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Using coal rejects and tailings as infills for standing supports in underground gateroads

Ting Ren

Zhenjun Shan

Xiaohan Yang

Hongchao Zhao

Jan Nemcik

USING COAL REJECTS AND TAILINGS AS INFILLS FOR STANDING SUPPORTS IN UNDERGROUND GATEROADS

Ting Ren[1]*, Zhenjun Shan[2], Xiaohan Yang[3], Hongchao Zhao[4] and Jan Nemcik[5]

ABSTRACT: Laboratory tests were conducted to investigate the uniaxial compressive strength (UCS) of two types of potential infill materials for standing supports. While one type of infill material was made from coal reject fines and a cementitious grout, the other was a mixture of tailings and a cementitious grout. 81 cylindrical specimens with a 50 mm diameter and 100 mm height were prepared and tested. The effect of various water-to-grout (w/g) ratios and grout-to-coal reject fines/tailings mix ratios on the UCS of the infills were investigated. Test results indicated that the strength of both infills was adversely affected by the w/g ratio. In addition, when the volume ratio of the coal reject fines in the infill was not greater than 50%, the strength of the infill was similar to that of the control group specimens. Interestingly, almost all the infills made of tailings and grout had a greater UCS when compared with the control group. The infill made from 50% tailings and 50% grout with the w/g ratio of 1.2 achieved the highest strength enhancement ratio, being 1.92 times the UCS of the control group.

INTRODUCTION

Ground stability in longwall gateroads plays an essential role in mine production and safety (Campoli 2015). To control the gateroad strata, primary supports such as rock bolts are generally applied in combination with a secondary supporting mechanism such as weld mesh, shotcrete and standing supports. Due to abutment loads and caving, longwall tailgates usually suffer from high loads and deformation, and the standing supports have found wide applications in these circumstances (Dolinar 2010). From a structural perspective, Galvin (2016) classified standing supports into 5 types: 1) props which mainly include timber props and hydraulic props; 2) timber chocks also known as timber cribs; 3) cementitious chocks such as concrete cribs, the CAN support and pumpable cribs; 4) steel arches and sets; and 5) pillars. In terms of loading characteristics, standing supports fall into the following 4 types: 1) non-yielding, 2) constant yielding, 3) load-increasing or strain-hardening yielding and 4) load-shedding or strain-softening yielding as shown in **Figure 1** (Barczak 2017). The concrete donut crib, the CAN support, pumpable crib and wood crib are the typical standing supports for the above-mentioned 4 types respectively (Barczak et al. 2005). The concrete crib generally has the least deformability among these standing supports, making it undesirable where large roof to floor convergence occurs. Historically, timber cribs and props were the most frequently used standing supports but their popularity has declined due to their availability, cost and load-carrying capacity (Barczak and Tadolini 2005a). Compared with the conventional concrete crib and timber based standing supports, the CAN support and pumpable standing support are more popular (Yu et al. 2019). As shown in **Figure 2**, both the CAN support and pumpable standing support consist of an external container and infill material, the external container provides confinement to the infill material when subjected to compressive loading. While the external container of the CAN support is usually a thin-walled steel tube, the infill materials could be pumice rock (Barczak and Tadolini 2005) and aerated cementitious material (Barczak 2017). Unlike the CAN support, the pumpable crib standing supports normally employ a fabric containment bag to confine

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[1] *School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia. Email: tren@uow.edu.au.*

* *Corresponding author*

[2] *School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia. Email: zshan@uow.edu.au.*

[3] *School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia. Email: xiaohan@uow.edu.au.*

[4] *School of Geology and Mining Engineering, Xinjiang University, Urumqi, Xinjiang 830000, China. Email: zhaohongchao@xju.edu.cn.*

[5] *School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia. Email: jnemcik@uow.edu.au.*

pumpable cementitious infill materials such as aerated cement, Portland fly ash cement, Portland pozzolan cement and ettringite-based cements (Barczak and Tadolini 2005b).

