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INVESTIGATION OF THE EFFECT OF USING FLY ASH IN THE GROUT MIXTURE ON PERFORMING THE FULLY GROUTED ROCK BOLT SYSTEMS

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ABSTRACT: This paper attempts to reveal the influence of using fly ash in the grout on the axial bearing capacity of fully grouted rock bolts. For this purpose, different fly ash contents, including 1% and 2%, have been applied with Stratabinder HS with a water-to-grout ratio of 30%. Also, after preparing and curing the required samples, the UCS tests were conducted to determine the influence of fly ash on the grout strength. Along with the UCS tests, several pull-out tests were examined by preparing and curing rock bolt samples with steel reinforcement rebars of 16 mm and steel pipes with a 50 mm length and 23 mm diameter. The results revealed that replacing a small amount of grout with fly ash could increase the strength of the grout. Also, the axial bearing capacity has risen by using fly ash in the grout mixture.

BACKGROUND

The application of rock bolt systems goes back to late 1940 when they were used as one of the most powerful methods of supporting underground excavations and spaces. Since then, these controlling and retaining systems have been extensively used and developed in other engineering disciplines, such as civil, geotechnical engineering and mining engineering, because of the simple composition, lower costs of rebars, versatility and uncomplicated installation in the field (Kilic et al., 2002; Phich Nguyen et al., 2017). There are three fundamental methods associated with reinforcing systems (a) continuously mechanically coupled (CMC), (b) continuously frictionally coupled (CFC), and (c) discretely mechanically or frictionally coupled (DMFC) (Windsor, 1997). Amongst all the related methods, fully grouted rock bolt systems, categorized as the CMC technique, are common in the industry, specifically in the Australian mining sector. In this type of rock bolt, strands from the bolts and surrounding grout, such as cement or resin, act as an internal fixture and will create a rock joint-like interface (Blanco-Martin et al., 2011; Feng et al., 2017).

Rock bolts are subjected to axial and shearing loads. As a result, many researchers have focused on the loading transfer mechanism of the rock bolt system. Pull-out testing, categorized as a tensile load test, is one of the most significant tests for determining the rock bolts' axial bearing capacity. Factors such as strength and type of grout, length, diameter, shape, and distance of ribs on rebars, materials and diameters of confinements as well as loading rate can affect the load-bearing capacity of the pull-out test results. Understanding these key parameters has resulted in several pieces of research work. For instance, Kilick et al. (2002) investigated the effect of the grouted properties on the pull-out capacity of fully grouted rock bolts. For this, they conducted 80 experimental pull-out tests in basalt rocks. The effects of several parameters, such as the bolt length and diameter, shear strength and uniaxial compressive strength (UCS) of the grouting materials and curing time for pull-out tests have been studied. In other research, Kilic et al. (2003) conducted a comprehensive pull-out test by utilising different shaped lugs for rock bolt systems. They suggested a conical lug provided better anchorage strength because of the wedging effect and the combination of the shear and compressive strength of the grouting material. Blanco-Martin et al. (2011) predicted mechanical behaviours for fully grouted pull-out tests with a new analytical approach. Ghadimi et al. (2015) investigated the influence of bolt shape parameters on shear strength. Mirza et al. (2016) examined some of the mechanical parameters of two standard but different grouts used in Australia, Jennmar Bottom-Up 100 (BU100) and Orica Stratabinder HS. They concluded that both mentioned grouts were suitable for reinforcing systems. In further research, Mirzaghorbanali et al. (2018) compared the effects of curing time on the mechanical properties of both small-scale samples with cubed shapes and large-scale cylindrically shape samples using

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Minova Stratabinder grout. They found that the small-scaled samples had higher UCS values and they achieved a faster strength response with respect to the curing procedure. Teyman (2017) added different mixtures of silica fume, blast furnace slag, and fly ash to the grout, and then they cured samples for 1, 3, 7, 28, and 90 days. Grout mixtures that had 15% of mineral admixtures replaced with cement by weight were prepared. After curing the samples, he conducted 150 pull-out tests to find the effect of mineral admixture on axial bearing capacity. In (2019), Mirzaghorbanali et al. studied the influence of fly ash mixtures on UCS values. For this, they prepared one hundred and eighty samples, considering different fly ash contents, ranging from 5% to 30%. The prepared samples were then cured over five different day ranges: 1, 7, 14, 21, and 28. The results revealed that the UCS values increased by adding fly ash to the grout. Nourizadeh et al. (2021) investigated the effects of curing time and water-to-grout ratio (W/G) on the peak load of fully grouted rock bolts. They conducted 36 pull-out tests based on three different ratios of (W/G): 30%, 36%, and 40%. The samples were cured for different times, ranging from 7 to 28. They found that a longer curing time could increase the ultimate load capacity while the increased ratios of (W/G) decreased the resistance of fully grouted bolts.

