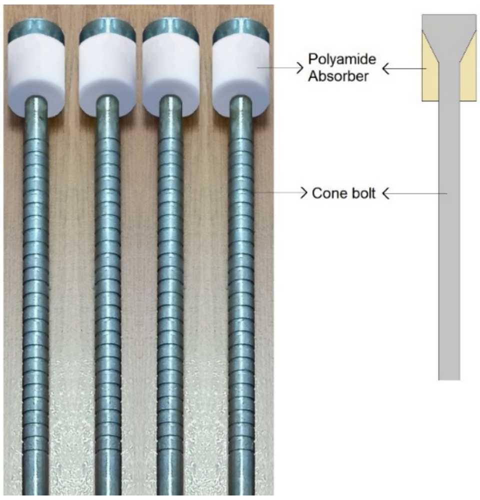

Fig. 5 Cone bolts with the polyamide absorber

To supply fully polymeric media ploughed by the displacement of the cone part, one sides of the polyamide rings were lathed and cut with same angle of the cone part for making a proper contact between them. The outside and inside diameters of the polyamide absorber rings were 22 mm and 11 mm, respectively. The polyamide rings were used on the bolts with the cone angle of 25°. The absorber rings were passed through the shanks and properly contacted to the cones before the insertion of bolts into the rock blocks (Fig. 5). The cement grout mix without the STP additive was used with the bolts including the polyamide absorber.

After two weeks grout curing period under the room temperature condition, bolted rock blocks were tested using a deformation controlled pull-out (adherence) test equipment (Figs. 6 and 7). Load values were read from the digital gauge of the test equipment. While loading bolt specimens axially, displacement data was also read and recorded by using a digital caliper with a sensitivity of 0.01 mm. The caliper was mounted on its stand and contacted on the moving part of the pull-out test machine. The bearing capacity values and load-displacement graphs were obtained from the test. The energy absorption capacities were calculated as the area under the load-displacement graphs in the unit of Joule (J: N · m).

Before filling the grout mixes into the drilled holes in rock blocks, the slump test was also performed in accordance with the ASTM C143 coded standard to compare workability of fresh grouts with and without the STP additive. The slump test is a widely used method to simply test the workability of freshly mixed cementitious materials such as grouts. As the workability of

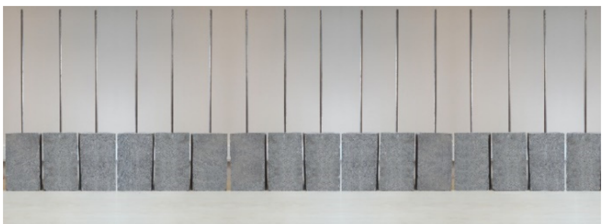

Fig. 6 Bolted rock blocks in this study

Fig. 7 The pull-out test performed in this study

a grout mix increases, the slump test result which is the difference between the initial and final heights of samples increases. The slump test cone with a height of 300 mm, an internal diameter of 100 mm at the top and of 200 mm 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 the slump value was measured as the distance between the top of the grout mixes and the mould height (ASTM 2020).

3. Results

Results of the pull-out test are given in Table 1. Even though the maximum load values of rock bolts were found to not significantly change, a notable increase in the energy absorption capacity was obtained due to the STP additive use. The cone end was found to be highly advantageous for the energy absorption capacity values. Bolts with cone heads have significantly higher load bearing and energy absorption capacities in comparison with those without the cone ends. It should be noted herein that the cone bolts let the increase in the load values until the failure of the

Table 1 The maximum load (F_{max}) values (B: bolts without cone ends, C: cone bolts without the polyamide absorber and in grout mixes without STP additive, S: cone bolts in the STP added cement grout, P: cone bolts with the polyamide absorber (SN: specimen number, SD: standard deviation)

Bolt type	F_{max} (kN)	SD for F_{max} (kN)	SN
B	14	2	4
C	36	3	4
S	37	4	4
P	39	3	4

Table 2 Mean displacement values under various load levels (Δ_{10kN}, Δ_{20kN}, Δ_{30kN} are displacements at 10 kN, 20 kN, 30 kN, respectively. Δ_{max} is the displacement at the maximum load level. NA: not available)

