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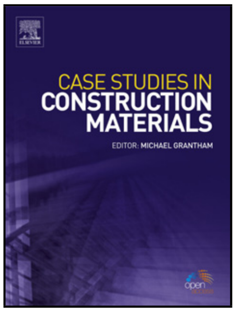

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Influence of Coconut Fibres and Lime on the Properties of Soil-Cement Mortar

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Abstract

Stabilisation of earth-based materials continues to gain attention among researchers in the field of construction. This study investigates the influence of coconut fibres and lime on the properties of soil-cement mortar. Fibres of 0.2-0.8%; the lime of 0-15%; cement of 5% by weight of soil were used and tested for density, water absorption, compressive strength, tensile strength and SEM/EDS. There were improved density, water-resistance and erosion of the specimen. The optimum strength was recorded at 0.2% fibre and 5% lime addition of the specimen. The study concludes that coconut fibres and lime positively influences soil-cement mortar properties for construction application.

Keywords: coconut fibres; compressive strength; erosion test; lime; soil-cement mortar; tensile strength.

1. Introduction

Soil-cement mortar is a composite material which is mainly composed of soil and cement, and sometimes other additives. Duan and Zhang [1] define soil-cement as a composite material made of cement, soil, and other components. Cement-lime mortar possesses good workability, good resistance against water, better bonding with units and good strength as compared with pure cement-mortar. According to Reddy and Gupta [2], replacing some quantity of cement with lime in such mortars gives cement-mortar some economic benefit. If agricultural by-products such as natural fibres are added to such mortars, then they do not only provide economic benefit, but also environmental and social benefits. The addition of cement, lime, fibres among others, is to stabilise the raw soil in order to improve its engineering properties.

Soil can be stabilised by reinforcement (thus, by the use of fibres and other waste), binders (by the use of cement, lime and other additives) and a combination of the two [3]. Reinforcement of soil has been investigated in many studies. *Hibiscus cannabinus* fibres [4], coir fibre [5,6], bagasse or sugarcane fibres [7], straw [8-11], banana fibres [12,13], corn silk fibres [14], palm fibres [15,16] jute fibres [17] and pineapple leave fibres [18] have been used to reinforced different soils to improve their properties. Stabilising soil with different binders has also been investigated extensively. Binders such as cement [19-21], lime [22,23], argillaceous minerals [24], liquid chemical [25], Bovine serum albumin [26] and cow-dung [27] have been used as stabilisers for different types of soils. Some investigations have also been conducted on the properties of soil stabilised with both reinforcement and binders. For example, the use of polypropylene fibre and cement [1, 28], staple wire and cement [29], wheat straw, rice straw, jute and polypropylene fibre and lime [30], basalt fibres and cement [31], asbestos fibre and cement [32], straw and cement [33] and oil palm empty fruit bunch fibers and cement for stabilising soil. The outcome of these studies showed improved physical, mechanical and durability properties of the composite materials made with soil matrix, cement/lime and natural fibres.

Duan and Zhang [1] investigated the effects of fly ash and polypropylene fibres on mechanical properties, failure mode, and microstructure of soil-cement. Zhang, Weng and Liu [28] studied the strength and water stability of cemented soil with fibre-reinforcement. Aydin [29] conducted a study on short wire staples which ranged from 0 to 3.5% by volume and were used to reinforce high-volume fly-ash cement paste. Wei, Chai, Zhang and Shi [30] investigated the mechanical properties of soil reinforced with both lime and four kinds of fibre. Chen [31] examined the strength and deformation characteristics of cement-soil reinforced with basalt fibres at an early age. Zhang, Yu, Ling, Yan, Liu and Chen, [32] conducted an experimental study on cement-soil which was reinforced with asbestos fibre fly ash. Ismail and Yaacob [33] also investigated the properties of mud brick reinforced with oil palm empty fruit bunch fibres and cement as a building material. In all these studies, different binders and fibres were used together to stabilise the soil. Another natural fibre which is common in sub-Sahara African, which has not been used in combination with different binders is coconut fibres. This study, therefore, investigates the influence of coconut fibres and lime on the properties of soil-cement mortar. In this work, the properties of soil used for the mortar were determined, and the tests conducted on the soil-cement mortar stabilised with coconut fibres and lime include density, water absorption, compressive strength, tensile strength and erosion resistance. The application of this study is for mortar, specifically for plastering and rendering which requires good resistance against aggressive conditions such as water resistance. This is novel as most of previous studies are for the application of blocks/bricks.