Although the CAN support and the pumpable standing support have been successfully used in longwall tailgate strata control for many years, they both have some deficiencies. The CAN support is highly yieldable (Barczak 2017), which is desirable for tailgate roof support as it allows the support element to provide resistance in large roof-to-floor convergence circumstances. However, the CAN support needs to be topped off to establish roof contact, which may adversely affect the stiffness of the support when the topping-off is not done properly (Barczak 2005). Moreover, the bulky size and large weight of the CAN support creates logistical challenges (Barczak 2005; Yu et al. 2019). In contrast to the CAN support, the pumpable standing support does not have transportation difficulties as the fabric bags are often light weight and the cementitious infill material can be pumped over a long distance, whereas the pumpable standing support experiences load shedding after yield due to the low strength of the fabric bag (Barczak 2005; Zhao et al. 2021a). As such, a conceptual fibre reinforced polymer (FRP) standing support was proposed and developed at the University of Wollongong (Yu et al. 2019; Zhao et al. 2021a; Zhao et al. 2021b; Zhao et al. 2021c). The innovative FRP standing support involved an FRP jacket as the external container which provides confinement to the infill material. Unlike the conventional pumpable standing support, the FRP standing support exhibited strain hardening performance as a result of the FRP confinement.

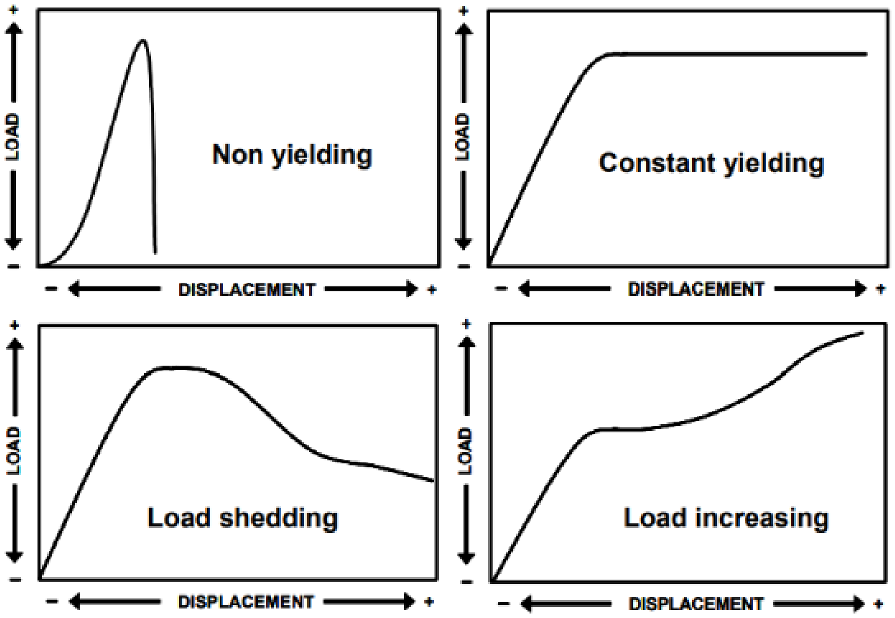

Figure 1: Load-displacement characteristics of various standing supports (Barczak 2017)