Bolt type	Δ_{10kN} (mm)	Δ_{20kN} (mm)	Δ_{30kN} (mm)	Δ_{max} (mm)
B	1.0	NA	NA	1.5
C	0.7	2.3	3.1	4.2
S	0.9	2.7	3.9	5.8
P	0.8	3.1	5.2	8.2

Table 3 Energy absorption capacity (EAC) values

Bolt type	EAC (J)	SD (J)	SN
B	12.5	0.7	4
C	94.6	5.0	4
S	139.3	18.4	4
P	207.2	9.1	4

steel, whereas the steel failure did not happen and the pull-out tests were completed owing to the reach of the adherence capacity between steel and grout in the tests of bolts without cone heads. It was assessed that the load bearing capacity of grouted rock bolts can be remarkably improved by the use of cone ends.

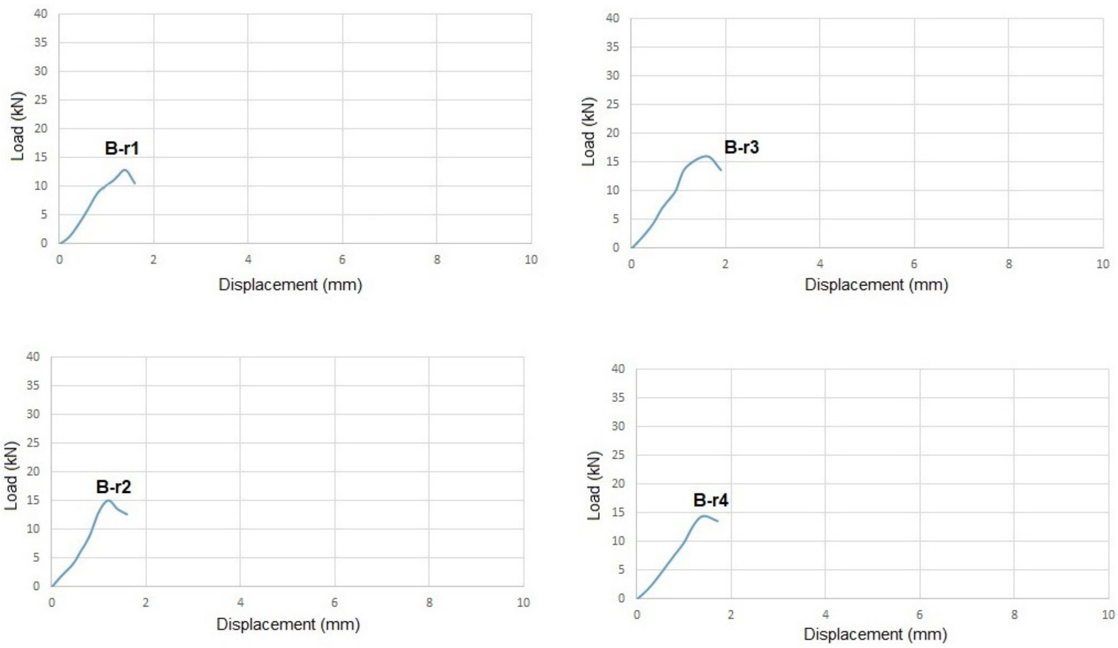

Fig. 8 Load displacement graphs from the pull-out test of bolts without cone ends (r: replicate)