It must however be noted that, some few studies have been conducted to stabilise soil matrix with coconut fibres with only cement. Raj, Mohammad, Das and Saha [34] investigated the optimum proportion of coconut fibre and cement suitable for rammed earth wall construction, and obtained increases in ultimate strengths. Yadav and Tiwari [35] also studied the compaction and strength behaviour of the cement-stabilized soil and sodium hydroxide treated coir fibre, which also resulted in increased strength.

2. Materials and Methods

2.1 Materials

The main materials used for this experimental study are soil, coconut fibres, lime and cement. The soil sample used for the study was obtained from Kumasi, Ghana. The properties of the soil are presented in Table 1. The soil sample had the optimum moisture content (OMC) of 11.19 %, maximum dry density (MDD) of 1.46 Mg/m3 as obtained from the standard proctor test, plasticity index of 28.7 and *pH* value of 6.50. The OMC is generally the water content at which the soil can be compacted to obtain maximum dry density, while the MDD is the compaction of soil at the optimum moisture content. The coconut fibres were mechanically extracted from coconut husks following the process used in the previous study [36] and were cut to 50mm length. Fig. 1 shows the sample and the scanning electron microscopy (SEM) image of coconut fibres used for the study. Close observation of the SEM shows a rough texture of the coconut fibre, which has the advantage of creating a good bond with the soil-cement mortar. More information about the fibres can be obtained from the previous study [36]. Hydrated lime and Type I Portland cement 32.5R were used.

2.2 Specimens preparation

Cylindrical and cube specimens were prepared for testing. The mortar used for preparing the specimens were made with soil; 5% cement by weight; 0, 5, 10 and 15% lime by weight; 0.2, 0.4, 0.6 and 0.8% coconut fibres by weight; and average water of 0.7 water-cement ratios. It must be noted that the fibres were immersed in water for 24 hrs to saturation before mixing. For homogeneity, the mortar was mechanically mixed with concrete mixer. One-third quantity of water was first poured into the mixing drum while tilting. The quantity of cement was added, followed by fibres and then soil, after which the remaining quantity of water was added. The mixer was then allowed to title for five minutes after all the materials have been poured in the drum to obtain the mortar. This procedure was followed for all the mixes. The mortar was then used to fill the cylindrical steel moulds with an internal dimension of 100 mm diameter and 200 mm length, and cube steel moulds of internal dimension 100 m^3. The fresh specimens were vibrated with electric table vibrator and allowed 24 hrs to set before demoulding. The specimens were then placed under a shed for curing (covered with polythene sheet and water sprinkled on it daily) for 28 days (see Fig. 2a) before testing. 120 specimens were prepared, consisting of 60 each for cylindrical and cube specimens.

2.3 Testing of specimens

After curing, the specimens were tested for density, water absorption, compressive strength, splitting tensile strength, erosion resistance and SEM/EDS. Three replicates were used for each test from each mix.

2.3.1 Density of specimen

The dry density of the specimens was determined following the procedure described by BS EN 771-1 [37]. The specimens were dried in an oven until they obtained a constant mass. They were then weighed and their dimensions recorded for calculating the volumes. The density of each specimen was determined with the equation:

$$\rho = \frac{m}{V} \qquad \text{Eq. 1}$$

where ρ is the density (kg/m^3), m is the mass (kg), and V is the volume (m^3).

