Physical and Mechanical Characteristics of Lime-based Cementitious Grout

S. Thienoosan
Department of Civil Engineering, Faculty of Engineering,
Sri Lanka Institute of Information Technology,
Malabe, Sri Lanka

D.J.C.Y. Goonewardena
Department of Civil Engineering, Faculty of Engineering,
Sri Lanka Institute of Information Technology,
Malabe, Sri Lanka

G. Tharmarajah
Department of Civil Engineering, Faculty of Engineering,
Sri Lanka Institute of Information Technology,
Malabe, Sri Lanka

ABSTRACT

Grout is an essential part in soil and rock anchoring while large amount of grout is consumed in anchoring process and capacity of anchoring can be increased by strengthening the grout. Increasing the strength of the grout or achieving the strength of the cement-based grout by partially replacing the cement with hydrated lime and by adding coir fiber can produce sustainable and structurally acceptable grout. This research study investigates grout with water/solid (w/s) ratio of 0.45, 0.7 while replacing the blended Hydraulic cement (BHC) content with hydrated lime by 35%, 50% and 65% with 1% coir fiber, superplasticizer and silica fume. The results show that flow of the grout is reduced with the addition of lime, fiber. Bleeding is improved in the lime-based grout. Compressive strength reduces with the addition of lime while grout achieves improved strength in long term. Compositions with 35% Lime content showed better performance and w/s ratio of 0.45 had the best compositions comparing the physical and mechanical characteristics. The fiber grout sample with w/s = 0.45 and 35% lime content had the best results with flow of 135mm, final bleeding of 3.75%, bleeding settlement in less than one hour and compressive strength at 7days, 28days are 10.4Mpa, 21.75Mpa respectively.

KEYWORDS: *Soil Anchoring, Lime-based grout, Coconut coir fiber, Mechanical characteristics, Physical properties.*

1 INTRODUCTION

Soil anchoring and rock anchoring are solutions to construct structurally and geotechnically sound structure in a way that it can stabilize temporary or permanent structures such as steep slopes, slopes with weak soils, rock excavations, tunnels etc. In Sri Lankan context anchoring is a currently used method in several occasions such as road constructions, Dam construction, soil slopes etc. Slopes are stabilized by the anchors in a way, the soil anchor resist and mobilizes the loads and forces of the soil mass in the failure plane [Chengyu Hong (2011)]. Typically shearing, chemical adhesion, mechanical interlocking and frictional resistance between anchor-grout are common mechanisms used by this system to transfer loads [B. Benmokrane et al (1995)].

Grout is introduced to the soil and rock anchoring system by pumping the grout under pressure in between soil and anchor shaft interface. The primary intension of grouting is to make a strong bond between tendon and soil or rock interface in order to have a smooth load transition and grout is used to transmit the load from one medium to another. B. Benmokrane et al states load transferring capability of the anchoring system is depended on the factors such as anchor type and cement grout type. Also grout application reduce the corrosion of steel elements used for anchoring. soil anchoring industries

https://doi.org/10.54389/HDST9141

predominantly using plain cement-based grout, in addition fine aggregate is mixed with plain grout for particular cases of drill holes with large diameter. And also, admixtures and super plasticizers are been used for various circumstances such as to reduce water content, setting retarders, high temperature grouting, improve workability [P.J. Sabatini et al (1999)].

This research investigates the physical & mechanical properties of the grout and studies the behavior of fiber incorporated lime-based grout with the addition of blended Hydraulic cement (BHC) and mechanical abilities of the grout. This study particularly focuses on the coconut coir fiber incorporated grout used for soil anchoring and rock anchoring. This research study aims to introduce Hydrated lime powder as a substitute to cement in the grout mixture. Replace cement with lime and introduce coir fiber to reinforce the grout composition. And studying the characteristics of the fiber modified grout to form a sustainable and economical grout composition.

The lime-based grout and coconut coir which is the incorporated fiber material are natural products. And coconut coir is a feasible product in Sri Lanka. Further the blended hydraulic cement used for this study is a blend of cement and fly ash which is an industrial by product. So, identifying best compositions and in the industrial implementation level most sustainable grouts can be produced and the whole soil & rock anchoring solution becomes a more sustainably improved option. In a phase where the world technologies are moving to sustainable options; A grout composition with natural ingredients and cement reduction can create more feasible and sustainable solution.