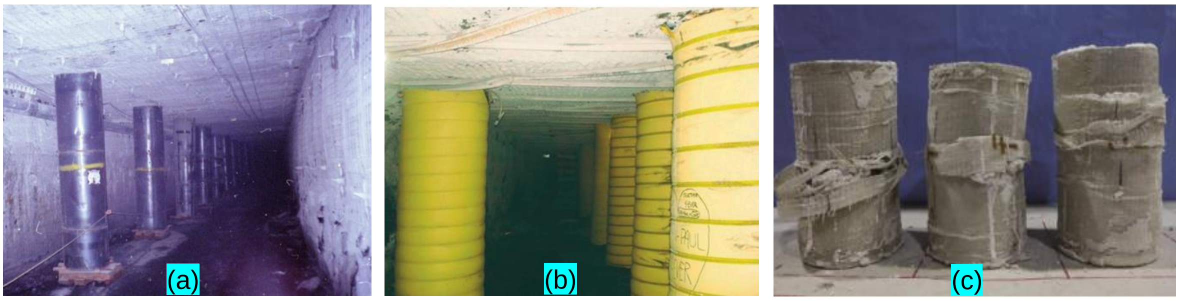

Figure 2: (a) the Can support (Galvin 2016), (b) pumpable standing support (Barczak 2017), and (c) FRP standing support (Zhao et al. 2021)

Considerable research has been conducted on the performance of the CAN support, pumpable standing support and the innovative FRP standing support but the investigation of the infill material used within these supports has been limited. Both coal rejects and tailings are typical mining industry by-products. One of the optimum uses for these mine wastes is to turn them into valuable products. This study attempts to evaluate the uniaxial compressive strength (UCS) of two types of infill material incorporating coal wash rejects and tailings. Successful application of these infills is able to not only help with the lowering of the cost of the standing support but also benefits the environment.

EXPERIMENTAL PROGRAM

Materials

Two types of infill material for the standing supports were evaluated in this study. One was the mixture of a cementitious grout (**Figure 3a**) and coal wash reject fines (**Figure 3b**), the other was the mixture of the cementitious grout and tailings (**Figure 3c**). The cementitious grout was provided by Minova Australia. Both coal wash rejects and tailings were acquired from local Illawarra mines. Before mixing with the cementitious grout, both coal rejects and tailings were firstly dried in a 105°C oven for 48 hours to minimize the effect of moisture, then they were crushed. **Figure 4** illustrates the particle size distributions of the coal reject fines and tailings. The majority of coal reject fines were in the range of 0.6 mm to 2.36 mm, whereas the tailings were much smaller with over 90% of the material being finer than 0.3 mm.