2.3.2 Water absorption

The water absorption was determined using the capillary method, which seeks to determine the rate at which water is absorbed by a material. The test procedure was guided by BS EN 772-11 [38]. The test was conducted using electronic weighing balance, container and water. The mass of each specimen was taken and recorded after oven-drying to obtained a constant mass. One side of the cube specimen was immersed to a depth of 5 mm in a constant head-water bath for 10 min. The mass of the absorbed specimen was recorded and the absorption of water by capillarity rise was calculated in the equation:

$$Cw, s = \left(\frac{Mt - Mi}{A\sqrt{t}}\right) \qquad \text{Eq. 2}$$

Where $C_{W,S}$ is coefficient of water absorption by capillary (kg/(m^2 × min), M_t is mass of the specimen after t (kg), M_i is the initial mass of specimen (kg), A is area of specimen in contact with water (m^2), and t is time (min).

2.3.3 Compressive strength

The compressive strength of the specimen was determined using Universal Testing Machine (WAW-1000H) with a maximum capacity of 1000 kN. The test procedure was guided by BS EN 772-1 [39]. Each specimen was placed in the test machine and a load applied at the rate of 0.05 N/mm^2/s until the specimen failed (Fig. 2b). The test machine generated the maximum stress at which the specimen failed, and the values were recorded. The stress-strain values generated by the test machine was also recorded.

2.3.4 Tensile splitting strength

The tensile splitting strength was conducted using the cylindrical specimens. The test was carried out using ELE Testing Machine (ADR 1500/2000) with a maximum capacity of 2000 kN. The test procedure was guided by BS BS EN 12390-6 [40]. Each specimen was placed in the testing machine and load at a rate of 0.05 N/mm was applied until the failure of the specimen (Fig. 2c). The maximum failure load was recorded and the stress calculated with the equation:

$$fct = \frac{2 \times F}{Л \times L \times d} \qquad \text{Eq. 3}$$

Where f_{ct} is the tensile splitting strength (MPa), F is the maximum load at which the specimen failed (N), L is the length of the line of contact with the specimen (mm), d is the diameter of the specimen (mm).

2.3.5 Erosion test

The erosion test was carried out using the Geelong method. The test was conducted following the New Zealand Standard NZS 4298 [41]. Glass container filled with 100 ml water, 30° angle support plate, 16 mm wick and a cylindrical probe with an end diameter of 3.15 mm were used to conduct the test. The test rig was set up (Fig. 3) with each specimen place on the 30° angle support plate with a glass container filled with 100 ml water with wick dripping the water to the specimen at 400 mm vertical height. The water dripped unto the specimen between 40 to 60 min, and any indent created was measured using the cylindrical probe in mm.

2.3.6 SEM and EDS Analysis

Scanning Electron Microscopy (SEM) analysis was conducted on the coconut fibres and the specimens. The analysis on the fibres was done to determine the texture of the fibres, and those on the specimens were done to find out the fibres interactions in the soil-cement matrix. Energy Dispersive Spectrometer (EDS) analysis also conducted on the specimen for element identification (EID). The analysis was conducted with Phenom ProX scanning electron microscope (with magnification range up to 150,000x) with high-performance SEM and EDS.

3. Results and Discussion

3.1 Density

The result of the density test of the specimen is shown in Fig. 4. The average densities recorded for all the specimens were between 1597 and 1717 kg/m^3. It can be observed that specimens with lime content from 0 to 10% and fibre content from 0.2 to 0.6% recorded marginal increase in density, with 5% lime and 0.2% fibres emerging the highest. However, the specimen with 15% lime for all the different fibre contents recorded decrease density. This implies that the addition of lime up to 10% and fibre content 0.2% provides comparably, a very good density. This result is inconsistent with previous studies results [3, 16, 42] which found that the higher the binder content in the soil the better the density, and the other studies results [16, 33, 43] which suggest that as the fibre content increase, the lower the density. The highest density which was obtained at the addition of few fibres (0.2%) and 5% lime content can be attributed to the binder (lime) acting like a gel and flowing into the pores in the soil matrix thereby reducing the air volume [42]. This, therefore, suggests that the trend of density performance of the specimens was greatly influenced by the lime in the composite. The density of a material is an important determinant of the function of the material and can sometimes be used as an indicator for strength characteristics.