2 LITREATURE REVIEW

In grout industry cement is an inevitable substance, majority of the journals are studied addition of artificial fiber materials to the grouts and specific artificial fiber addition in cement-based grout is been investigated majorly. Researches are conducted on cement-based grouts with artificial fibers focusing on enhancing grout characteristics and used for different practical problems. The studies conducted by [Wei-Hsing Huang (2001), Dong Joo Kim et al (2016), Zhenyue Shi et al (2020), Pu Zhang et al (2021), M. Jamal Shannag (2001), Chunjing Zhang et al (2021), Xiaojuan Shu et al (2022)] are used the artificial fibers such as Polypropylene fiber, Plasma functionalized graphene fiber, Polyvinyl alcohol fiber, basalt fiber. In a study natural source of fiber which is polymer modified jute fiber in the cement grout [Chakraborty et al (2013)] and using pre-treated coconut coir fiber added cement grout lightweight cement boards are constructed and achieved recommended mechanical standards [C. Asasutjarit et al (2009)]. Further Chakraborty et al (2013) mentions major components influencing the modified grout which are fiber characteristics, cement matrix and mix design, specimen handling including sample mixing, casting and curing. Pu Zhang et al (2021) says grout, grout type, length and volume fraction are influencing factors of the grout’s mechanical characteristics. In addition to mechanical properties several other enhanced properties including impervious and high resisting performance in harsh environments, crack control, controlling catastrophic failures are observed by following authors [Wei-Hsing Huang (2001), Zhenyue Shi et al (2020), Dong Joo Kim et al (2016) and S. Chakraborty et al (2013)] respectively in fibered Cementitious grout.

Limited studies are conducted on fiber reinforced lime-based grouts. Natural fibers are not used in these studies instead artificial fibers such as linen fiber and glass fibers are used as the reinforcing agents [Urs Müller et al (2016), Vasiliki Pachta (2021)]. Vasiliki Pachta (2021) indicates that mechanical characteristics including compressive strength, flexural strength and modulus of elasticity are improved tremendously and further results of the grout showed more matured and improved values in long term. Urs Müller et al (2016) points out flow of the grout which deicides the workability of the grout can be adjusted with the superplasticizers type admixture.

Focusing on the researches based on grouts used for anchoring purposes; Jingke Zhang et al studied calcined ginger nuts grout with fly ash and quartz sand. Authors used several combinations of the materials and concluded the mix with calcined ginger nuts grout with fly ash and quartz sand in a ratio of 1:0.5:0.5 as a suitable mix for earthen structures in the basis of its workability and durability. A study on anchor grout used different percentage of styrene-butadiene rubber (SBR) polymers in cement-based grout on dry and wet conditions and investigated the behavior of grout [Joseph J. Assaad et al (2018)]. Further author concludes that the addition of SBR improved physical properties such as resistance for bleeding and washout loss and improves the mechanical properties such as compressive, flexural and bond strength in aquatic conditions.

As mentioned earlier, in anchoring system capacity of the anchor depends on anchor tendon and the grout. Strengthening anchors and reducing the spacing between tendons are costlier option to increase the capacity of anchor system while increasing the strength of grout is a more feasible and economical option. In overall limited number of literatures studied about the utilization of natural fibers in grout and coconut coir fiber is not fully utilized as a reinforcing agent in grouts. Further literatures shown interest in replacing cement with materials such as fly ash, slag and pozzolan. No interest is been shown for the naturally available lime to replace cement in grout. The broad scope and application of grout makes a more broader research gap. So, this study will focus on coconut fiber reinforced lime-based grout with partial replacement of cement for the application of soil and rock anchoring.

3 METHODOLOGY

3.1 Materials

In the lime-based grout BHC is added to the compositions of hydrated lime, in addition superplasticizer, silica fume is used to improve the workability and strength of the composition respectively and reinforced with coconut coir fiber. The material compositions are designed using the literature data and sample castings are done for the compositions before proceeding to the other tests. Material composition is given in table 1. The control sample is designed with 100% ordinary Portland cement (OPC) and superplasticizer to match with the current industrial practices.