Although several valuable pieces of research work have been conducted on investigating the effect of fly ash on determining the UCS values, it has been the focus of a few of them on the fly ashes' effect on the ultimate axial bearing capacity. Therefore, this paper will answer the further question: Would replacing a small amount of grout with fly ash affect the UCS and pull-out results?

MATERIALS AND METHODS

UCS Samples

Several tests have been conducted at the University of Southern Queensland by utilising a compression testing machine under a load of 1 kN per second to investigate the strength of different grouts. For this purpose, the applied grout chosen was Stratabinder HR, common in the Australian industry. Two volumes of fly ash contents, including 1% and 2%, were used in the grouts to study the role of fly ash on the strength of the grout. The water-to-grout ratio was 30%. After designing sample preparation, the prepared grout samples were cast into the cube moulds with dimensions 50 mm x 50 mm x 50 mm. Grout preparation and a view of moulds in one of the conducted tests are shown in **Figure 1**. After preparing the samples, they were then cured for a munmer of days, ranging from 1, 7, 14, 21, and 28 days.

(a)

(b)

Figure 1: (a) a view of the moulds; (e) a view of curing the UCS samples

Pull-out Test

In order to investigate the influence of replacing the grout with fly ash as a filler on axial bearing capacity, forty-five experimental tests were conducted. The rock bolt system included steel reinforcement rebars of 16 mm and steel pipe with a 50mm length and 23 mm diameter. It is worth noting that the steel pipe played the role of surrounding rocks. Also, an additional washer was designed and added to the system to bring the system closer to reality. Eventually, an attachment made from a square steel tube, a steel bolt, and a nut was designed for the tensile testing machine (**Figure 1e**). Like UCS samples, all samples were left to cure for five different times, ranging from 1 to 28 days. After preparing the required samples, the pull-out tests were conducted by a tensile testing machine made by measure test simulate (MTS) Insight® electromechanical testing systems at the University of Southern Queensland. The test rate was 1 (mm/min). A view of cast and pull-out samples has been displayed in the curing room.

(a) (b)

Figure 2: (a) cast samples; (b); view of pull-out samples in the curing room

RESULTS AND DISCUSSION

Due to the limitations, the results of days 7 and 28 are presented in this section. **Figure 3** presents photographs of the UCS samples before and after compression tests. The ultimate load of the UCS tests have been illustrated in **Figure 4**. The ultimate loads of the UCS of grouts without fly ash, with 1% and 2% of fly ash, were 108.9, 120.3, and 139.25 kN for day 7, while these values for the same grout samples were 158.7, 170.5, and 178.7 kN for day 28. Strength values were better on day 28 than day 7. As can be seen clearly in **Figure 4**, the strength of the grout samples has been increased by applying fly ash. It seems that fly ash could play a filler role throughout the voids and improve the strength of the grout. Also, the grout with 2% fly ash content achieved the highest strength values.

(a) (b)

Figure 3: one of the UCS samples with 2% fly ash before and after the compression test. F2 representing 2% fly ash and 30 referring to (W/G)%

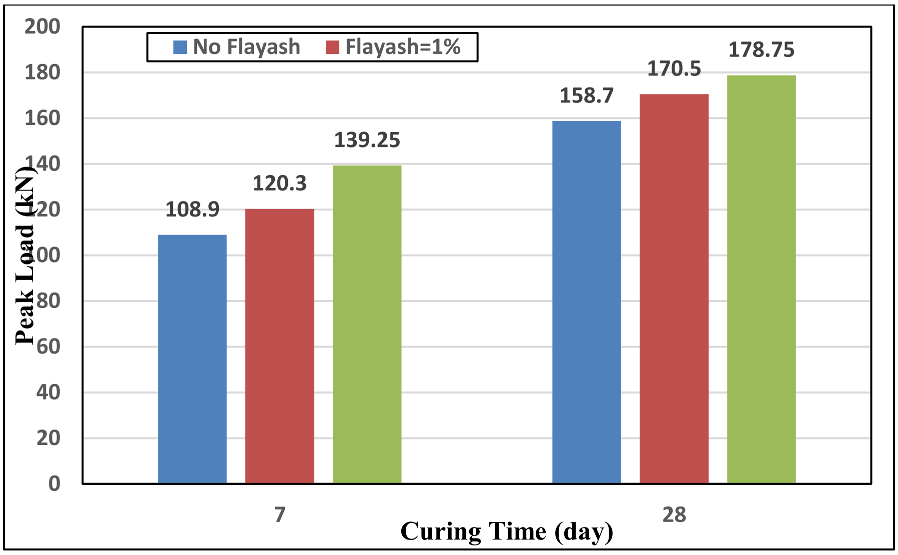

Figure 4: the UCS results for 7 and 28 days

Figures 5 and **6** demonstrate the results of pull-out tests for days 7 and 28, respectively. Axes x and y are load and displacement, respectively. As found in the figures, all diagrams are comprised of the three following phases:

1. Increasing the displacement values under steady loads.
2. Plateau with ultimate load: During this phase, the samples emitted high-pitched-metallic sounds, assumed to be cracking.
3. Decreasing the load: after reaching the top in the second phase, the load decreased steadily, but the displacements will be increased until they would be plateaued out again.