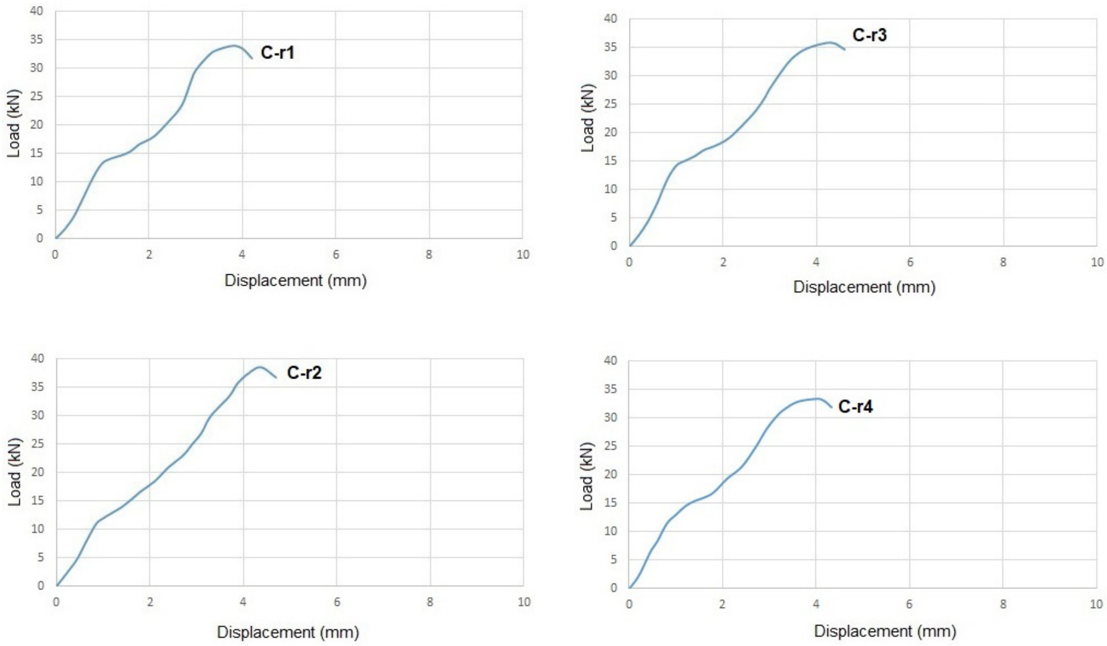

Fig. 9 Load displacement graphs from the pull-out test of cone bolts without the polyamide absorber ring and in the grout mix without the STP additive

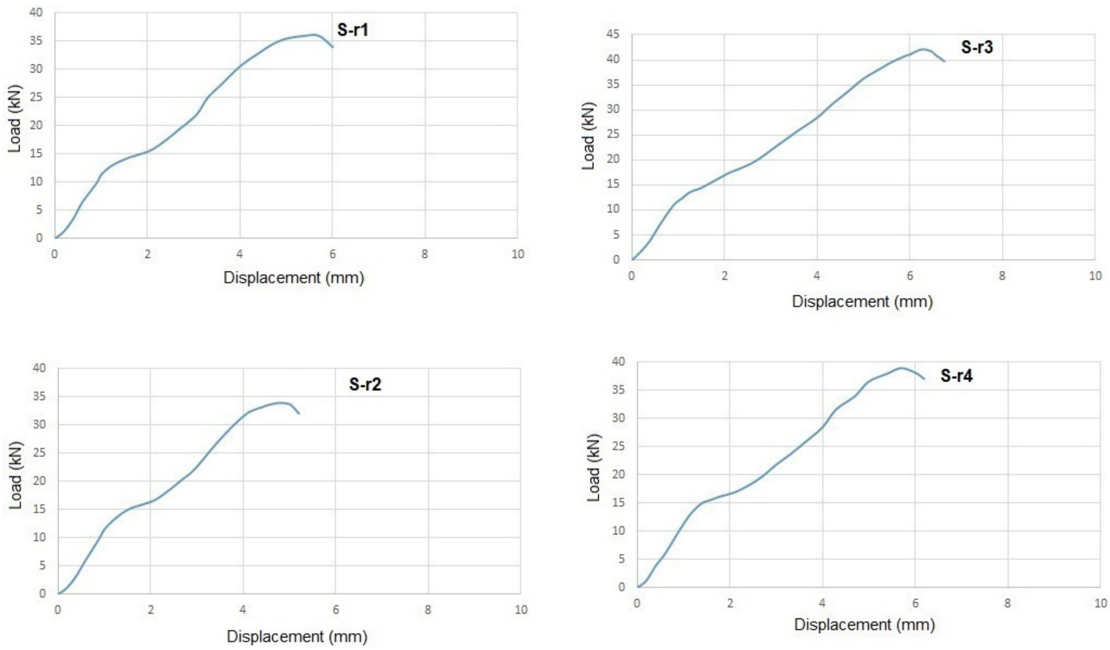

Fig. 10 Load displacement graphs from the pull-out test of cone bolts in the STP added cement grout