Table 1: Material matrix

W/S ratio	L: C ratio	Fiber	additives	Abbreviation
0.45	Control sample	0%	1% SP, 0% SF	45CS
	0.35:0.65	1%	1% SP, 5% SF	W45L35
	0.5:0.5	1%	1% SP, 5% SF	W45L50
	0.65:0.35	1%	1% SP, 5% SF	W45L65
0.7	Control sample	0%	1% SP, 0% SF	70CS
	0.35:0.65	1%	1% SP, 5% SF	W70L35
	0.5:0.5	1%	1% SP, 5% SF	W70L50
	0.65:0.35	1%	1% SP, 5% SF	W70L65
0.9	Control sample	0%	1% SP, 0% SF	90CS
	0.35:0.65	1%	1% SP, 5% SF	W90L35
	0.5:0.5	1%	1% SP, 5% SF	W90L50
	0.65:0.35	1%	1% SP, 5% SF	W90L65
Fiber: 10mm non-treated coconut coir fiber | W/S ratio – water / solid ratio				
SP – Superplasticizer | SF – Silica fume | L:C ratio – Hydrated Lime: BHC ratio				

The control sample (CS) used in the testing consist of 100% OPC with 1% superplasticizer. Hydrated lime, blended hydraulic cement (BHC) is used and mentioned in all the fibered lime-based grout compositions.

3.2 Test sample preparation

The mixing of grout is done by using a mechanical mixer and the mixing procedure is adopted from ASTM C-305. And same mixing procedure and method is followed for all the samples.

3.3 Experimental procedure

As mentioned earlier sample casting is done for the compositions and suitable compositions are selected for the testing. Then grout mixes are tested for its fresh properties and hardened properties. Following properties are experimented on the different grout compositions to study the behavior of the test specimens.
The physical properties tested are,

I. Flowability of grout
II. Bleeding of grout
III. Wet/Dry density

The mechanical properties tested are,

I. Compressive strength

3.3.1 Flowability of grout

Flowability of grout is tested by using grout spread method, The methodology of the test is adopted form EN 445:2007, clause 4.3.2. Initially Mold is placed over the plate and prevent it from sliding. grout is Poured slowly into the mold up to the top level of the mold. Mold is Steadily lifted from the plate and kept it to spread for a maximum of 30s. After 30s from the lifting of the mold, spread is measured in two perpendicular directions and average of two values is calculated.

3.3.2 Bleeding of grout

Bleeding of the grout is tested according to the standard 79 ASTM C 940 – 98a. After grout preparation, an 800ml fresh grout is added to the 1000ml graduate cylinder and initial volume and time is recorded. graduate cylinder is placed in a level surface without any vibrations and closed it to prevent evaporation of bleed water. Record of water volume segregated in the top surface is recorded in 15-mintues time interval for one hour and in hourly basis for next hours. Finally, after concluding the test, bleed water is poured into 25mi glass graduate and total volume is recorded. Bleeding values in different time intervals are given as the percentage of the total bleed volume. Bleeding of grout specimen is calculated by eq 1 and 2. Bleeding test setup is shown in figure 1.

$$Bleeding\% = \frac{V_2 - V_g}{V_1} \times 100 \quad (1)$$

$$Combined\ Bleeding\ \% = \frac{V_w}{V_1} \times 100 \quad (2)$$

Figure 1: Bleeding test setup

Where Vw is volume of decanted bleed water in mL, V1 is volume of sample at beginning of the test in mL, V2 is volume of sample at prescribed intervals, measured at upper surface of water layer in mL and Vg represents volume of grout portion of sample at prescribed intervals, at upper surface of grout in mL.