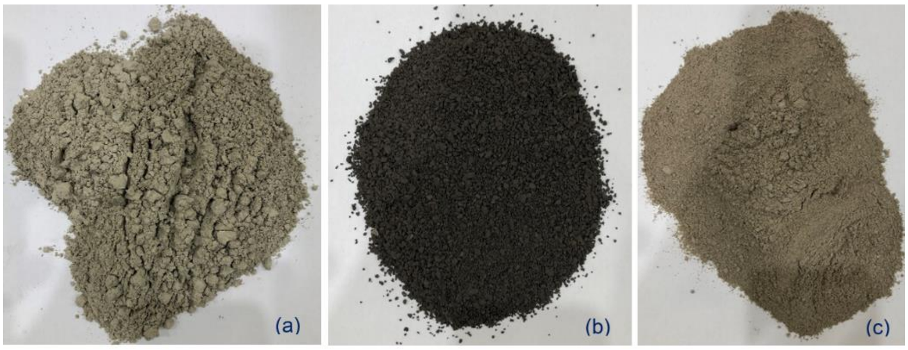

Figure 3: Materials – (a) grout, (b) coal wash reject fines and (c) tailings

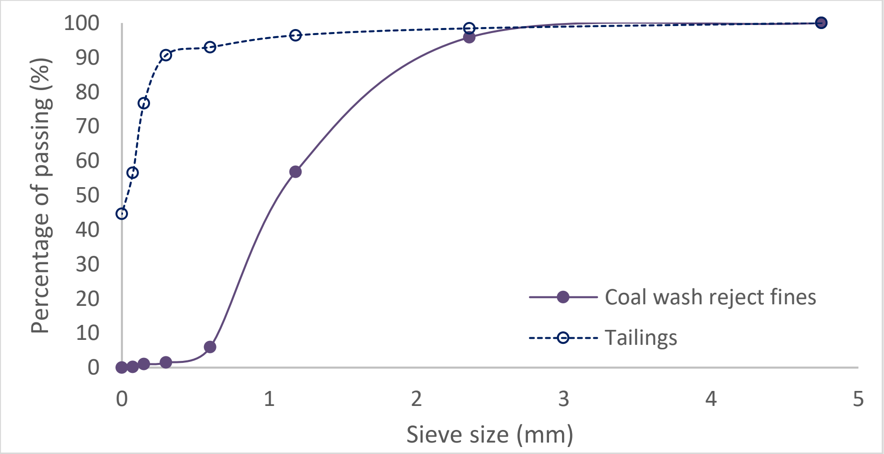

Figure 4: Particle size distribution of coal wash reject fines and tailings

Groups of specimens

As shown in **Table 1**, three sets of specimens were prepared for this study. The first set included 3 groups of specimens, serving as the control groups. The control group specimens were made of the cementitious grout with water-to-grout (w/g) mass ratios of 0.8, 1 and 1.2. The naming of the control groups included the letter ‘G’ representing the grout followed by the letter ‘R’ and a number indicating the w/g ratio. The second set consist of 12 groups of specimens made of the grout and coal reject fines. The volume ratio of coal reject fines in the groups varied from 10% to 70%, with an increment of 20%. The 3 w/g ratios applied in the control groups were also used in the second set. The group name in this set started with the letter ‘C’ and a number followed by the letter ‘G’ and another number, which indicated the volume ratios of the coal reject fines (c/m) in the mixture; The group name finished with a letter ‘R’ and a number, representing the w/g ratio used in this group. Take C3G7R0.8 for example, the name referred to the group of specimens which were made of 30% coal reject fines and 70% grout, and the w/g ratio was 0.8. The third set of specimens was similar to the second set, except that the grout was mixed with tailings rather that coal reject fines. The naming of the specimen groups in this set was also similar to that of the second set. The letter ‘C’ in the second set was replaced with the letter ‘T’ representing tailings.

Table 1: Proposed specimens and summary of test results

Group of specimens		UCS (MPa)				f_i / f_c
		1	2	3	Average	
Control groups	GR0.8	16.1	15.8	19.7	17.2	-
	GR1	7.3	12.4	10.5	10.1	-
	GR1.2	7.6	9.7	5.6	7.6	-
Coal wash reject fines groups	C1G9R0.8	14.5	18.1	14.3	15.6	0.91
	C1G9R1	12.4	10	11.4	11.3	1.12
	C1G9R1.2	9.4	9	8.9	9.1	1.19
	C3G7R0.8	18.6	15.9	16.7	17.1	0.99
	C3G7R1	12	8.8	13.2	11.3	1.13
	C3G7R1.2	7.3	8.8	8.7	8.3	1.08
	C5G5R0.8	15.6	15.6	13.9	15.0	0.87
	C5G5R1	14.3	13.8	12.8	13.3	1.32
	C5G5R1.2	11.3	9.9	8.9	10.0	1.31
	C7G3R0.8	5.6	8.4	6.6	6.9	0.40
	C7G3R1	11.3	8.2	6.3	8.6	0.85
	C7G3R1.2	4.4	6.1	6.8	5.8	0.76
Tailings groups	T1G9R0.8	13.8	19.2	19.7	17.6	1.02
	T1G9R1	12.1	12.2	9.3	11.2	1.11
	T1G9R1.2	8.9	11.9	7.9	9.6	1.25
	T3G7R0.8	23.9	21.3	21.4	22.2	1.29
	T3G7R1	14.7	13	17.4	15.0	1.49
	T3G7R1.2	12.2	10.6	12.6	11.8	1.55
	T5G5R0.8	25.1	21.5	16	20.9	1.21
	T5G5R1	14.6	16	16.5	15.7	1.56
	T5G5R1.2	16.2	17.7	10.1	14.7	1.92
	T7G3R0.8	-	7.7	7.3	7.5	0.44
	T7G3R1	13.2	8.3	15	12.2	1.21
	T7G3R1.2	9.3	11.9	14.5	11.9	1.56