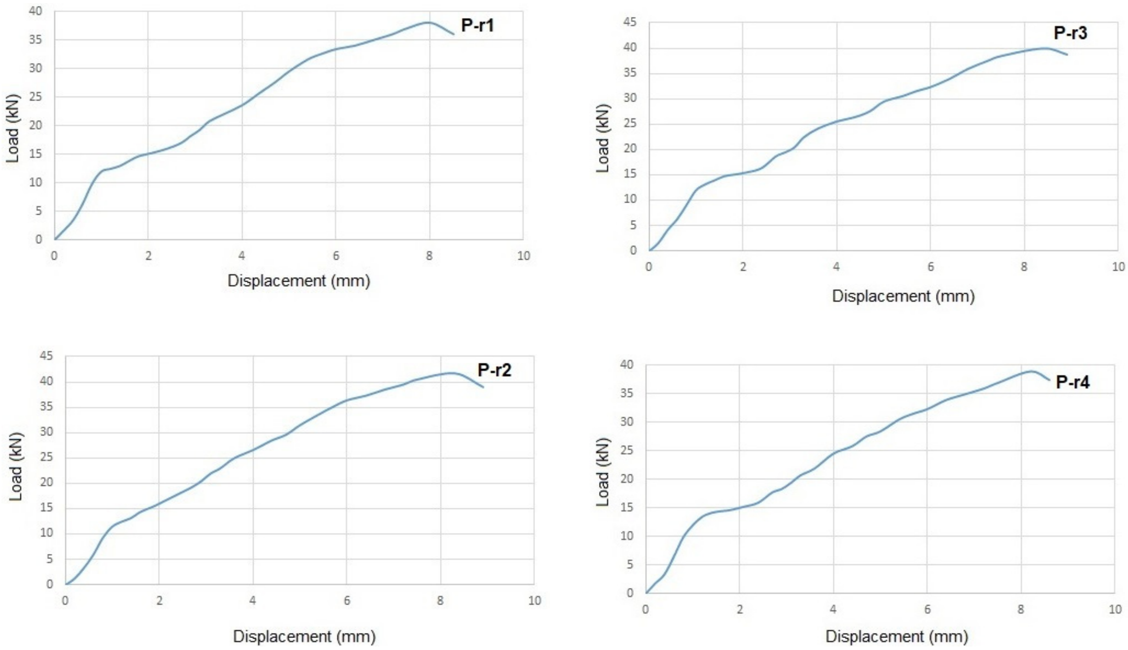

Fig. 11 Load displacement graphs from the pull-out test of cone bolts with the polyamide absorber

The load displacement graphs obtained from the pull-out tests are given in Figs. 8-11. In comparison with the use of ordinary grouts, the bolts in the STP added grout mixes were determined to supply higher displacements without steel failure and better energy absorption capacities. On the other hand, stiffness values decreased as a result of using STP additive. Displacement values for different load levels were seen to increase because of the STP additive use (Table 2).

The energy y absorption capacity values of rock bolt specimens are given in Table 3. According to the results obtained from this study, polyamide absorber rings can supply significant improvements in energy absorption capacity values of cone bolts. Because the displacement capacity of the bolt shank was found to notably increase, the energy absorption capacity until the steel failure doubled up due to the use of the polyamide absorber. Instead of using STP added grout mixes, the polyamide absorber was determined to supply a better improvement in the energy absorption capacity. Even so, an improvement of 47% can be noted as a significant increase in the energy absorption capacity, which was supplied by the STP additive. The STP additive was found to make increases in the viscosity of fresh cement grout mixes. The slump values of cement grouts with and without the STP additive were determined to be 10 cm, 13 cm, respectively.

4. Discussions

It is an important outcome of this study to obtain notably higher energy absorption capacities from STP added specimens in comparison with the case of using ordinary cement grout mixes. The brittle support reactions, low displacement limits and early loss of the bearing capacity can be stated as problems of ordinary grouted rock bolts (Li 2007, Yang *et al*. 2017, Skrzypkowski *et al*.

2020b, Zhang *et al*. 2020b, 2022). Because of ploughing in the grout while increasing in the load values until the failure of the steel shank, cone bolts are more effective to improve the support performances rather than the ordinary bolts like simple ribbed rebars. The improved energy absorption capacity property makes the use of cone bolts advantageous for various aims such as combatting the rock burst (Stacey 2016, Kabwe and Wang 2015, Liu *et al*. 2019).