3.3.3 Density of grout

Wet density is calculated by weighing the mass of 50mm cubic mold and 50mm cubic mold with fresh grout. Grout mass is taken from the difference and with the known dimension's density is calculated using eq 3. Dry density is calculated by oven drying the casted sample for 24 hours in a temperature of 100 ⁰C and weighing the mass of the sample, with the known dimensions of the 50mm cube the dry destiny is calculated using eq 3.

$$D = M/V \tag{3}$$

Where D is wet/dry density (Kg/m3), M is wet or dry mass in Kg and V represents volume of the specimen in m3.

3.3.4 Compression test

Compressive strength of the test specimens is tested by the compression test procedure adopted from the standard ASTM C109. Following the standard 50mm cubes are casted for compression test and 3 cubes are casted per composition. Grout is mixed and casted in the molds as given in the standard. Cubes are kept for 16-24 hours from casting for the grout setting and demolded; In case of not achieving the adequate strength, cubes are further kept in the mold for 2 hours. Grout samples are cured for 7days, 28 days testing in a water tank with a maintained temperature of 23ºC ± 2ºC. compressive strength is calculated using eq 4.

$$Rc = Fc / A \tag{4}$$

3.3.5 Sample casting

Sample casting and curing is done following the sections 3.2 test sample preparation and 3.3.4 compression test. Test samples with water / solid ratio of 0.45 and 0.7 showed satisfactory results while samples of w/s = 0.90 does not achieve its casted properties after the setting time. Samples were not set with in the setting time and inconsistent mixes were obtained with floating fibers on the top surface. Samples of that nature is shown below.

Figure 2: w/s = 0.90 samples

So that samples with w/s of 0.9 is neglected for the further testing and w/s = 0.45 and w/s = 0.7 compositions are tested and investigated throughout this study.

4 RESULTS AND DISCUSSION

4.1 Density of grout

Wet and dry density of grout is measured using the procedure mentioned in section3.3.3 and calculated according to eq 3. The results are shown in figure2.

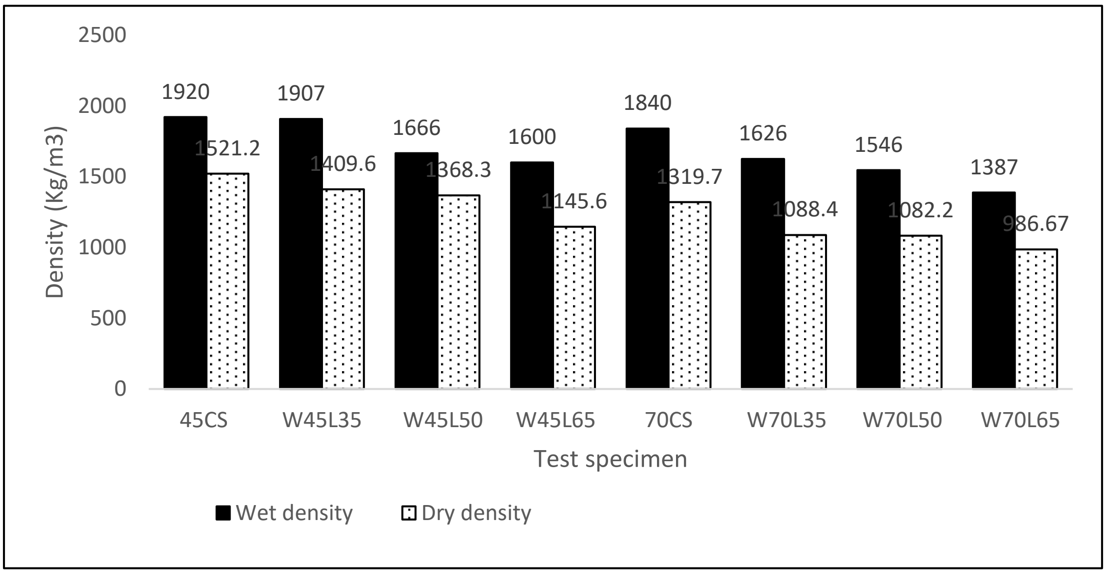

Figure 2: wet and dry density of grout

According to the results shown in figure 3, the Dry density of grout samples is greater than its wet density further a noticeable result is with increment of lime content and water content, both the wet and dry density is reduced. Reasonably after the drying out of water content from the sample will reduce the density and increment of water and reduction in solid content further reduces the density. Composition with 35% lime has wet density of 1907 kg/m^3 and 1626 kg/m^3 for W45L35 and W70L35 respectively. Which are the highest densities compare to other lime added compositions and 45CS has the highest wet and dry density of 1920 kg/m^3 and 1521.2 kg/m^3 compare the all-other composition.