Preparation of specimens

Plastic moulds (**Figure 5a**) with an inner diameter of 50 mm and a height of 100 mm were used to cast the cylindrical specimens. To prepare the specimens, the plastic moulds were firstly placed on a flat surface and a thin layer of oil was sprayed into the moulds to ease the removal of the specimens; The grout and coal reject fines or tailings with the specified volume ratio were mixed evenly, then the pre-determined mass of water was added and mixed till the mixture was homogeous (**Figure 5b**);.After that, the mixture was gently poured into the moulds and cured for at least 4 hours before removing the specimens from the moulds (**Figure 5c**); Specimens were then further cured a normal room environment for at least 28 days before testing (**Figure 5d**).

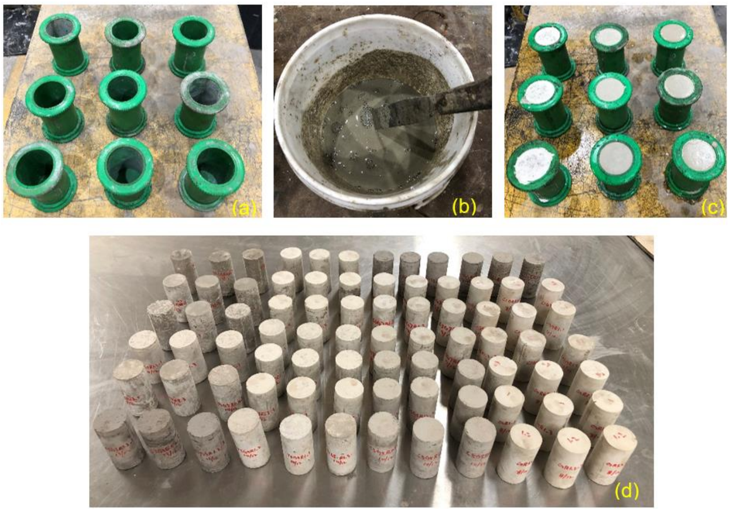

Figure 5: Preparation of specimens

Test setup

Figure 6 illustrates the setup of the uniaxial compressive test. A 500 kN Instron testing machine was used to load the specimens. In order to ensure uniform loading during the test, both ends of the specimens were ground prior to the testing, and the specimen was placed on a bowl-joint. The displacement control model was selected with the loading rate of 0.6 mm/min for all specimens.

Figure 6: Test setup

RESULTS AND DISSCUSSIONS

The performance of the pumpable standing support and FRP standing support were not only correlated with the external containment element but were also a function of the infill material (Batchler 2017; Zhao et al. 2021b). In this study, two types of potential infills with various water-to-grout (w/g) mass ratios and coal reject fines-to-the mixture (c/m) / tailings-to-the mixture (t/m) volume ratios were evaluated using laboratory tests with the test results being summarised in **Table 1**.

Effect of water-to-grout ratio on the UCS of the infills

Figure 7 illustrates the influence of various water-to-grout (w/g) ratios on the UCS of the infills. As expected, the UCS of the infills generally decreased as the w/g ratio increased, except for the two groups in which the coal reject fines and tailings accounted for 70% of the volume of the specimens. The UCS of the C7G3 and T7G3 group specimens firstly increased as the w/g ratio grew from 0.8 to 1, and then it declined as the w/g ratio increased to 1.2. To be specific, the UCS of C7G3 group specimens averaged 6.9 MPa with the w/g ratio being 0.8, then increased to 8.6 MPa when the w/g ratio was equal to 1, but fell to 5.8 MPa when the w/g ratio increased further to 1.2. This is likely due to the poor workability of the mixture at the relatively low w/g ratio of 0.8. As shown in **Figure 8**, the low workability mixture resulted in honeycombs in the specimens, which adversely affected the strength of the specimens.