As seen in **Figure 5**, the maximum peak loads for those rock bolts prepared without fly ash contents are 25.3 kN and 45.95 kN for days 7 and 28, respectively. The values for the grouts, including 1% of fly ash contents for similar curing times, are 28.2 kN and 47.5 kN, respectively, while for those grouts with 2% fly ash, the values are 47.5 kN and 52.3 kN, respectively. It means that the ultimate peak loads have risen by increasing the curing time.

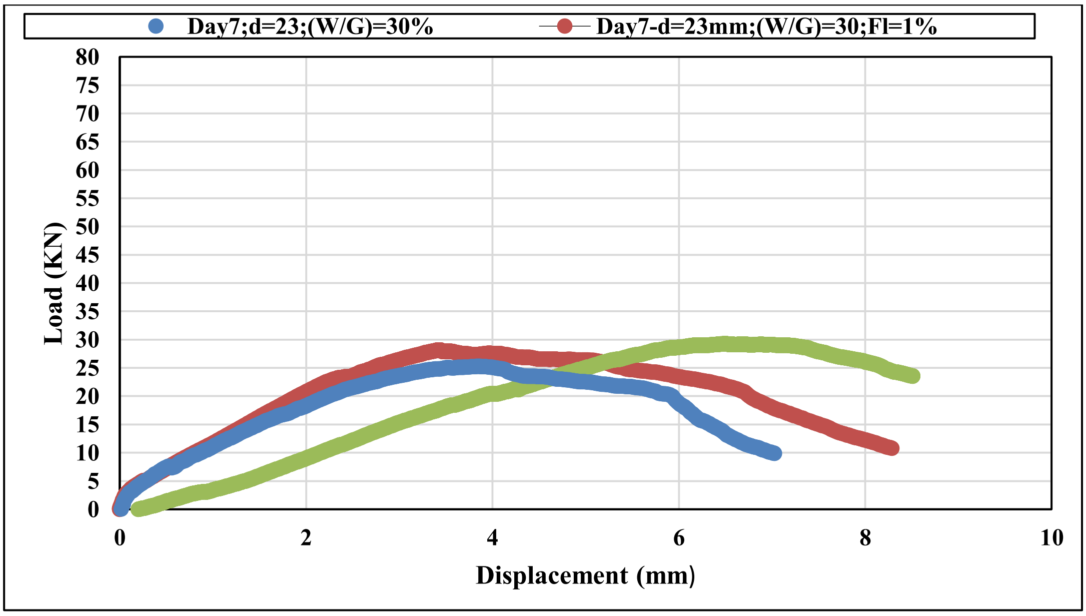

Figure 5: the results of the pull-out test for different types of grouts, including those without fly ash content, with using 1% and 2% fly ash to gout for day 7th