4.2 Flowability of grout

Test results of the grout flowing test is shown in figure 4 below. In figure 4, In the primary axis Flow value of each composition is given and in the secondary axis deviation of flow value of the fibered grout composition compare to its respective control sample is shown as flow deviation percentage.

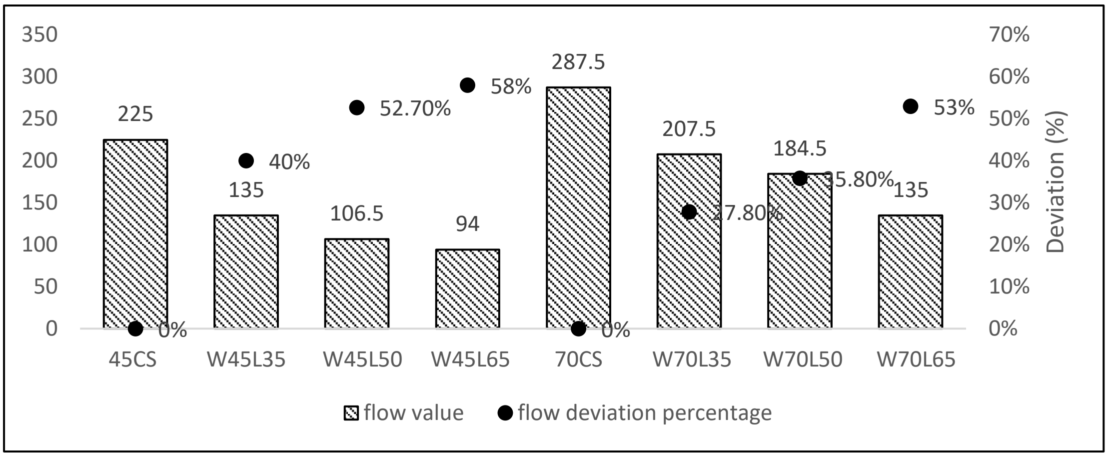

Figure 4: Flow of grout

Figure 4 shows results about the flow of the grout. flowability of grout control samples is observed to be higher values compare to fiber added lime grout samples. Flow of the test specimens increased with the increment of water content and flow decreasing pattern is observed for the increased amount of lime in the composition. Addition of lime and increment of lime content in the samples decreased the flow of the grout sample; due to water absorbing property of lime and L. Gulbe et at also noticed that with the decreasing rate of cement content flow of the specimen is reduced. Both the control samples 45CS and 70CS has acceptable flow values and W45L35 and W70L35 compositions poses a better flow value of 135mm and 207.5mm respectively with minor deviations compare to other two 50% and 65% lime content compositions.

Further an interesting trend noticed, which is flow of the compositions increased when the water content is increased and deviation of the flow values in fiber grout composition compare to its control sample is decreasing with the increment of water content which is shown in the flow deviation percentage points in figure 4. According to figure 3 flow deviation points of w/s=0.45 compositions are notably higher than that of flow deviation points of w/s=0.70 grout compositions. In addition, the workability of the grout can be further improved using admixtures such as superplasticizers [Urs Müller et al (2016)]

4.3 Bleeding of grout

Bleeding of grout is discussed in this part and both final bleeding, bleeding in given time intervals are presented. The bleeding rate of grout in given time intervals which are shown in figure 5 and figure 6 are calculated using eq 1. Final bleeding is calculated using the eq 2 and shown in figure 7.