Compared to the two types of infill material, the control group, made of 100% cementitious grout, experienced the most significant decrease in UCS when the w/g ratio increased. This was due to excessive amounts of water in the control group that was not observed in the infill groups. Evaporation of the excessive water resulted in the formation of pores in the specimen and consequently lowered its strength. Specifically, the average compressive strength of the control group was 17.2 MPa at the w/g ratio of 0.8, it dropped by 41% and 56% when the w/g ratio increased to 1 and 1.2 respectively. The infill material made of 10% coal reject fines and 90% cementitious grout exhibited a relatively smaller fall in strength when compared with the control group, the decreases in UCS were 28% and 42% when the w/g ratio increased from 0.8 to 1 and 1.2 respectively. The smallest decline in UCS for this infill occurred in the group of specimens made of 50% coal reject fines and 50% cementitious grout, with a UCS reduction of 12% and 33% respectively. Likewise, the smallest drop in UCS for the other infill material occurred in the group of specimens made of 50% tailings and 50% grout.

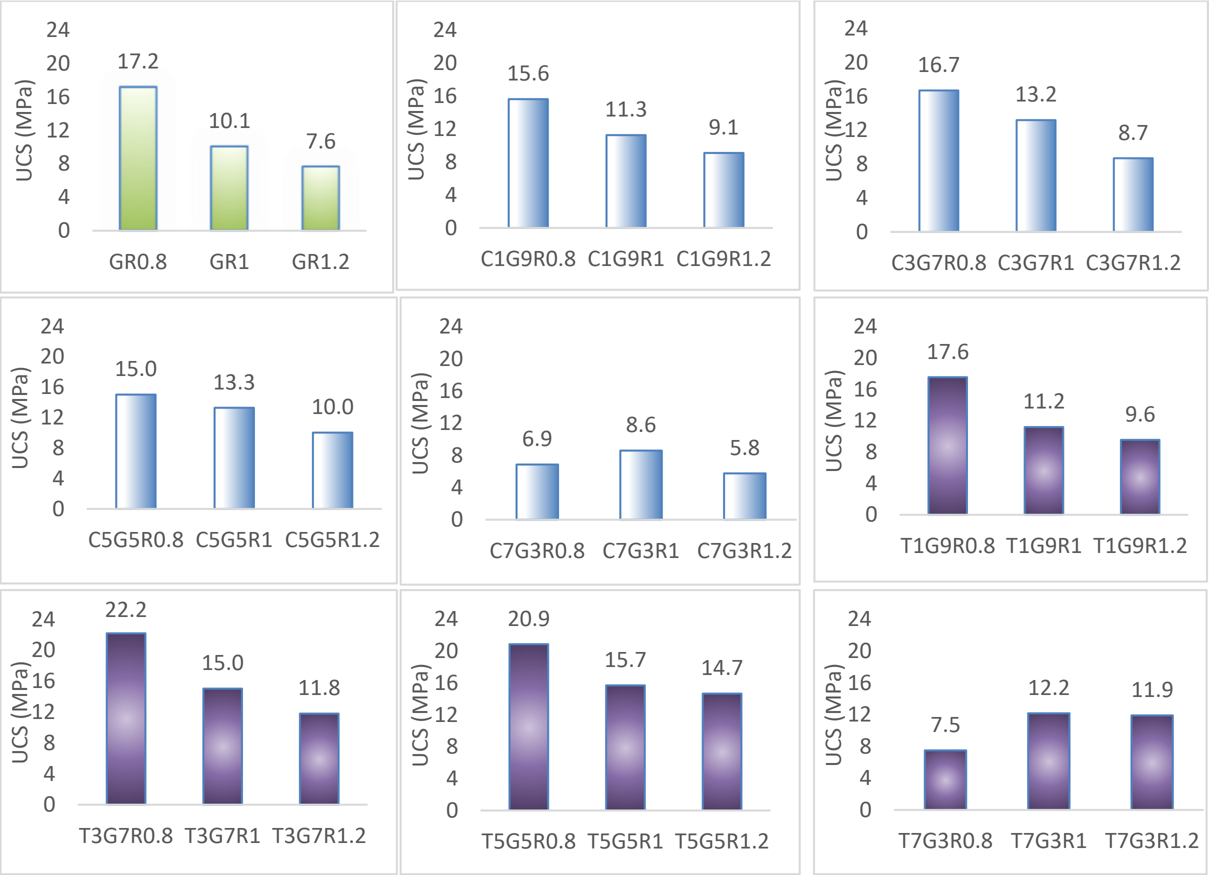

Figure 7: Effect of water-to-grout ratio on the UCS of the infills

Figure 8: Honeycombs in the specimens

Effect of coal reject fines/tailings volume ratio on the UCS of the infills

To investigate the feasibility of incorporating coal reject fines and tailings into the infills for standing supports, various groups of specimens with different coal reject fines-to-the mixture (c/m) and tailings-to-the mixture (t/m) volume ratios were tested. The evaluated c/m and t/m ratios ranged from 10% to 70%, with an increment of 20%. To better demonstrate the effect of the mine waste on