The grout material properties are determinative for energy absorption capacities of cone bolts. Cement grout materials ductility can be increased by ductile additive materials. In a previous study carried by Komurlu (2020), the STP type elastic and ductile materials were assessed to be usable for increasing the ductility of cement paste mixes. As parallel to that outcome, use of the STP additive was found to increase the energy absorption capacities and ductility in the support reactions of the cone bolts in this study. Because of maintaining load bearing capacities under high displacement values, the STP additive is estimated to improve the performances of the rock bolts exposed to the rock bursting. In addition, deformability characteristics of bolts in STP added grouts also make their usage advantageous in rock masses with squeezing and/or swelling problems (Barla 2016, Aksoy *et al*. 2012, Oge 2021).

Instead of the polymer added cementitious composite media, a fully polymeric ploughed material can be used to supply a higher level of energy absorption. The displacement levels at the steel failure loads of bolts with polyamide absorbers were measured as higher than those of specimens with the STP added grout mix. Because the energy value is a dependent of the displacement parameter, this situation can be assessed to be the reason for a better improvement of the energy absorption capacity by using the absorber rings (Cai 2019, Hao *et al*. 2020, Komurlu *et al*. 2020, Wang *et al*. 2022).

The main reason for improving the energy absorption capacity is an increase in the deformability while supplying no decrease in the load bearing capacity. As the polyamide material is much deformable in comparison with the cement grout, a bettered energy absorption capacity can be supplied by using the new energy absorber rings. The ductility property of the ploughed media in the cone bolt applications is another relevant parameter that an increase in the ductility of grout materials improves the support reaction ductility and the energy absorption capacity of the cone bolts

For a relatively stiff support reaction, use of STP added grout mixes can be preferred instead of the polyamide absorbers. Because of having a fully polymer and relatively more deformable ploughed media, the polyamide absorber usage makes a decreased stiffness of the support reaction. Therefore, the bolts with the polyamide energy absorbers were found disadvantageous to be used in the stiff support needed areas like those with a frequently jointed rock mass. The viscosity of the cement grout mixes is another important parameter for usability in a relevant engineering work. Although the viscosity of the grout mix increases by the STP additive, its 4% amount in the mix was not that high to prevent its usability. In a study carried out by Komurlu (2020), the STP product tested in this study was also used as a grout additive in an underground mine and the 4% STP amount was found to not prevent the systematic applications of the cement grout mixes. Moreover, the STP additive was found advantageous in terms of prevention of the grout flowing from the upward drill holes in the roof. On the other hand, 7% STP additive amount was found to cause some difficulties in grouting operations because of the high viscosity property (Komurlu 2020). Modified equipment use is needed to apply cement grouts including high amounts of STP additives. In case of using polyamide absorbers, remarkable increases in the energy absorption capacity can be supplied by using ordinary cement grouts. Its effective support performance improvement without a need for a cement grout additive is an important advantage of the polyamide absorbers.

Because same type polymer materials can exhibit significant variations depending on their production details, self properties of a product should be examined instead of considering typical mechanical properties of a polymer material. Various thermosets can be investigated for the aim of making better cement grout performances. The material properties of candidate thermosets are needed to know prior to start of systematical investigations to foresee undesired results. For instance, acrylic based thermosets have a problem of deterioration in contact with water during polymerization reactions (Jiang *et al*. 2019). The ability to properly polymerize in contact with water is a main topic for selection of a thermoset as a cement grout additive.

The STP additive used in this study has a price of 6 USD/kg. Considering a typical rock bolt drill hole with three meters length, approximately 2 USD is spent for STP additive for a bolt. On the other hand, a polyamide absorber ring cost is about 0.5 USD. Therefore, use of the polyamide absorbers can be assessed more economical than the STP additive. For supplying over 200% increase in the energy absorption capacity, the polyamide absorber cost can be accepted as quite economical. It is possible to obtain outstanding performances and solutions for rock engineering works by using new materials and following the polymer technology which is rapidly developed nowadays.