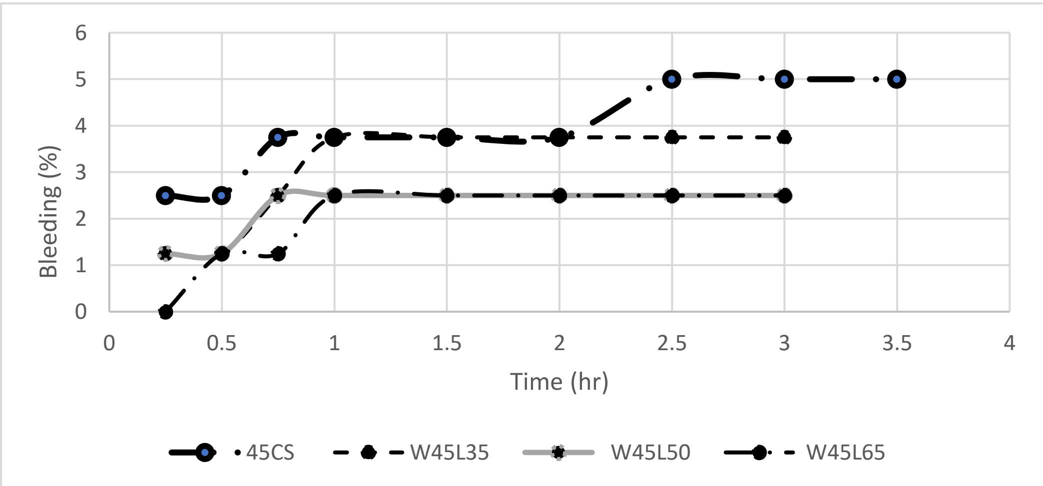

Figure 5: Bleeding rate of w/s=0.45 compositions

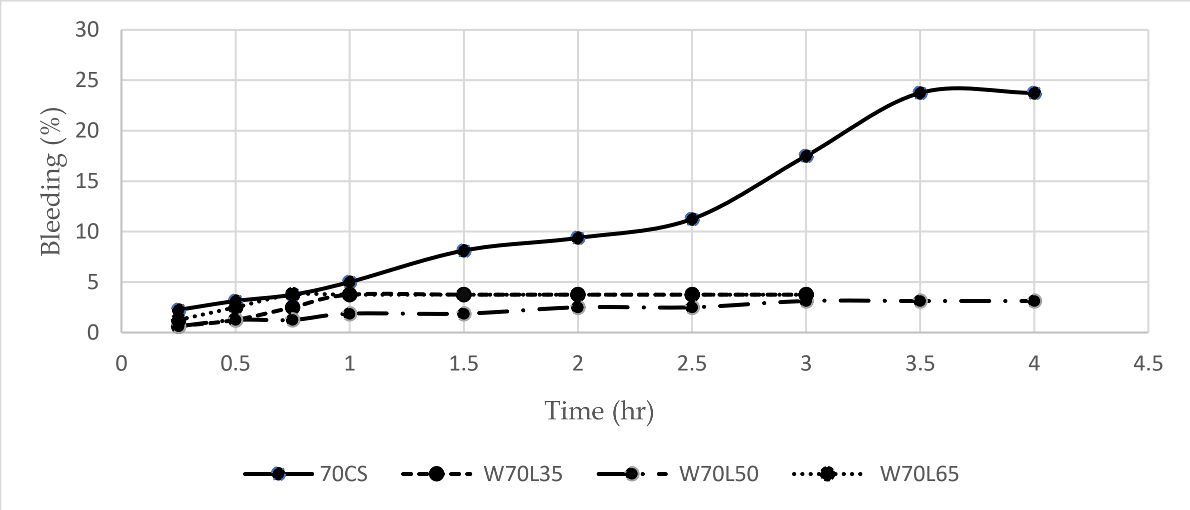

Figure 6: Bleeding rate of w/s=0.7 compositions

Bleeding is an important factor in grout which can directly affects the strength of the grout. Bleeding of the grout combinations are tested according to the methodology given in section 4.3. The readings shows that the control samples(cs) have higher bleeding with higher rate and fibered lime-based grout has a less bleeding value compare to the cs. Further the water content looks to be affecting the bleeding amount; with the increment of water bleeding rate also get increased. Similar results were obtained by Wei-Hsing Huang (2001) and the author observes that excessive water content causes segregation and further states that addition of superplasticizer is also cause for bleeding. In consideration of the grout bleeding rate a notable trend in both the w/s combination is fibered lime-based grout achieves a constant bleeding value in a short period of time compare to control samples which takes 3-4 hours to settle down. Bleeding of fibered compositions with w/s=0.45 is within a range of 1-4 % and fiber grout compositions with w/s =0.7 also has bleeding in similar range. While the control samples having bleeding rate higher than 5% which is not a recommended level of bleeding in industries.