the strength of the infills, a strength enhancement ratio (f_i/ f_c) was proposed for this study, it referred to the ratio of the UCS of the infill (f_i) to the UCS of the corresponding control group specimen (f_c). The results are listed in **Table 1** and illustrated in **Figure 9**.

It is clear from **Figure 9a** that the strength enhancement ratio of the infills comprising coal reject fines and the grout was smaller than 1 at the w/g ratio of 0.8, indicating that the UCS of the infill was lower than that of the control group specimens. The UCS of the infill generally decreased as the coal reject fines volume increased. This was probably because the workability of the mixture deteriorated as a result of increased volume of the coal reject fines. The lower workability was likely to lead to more air voids in the mixture. which resulted in a weaker specimen. At the w/g ratios of 1 and 1.2, the infills were generally stronger than the control group specimens, except for the infills with a c/m ratio of 70%, again this was attributed to the poor workability as explained above. When the w/g ratio was 1, the strength enhancement ratio of the infill increased slightly from 1.12 at the c/m ratio of 10% to 1.13 at the c/m ratio of 30%, it kept increasing and reached the peak of 1.32 at a c/m ratio of 50%, after that, the strength enhancement ratio started to drop to 0.85 at the c/m ratio of 70%. A similar tendency was also observed when the w/g ratio was 1.2, the peak strength enhancement ratio also occurred at the c/m ratio of 50%, being 1.31. The results demonstrated that the improvement in the UCS of the specimens was not significant when replacing up to 30% of the grout, whereas an increase of over 30% in UCS was achieved when 50% of the grout was replaced by the coal reject fines.