5. Conclusions

Various new methods to improve energy absorption capacities of the cone bolts were investigated within this study. According to the results, following research findings can be noted as conclusion matters.

1. STP additives can be used in grout mixes for the cone bolt applications.
2. Polyamide absorbers were found to be more advantageous in comparison with the STP type grout additive and strong candidate to be popular in rock engineering.
3. Instead of the increase in the maximum load bearing capacities of grouted cone bolts, use of STP additives or polyamide absorber rings is significantly beneficial to improve the displacement limits, ductility of the support reactions and energy absorption capacities.
4. More than 200% increase in the energy absorption capacities of cone bolts can be economically supplied by the use of polyamide absorbers.

References

Abdelbary, A. and Nasr, M.N.A. (2016), "Fatigue wear of polyamides with surface defects under different loading conditions", *Adv. Mater. Res., Int. J.*, **5**(3), 193-203. http://dx.doi.org/10.12989/amr.2016.5.3.193

Aksoy, C.O., Ogul, K., Topal, I., Ozer, S.C., Ozacar, V., Posluk, E. (2012), "Numerical modeling of non-deformable support in swelling and squeezing rock", *Int. J. Rock. Mech. Min. Sci.*, **52**, 61-70. https://doi.org/10.1016/j.ijrmms.2012.02.008

ASTM (2020), ASTM C143/C143M-20: Standard Test Method for Slump of Hydraulic-Cement Concrete. ASTM International, West Conshohocken, PA, USA.

Barla, G. (2016), "Full-face excavation of large tunnels in difficult conditions", *J. Rock Mech. Geotech. Eng.*, **8**(3), 294-303. https://doi.org/10.1016/j.jrmge.2015.12.003

Cai, M. (2019), "Rock support in strainburst-prone ground", *Int. J. Min. Sci. Technol.*, **29**, 529-534.