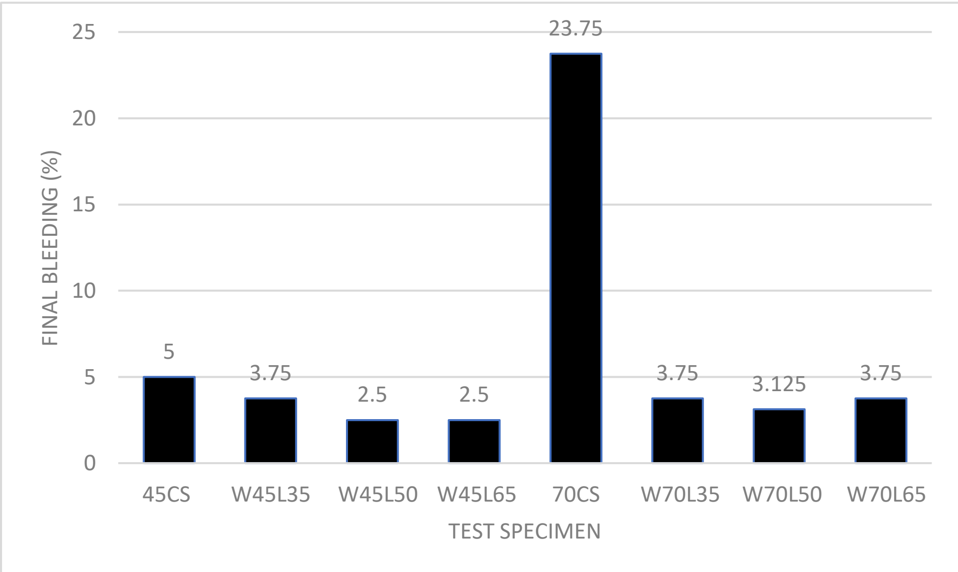

Figure 7: Final bleeding rate of test compositions

Final bleeding chart shows a clear pattern that the control samples have higher bleeding compare to other combination specimens. Addition of silica fume to the fibered specimens is a reason to reduce bleeding by reducing the porosity (M. Jamal Shannag 2001) and further addition of lime which has high water absorption capability is also a reason for low bleeding compare to control sample. In this test results it can observed that the fiber reinforced lime grouts have very low level of bleeding and in an industrially acceptable level while the control samples have an unacceptable amount of bleeding specially 70cs shows a very high final bleeding of 23.75%. In this case coir fiber and lime is a useful addition to the grout composition and it takes the grout to an advantageous position.

4.4 Compressive strength of grout

The compressive test is a primary test to identify the mechanical properties and compression test is done according to ASTM C109 and strength is calculated using eq 4. Figure 8 shows the compression test of a sample and Figure 9 below shows the compression strength at the age of 7days and 28days for the different combinations.