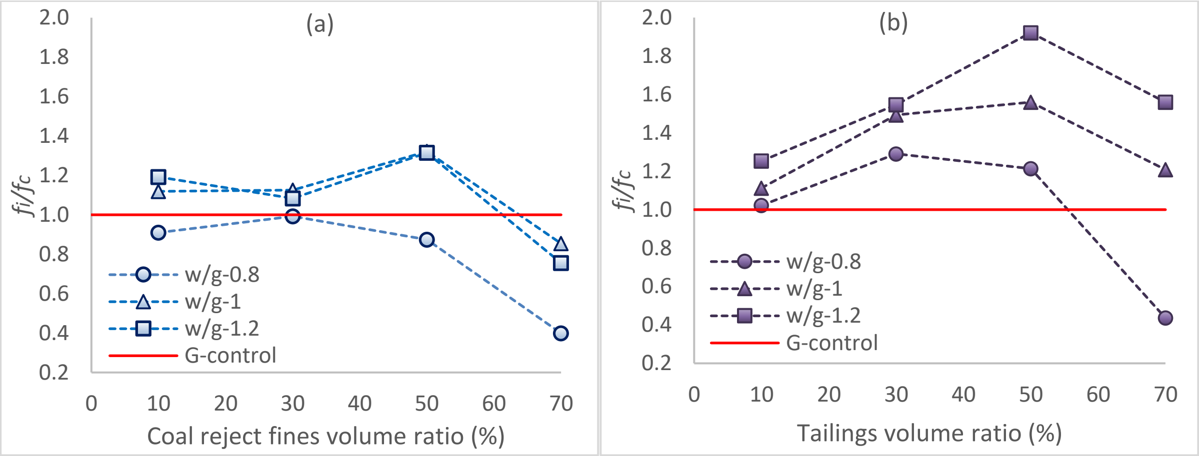

Figure 9: Effect of the volume ratio of (a) coal reject fines and (b) tailings on the UCS of the infill material

As shown in **Figure 9b**, only the group of specimens made of 70% tailings and 30% grout at the w/g ratio of 0.8 had a strength enhancement ratio lower than 1, the strength enhancement ratios of all the other groups were greater than 1, indicating that it is feasible to replace part of the grout in the infill without decreasing its strength. At the w/g ratio of 0.8, the strength enhancement ratio of the infill increased from 1.02 to 1.29 when the tailings volume ratio grew from 10% to 30%, then it started to slightly decline to 1.21 with the t/m ratio at 50%, followed by a significant drop to 0.44 at the t/m ratio of 70%. The reason for the remarkable drop in UCS was again due to the low workability of the mixture as explained above. When the w/g ratio was 1, the strength enhancement ratio of the infill initially increased as the volume ratio of the tailings went up, it peaked at 1.56 at the t/m ratio of 50% and then it started to drop. The groups of specimens with the w/g ratio of 1.2 experienced the same trend as those with the w/g ratio of 1. The group of infills with the t/m ratio of 50% had the greatest strength enhancement ratio, being 1.92. It is worthwhile to note that the strength enhancement ratio of the infills made of tailings and grout was positively proportional to the w/g ratio.

Compared with the infills made of coal reject fines and the grout, the infills made of tailings and grout generally had a greater strength enhancement ratio. This was probably because the particles in the tailings were finer than those of the coal reject fines, the finer particles were likely to reduce the air voids in the mixture thus contributed to stronger specimens.

CONCLUSIONS

This study assessed two potential infills for standing supports using laboratory testing. One of the infills was made of coal reject fines and a cementitious grout, the other was made of tailings and cementitious grout. 81 specimens were prepared and subjected to the UCS test, effects of water-to-grout (w/g) ratio and coal reject fines-to-mixture (c/m)/tailings-to-mixture (t/m) ratio on the UCS of the infills were evaluated. The UCS of both of the two infills decreased as the w/g ratio increased, except for the groups in which the mine waste volume ratio reached 70%.

Test results indicate that at the w/g ratio of 0.8, it was not feasible to replace part of the grout in the infill with coal reject fines, because the UCS of the infill was weakened. However, the infills with the coal reject fines not greater than 50% with w/g ratios of 1 and 1.2 were stronger than their control group specimens.

Almost all the groups of infills made of tailings and grout were stronger than their control group counterparts, with the exception of the group of infills made of 70% tailings and 30% grout at the w/g ratio of 0.8. At the w/g ratio of 1 and 1.2, the UCS of this infill generally increased as the volume of the tailings grew when the t/m ratio was not greater than 50%. The group of infills with a w/g ratio of 1.2 and t/m ratio of 50% had the highest strength enhancement ratio of 1.92. The infill made of tailings and the grout was generally stronger than that made of coal reject fines and the grout.

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