https://doi.org/10.1016/j.ijmst.2019.06.008
Carmona, S., Molins, C. and Garcia, S. (2020), "Application of Barcelona test for controlling energy absorption capacity of FRS in underground mining works", *Constr. Build. Mater.*, **246**, 118458. https://doi.org/10.1016/j.conbuildmat.2020.118458
Galimzyanova, R.Y., Lisanevich, M.S. and Khakimullin, Y.N. (2020), "Sealing materials based on polymers", *Key Eng. Mater.*, **869**, 93-100. https://doi.org/10.4028/www.scientific.net/kem.869.93
Hao, Y., Wu, Y., Ranjith, P.G., Zhang, K., Hao, G. and Teng, Y. (2020), "A novel energy-absorbing rock bolt with high constant working resistance and long elongation: Principle and static pull-out test", *Constr. Build. Mater.*, **243**, 118231. https://doi.org/10.1016/j.conbuildmat.2020.118231
Jager, A.J. (1992), "Two new support units for the control of rockburst damage", In: *Proceedings of International Symposium on Rock Support in Mining and Underground Construction*, A.A. Balkema, Rotterdam, The Netherlands, pp. 621-631.
Jiang, B., Oh, K.H., Kim, S.Y., He, X. and Oh, S.K. (2019), "Technical evaluation method for physical property changes due to environmental degradation of grout-injection repair materials for water-leakage cracks", *Appl. Sci.*, **9**(9), 1740. https://doi.org/10.3390/app9091740
Kabwe, E. and Wang, Y. (2015), "Review on rockburst theory and types of rock support in rockburst prone mines", *Open J. Saf. Sci. Technol.*, **5**(4), 104-121. http://dx.doi.org/10.4236/ojsst.2015.54013
Kim, H.J., Kim, K.H., Kim, H.M. and Shin, J.H. (2018), "Anchorage mechanism and pullout resistance of rock bolt in water-bearing rocks", *Geomech. Eng., Int. J.*, **15**(3), 841-849. http://dx.doi.org/10.12989/gae.2018.15.3.841
Kim, H., Rehman, H., Ali, W., Naji, A.M., Kim, J.J., Kim, J. and Yoo, H. (2019), "Classification of factors affecting the performance of fully grouted rock bolts with empirical classification systems", *Appl. Sci.*, **9**, 4781. http://dx.doi.org/10.3390/app9224781
Komurlu, E. (2020), "An Investigation of Using Thermoset Polymer type Liquid Additives to Improve Cement Grout Performances in Rock Bolting Applications", *Int. J. Geosynth. Ground Eng.*, **6**, 52. https://doi.org/10.1007/s40891-020-00236-9
Komurlu, E. and Kesimal, A. (2017), "Experimental study on usability of friction rockbolts with plastic bodies", *Int. J. Geomech.*, **17**(9), 04017058. https://doi.org/10.1061/(ASCE)GM.1943-5622.0000960
Komurlu, E., Kesimal, A. and Aksoy, C.O. (2017), "Use of polyamide-6 type engineering polymer as grouted rock bolt material", *Int. J. Geosynth. Ground Eng.*, **3**, 37. https://doi.org/10.1007/s40891-017-0114-6
Komurlu, E., Demir, A.D. and Celik, A.G. (2020), "Investigation of load bearing capacities of grouted rock bolts with new auxetic head designs", *Period Polytech. Civil Eng.*, **64**(3), 782-791. https://doi.org/10.3311/PPci.16366
Korzeniowski, W., Skrzypkowski, K. and Zagórski, K. (2017), "Reinforcement of underground excavation with expansion shell rock bolt equipped with deformable component", *Studia Geotechnica et Mechanica*, **39**, 39-52. https://doi.org/10.1515/sgem-2017-0004
Li. C.C. (2007), "A Practical problem with threaded rebar bolts in reinforcing largely deformed rock mass", *Rock Mech. Rock Eng.*, **40**(5), 519-524. https://doi.org/10.1007/s00603-006-0094-7
Li, C.C. (2017), "Principles of rockbolting design", *J. Rock Mech. Geotech. Eng.*, **9**(3), 396-414. https://doi.org/10.1016/j.jrmge.2017.04.002
Li, C.C., Stjern, G. and Myrvang, A. (2014), "A review on the performance of conventional and energy-absorbing rockbolts", *J. Rock Mech. Geotech. Eng.*, **6**(4), 315-327. https://doi.org/10.1016/j.jrmge.2013.12.008
Li, C.C., Kristjansson, G. and Hoien, A.H. (2016a), "Critical embedment length and bond strength of fully encapsulated rebar rockbolts", *Tunnel. Und. Space Tech.*, **59**, 16-23. http://dx.doi.org/10.1016/j.tust.2016.06.007
Li, C., Wu, J., Wang, J., Li, X. (2016b), "Layout and length optimization of anchor cables for reinforcing rock wedges", *Bull. Eng. Geol. Environ.*, **75**, 1399-1412. https://doi.org/10.1007/s10064-015-0756-3
Liang, Y., He, M., Cao, C., Wang, S. and Ren, T. (2017), "A mechanical model for conebolts", *Comput. Geotech.*, **83**, 142-151. https://doi.org/10.1016/j.compgeo.2016.10.017

Liu, H., Yu, B., Liu, J. and Wang, T. (2019), "Investigation of impact rock burst induced by energy released from hard rock fractures", *Arab. J. Geosci.*, **12**, 381. https://doi.org/10.1007/s12517-019-4536-4

Magalhães, S., Alves, L., Medronho, B., Fonseca. A.C., Romano, A., Coelho, J.F.J. and Norgren, M. (2019), "Brief overview on bio-based adhesives and sealants", *Polymers*, **11**(10), 1685. https://doi.org/10.3390/polym11101685

Obeid, H., Clement, A., Freour, S., Jacquemin, F. and Casari, P. (2018), "On the identification of the coefficient of moisture expansion of polyamide-6: Accounting differential swelling strains and plasticization", *Mech. Mater.*, **118**, 1-10. https://doi.org/10.1016/j.mechmat.2017.12.002

Oge, I.F. (2021), "Revisiting the assessment of squeezing condition and energy absorption of flexible supports: A mine development case", *Tunnel. Und. Space Tech.*, **108**, 103712. https://doi.org/10.1016/j.tust.2020.103712

Owen, M.J. (2017), "Silicone hydrophobicity and oleophilicity", *Silicon*, **9**, 651-655. https://doi.org/10.1007/s12633-014-9188-0