Figure 8: Compression test on a test specimen

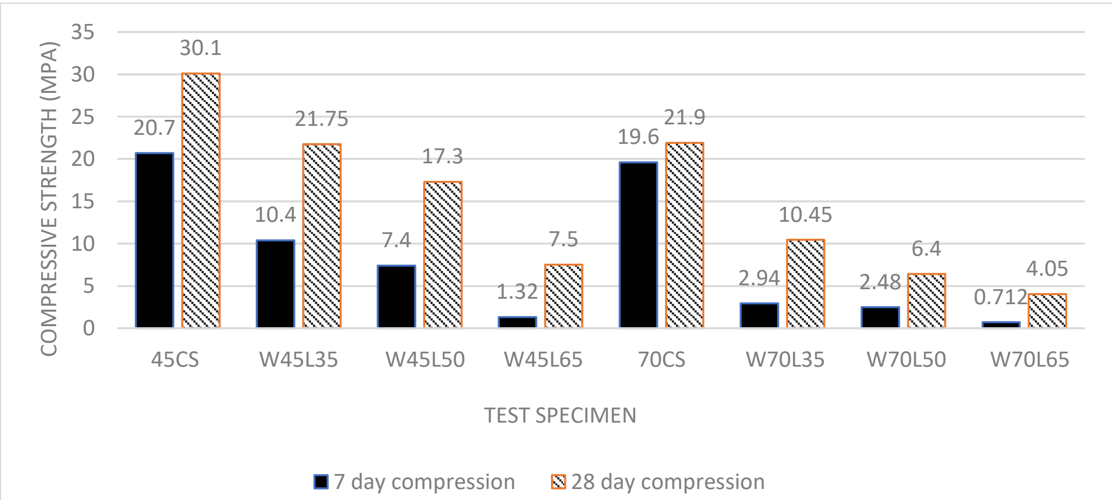

Figure 9: Compressive strength of test specimen

Compressive strengths of the test specimens are shown in figure 9 with the age of 7days and 28days. The control sample, combination with 65% lime powder achieves the highest strength and lowest strength respectively; for both the w/s combinations. Decrement in compressive strength of the samples with the increment of the lime content is been the trend for all the combinations. Further compressive strength reduction is observed in grout samples with increasing water content in the samples. Similar trend is observed by J. Mirza et al (2002) for cement grout. Even though the reduction in compression strength is observed for lime-based grouts, W45L35 and W70L35 has a smaller reduction in strength compare to control sample. And strength deviation of W45L35 and W70L35 compare to other lime-based grouts is high. A common pattern among the lime based fibered grout samples is the increment of compressive strength with age, similar pattern s observed by Vasiliki Pachta (2021) for lime-based grouts. This observation is due to slow reaction of lime in the grout composition.

The compressive strength of 45cs barely satisfies the National Building Research Organization standards and other compositions are not satisfactory. In the lime-based compositions even though the 7days and 28days strength are not satisfactory, further investigation of the lime-based grout sample with compression tests for more aged samples need to be done for better understandings.

The compression tested samples showed a difference in failure patterns for the control samples and fibered grout samples which is shown in following figures. Control samples which have 100% cement showed a brittle behavior and fibered samples showed more elastic behavior which failed in layer-by-layer pattern.

Figure 10: Compressed fiber grout samples

Figure 11: Compressed control samples

5 CONCLUSION

The addition of fiber to grout composition and replacement of cement with lime powder have influenced the physical properties and mechanical properties of the grout composition and comparison with the control sample the fiber grout compositions had an advantage in bleeding test and drawback in flowability and compressive strength. This research can conclude the following.

- Flow of the grout effected by the addition of lime and fiber. Increment of lime powder further decreased flow of the grout. But deviation between flow of fibered sample and control sample is decreased with increasing water content. i.e., Deviation between W45L50, 45CS and W70L50, 70CS are 53% and 36% respectively.
- Bleeding of the control sample is higher compare to other composition. Final bleeding of the fibered sample has a huge difference compare to CS. Addition of silica fume and lime powder reduced the final bleeding of fiber grout and steady the bleeding rate to a constant value in a shorter period.
- Compressive strength of the fibered samples is less compared to CS. Addition of lime powder further reduces the compressive strength. Compressive strength of fiber grout samples improves with age.

Analyzing all the test result the compositions can be ordered in a following way, considering the performance of fiber reinforced grouts. W45L35, W45L50, W45L65, W70L35, W70L50 and W70L65 is the performance order and comparing the results of these compositions further the compositions can be narrow down into 35% lime content grout compositions which had minor variations comparing to the control sample in flow, compression test and better performance in bleeding test.

The 35% lime content grout compositions can go under further testing and it can improve for further improvement in material composition can be done for the future practical applications.

6 ACKNOWLEDGEMENT

This research study is supported by faculty of engineering, SLIIT. I acknowledge all the academic and non-academic staffs of faculty of engineering, SLIIT helped to conduct this research study.

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