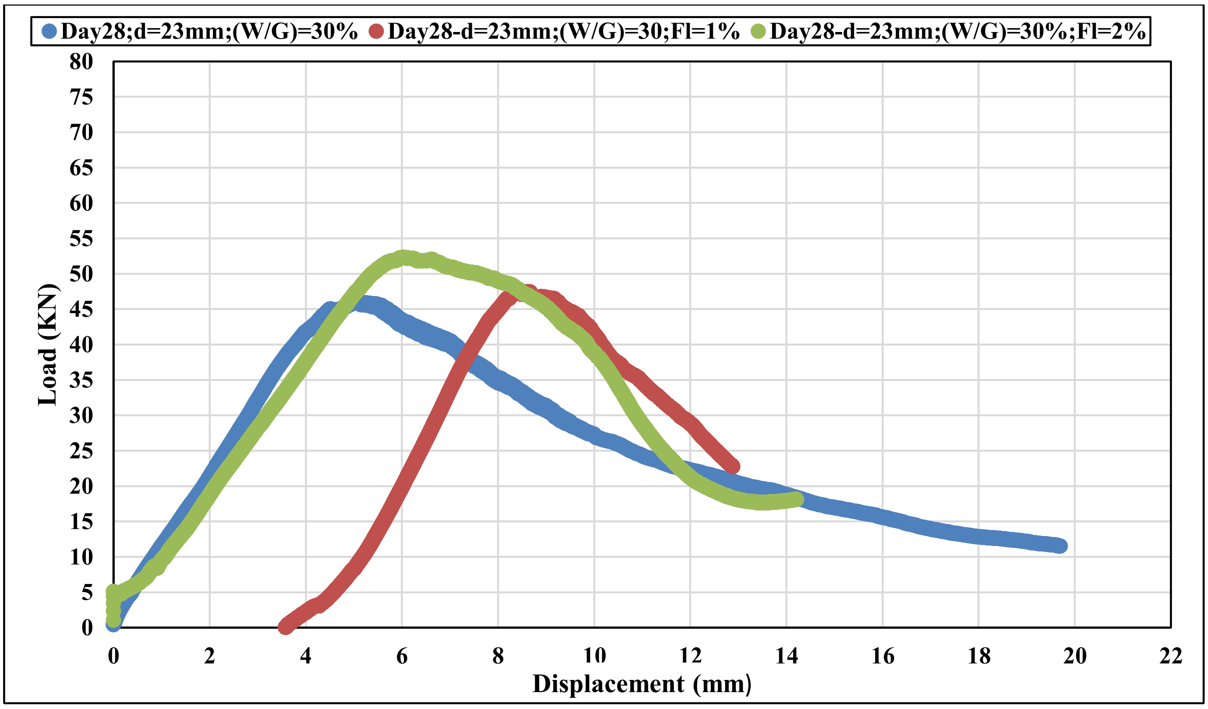

Figure 6: the results of the pull-out test for different grouts, including those without fly ash content, by using 1% and 2% fly ash in gout for day 28th

Figure 7 described all ultimate peak load values for different grout samples, including those without fly ash, by adding 1% and 2% of fly ash contents for days: 7 and 28. As seen, the peak loads have risen with increasing curing times. The results for day 28 show that the ultimate peak load value amplified by approximately 14% by adding 2% of fly ash, while it was almost 4% for the grout with 1% fly ash content.

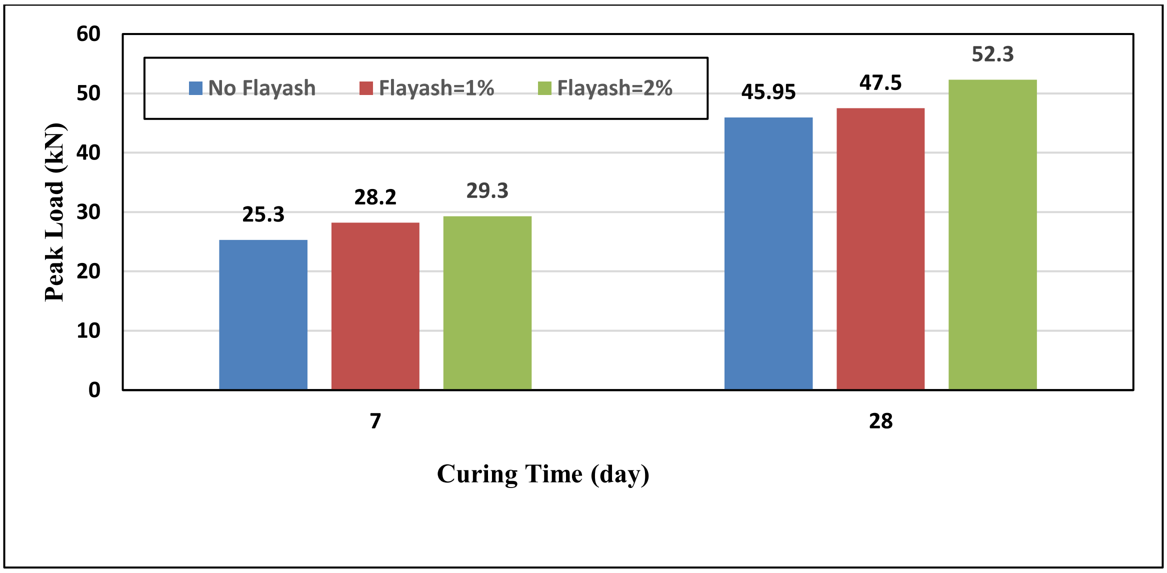

Figure 7: the results of the pull-out test for the different grouts, including those without fly ash content, by using 1% and 2% fly ash in grout for days 7 and 28

CONCLUSIONS

In this paper, the effects of using fly ash in the grout on the UCS and pull-out tests were studied. When considering rock bolt systems, some samples with steel reinforcement rebars of 16 mm and steel pipe with a 50 mm length and 23 mm diameter were chosen. Then different contents of Stratabinder HS, 1% and 2% were replaced with fly ash. The prepared samples were cured at different times: both 7 and 28 days. The results revealed that the peak loads of UCS and pull-out tests increased by 13% and 14% by adding 2% of fly ash in the grout on day 7 and28, respectively.

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