Ranjbarnia, M., Fahimifar, A. and Oreste, P. (2016), "Practical method for the design of pretensioned fully grouted rockbolts in tunnels", *Int. J. Geomech.*, **16**(1), 04015012. https://doi.org/10.1061/(ASCE)GM.1943-5622.0000464

Skrzypkowski, K., Korzeniowski, W., Zagórski, K. and Zagórska, A. (2020a), "Modified rock bolt support for mining method with controlled roof bending", *Energies*, **13**, 1868. https://doi.org/10.3390/en13081868

Skrzypkowski, K., Korzeniowski, W., Zagórski, K. and Zagórska, A. (2020b), "Adjustment of the yielding system of mechanical rock bolts for room and pillar mining method in stratified rock mass", *Energies*, **13**, 2082. https://doi.org/10.3390/en13082082

Stacey, T.R. (2016), "Addressing the consequences of dynamic rock failure in underground excavations", *Rock Mech. Rock Eng.*, **49**(10), 4091-4101. https://doi.org/10.1007/s00603-016-0922-3

Teymen, A. (2017), "Effect of mineral admixture types on the grout strength of fully-grouted rockbolts", *Constr. Build. Mater.*, **145**, 376-382. https://doi.org/10.1016/j.conbuildmat.2017.04.046

Uyar, G.G. and Aksoy, C.O. (2018), "New support suggestions to high swelling clayey rock mass", *J. Min. Sci.*, **54**(4), 617-627. https://doi.org/10.1134/S1062739118044087

Wang, H., Li, S., Wang, Q., Wang, D., Li, W., Liu, P., Li, X. and Chen, Y. (2019), "Investigating the supporting effect of rock bolts in varying anchoring methods in a tunnel", *Geomech. Eng., Int. J.*, **19**(6), 485-498. http://dx.doi.org/10.12989/gae.2019.19.6.485

Wang, B., He, M. and Qiao, Y. (2021), "Resistance behavior of Constant-Resistance-Large-Deformation bolt considering surrounding rock pressure", *Int. J. Rock. Mech. Min. Sci.*, **137**, 104511. https://doi.org/10.1016/j.ijrmms.2020.104511

Wang, Y., Xiang, X., Li, C., Zhu, G., Song, C., Xian, J. and Zhang, J. (2022), "Load transfer laws of tensile anchors in rock masses with weak interlayers based on a shear-slipping updating model", *J. Mount. Sci.*, **19**, 812-825. https://doi.org/10.1007/s11629-021-6931-z

Yang, S.Q., Chen, M., Jing, H.W., Chen, K.F. and Meng, B. (2017), "A case study on large deformation failure mechanism of deep soft rock roadway in Xin'An coal mine, China", *Eng. Geol.*, **217**, 89-101. http://dx.doi.org/10.1016/j.enggeo.2016.12.012

Yokota, Y., Zhao, Z., Nie, W., Date, K., Iwano, K., Koizumi, Y. and Okada, Y. (2020), "Development of a new deformation-controlled rock bolt: Numerical modelling and laboratory verification", *Tunnel. Undergr. Space Tech.*, **98**, 103305. https://doi.org/10.1016/j.tust.2020.103305

Zander, L. and Peng, J. (2018), "New silane-terminated polymers for sealants and adhesives", *Adhes. Adhes. Sealants*, **15**, 20-23. https://doi.org/10.1007/s35784-018-0014-8

Zhang, C., Cui, G., Chen, X., Zhou, H. and Deng, L. (2020a), "Effects of bolt profile and grout mixture on shearing behaviors of bolt-grout interface", *J. Rock Mech. Geotech. Eng.*, **12**, 242-255. https://doi.org/10.1016/j.jrmge.2019.10.004

Zhang, W., Huang, L. and Juang, C.H. (2020b), "An analytical model for estimating the force and displacement of fully grouted rock bolts", *Comput. Geotech.*, **117**, 103222. https://doi.org/10.1016/j.compgeo.2019.103222

Zhang, W., Song, Y., Huang, L. and Gong, S. (2022), "Analytical relations for the mechanical properties of full-length bonded rock bolts when subjected to freeze–thaw processes", *Comput*. *Geotech*., **145**, 104667. https://doi.org/10.1016/j.compgeo.2022.104667

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