3.2 Water absorption

Fig. 5 shows the influence of the coconut fibres and lime on the water absorption by capillary of the soil-cement mortar. It can be observed that the 0% fibre content specimens recorded the lowest water absorption coefficient. As the lime content increased without fibres, the absorption coefficient decreased. This trend is in line with earlier studies [25, 44] with binders which also obtained decrease water absorption with increased binder content. However, all the specimens with fibres recorded high absorption coefficient as the fibre content increased. This trend is also in line with earlier studies [7, 16] result in fibre addition. Conversely, there was decreased water absorption with increase lime content in the specimens with fibre addition. This suggests that the influence of the stabilisers on the water absorption coefficient can largely be associated with the addition of the lime in the specimens. It, therefore, means that soil-cement mortar stabilised with lime and coconut fibres have better resistance against water absorption. This is particularly important as earth-based construction materials have deficiencies when they come in contact with water. Studies have earlier recommended the introduction of stabilisers to improve the water-resistance properties of earth-based construction materials [3, 25].

3.3 Compressive strength

The influence of the coconut fibres and lime on the compressive strength of the soil-cement mortar is presented in Fig. 6. The result shows that all the lime addition specimens gained better strength than the 0% lime content. 0 to 5% lime addition specimens had an increase in strength and then declined with the further addition of 10 and 15%. For fibres addition of 0.2, 0.4, 0.6 and 0.8%, the compressive strength of the soil-cement mortar with 5% lime increased by 22.22, 1.93, 1.45 and 14.49% respectively, as compared with that of the soil-cement without fibres. Conversely, at the addition of 15% lime, the compressive strength decreased by 7.11, 22.84, 22.84 and 15.74% respectively, for 0.2, 0.4, 0.6 and 0.8% fibre addition as compared with that of the soil-cement without fibres. This trend is similar to all the fibre addition, which provided an optimum strength at 5% lime addition. It can further be observed that the 0.2% fibre contents obtained the highest strength. This, therefore, implies that the general optimum strength is at 0.2% fibre and 5% lime contents which recorded 2.53 MPa strength. The trend of the result is in line with the results of earlier studies which used fibres [7,43] as reinforcement in soil, but inconsistent with studies that used binders in soil [2, 20, 21]. The earlier studies with fibres only [7,45] had optimum strength, while those with binders only [2, 20, 21] recorded continuous increase strength as the binder content increased. This suggests that the trend of the result is largely influenced by the fibre content in the specimens.

Fibres addition to the soil-cement composite has shown to be influential to some level and beyond that, there is a decline in strength. The increase in strength has been attributed to the increased friction between the soil particles and the fibres, and again prevention of spreading of cracks due to the association of soil and fibres which bridge across cracks [46]. After the optimum strength, the fibres begin to overlap each other which result in poor cohesion with the soil matrix resulting in decline strength of the composite [16]. The lime also plays an important role in the strength development of the composite. Substances such as calcium oxide, alumina and silica in the lime (as shown in table 2) with hydration reaction of the cement form a gel that interlaced with the soil particles thereby sealing the pores which result in improved strength [1].

Fig. 7 shows the stress-strain curve of the specimens in continuous compression. It can be observed that the stress-strain relationship of the specimen is in the form of parabolic curves. This result is consistent with the results in previous studies conducted with soil blocks stabilised with different binders [46, 47]. The highest stress was achieved on the average at 0.2% fibre content followed by 0.4%, with the least recorded at the 0% fibre content. It can further be observed that the strain recorded was high, which implies that the specimens are ductile [47]. This can be attributed to the addition of the fibres because the fibres held the broken pieces of the specimen together in the rapture field as was observed during the compressive test. Similar trends were also observed in previous studies [16, 48].

3.4 Tensile splitting strength

The result of the coconut fibres and lime influence on the tensile splitting strength of the soil-cement mortar is shown in Fig. 8. All the fibre reinforced specimen obtained increased strength from 0 to 5% lime addition and then decreased with further increase with the fibre. The highest tensile strength was obtained with 0.2% fibre content, with the 0.8% recording the least strength. The 0% fibre content achieved a better result than the 0.6 and 0.8% fibre specimens. This trend of the result is consistent with the results obtained in earlier studies with other natural fibres in soil matrix [4, 16, 48]. Further observation indicates that the 5% lime addition obtained an optimum result, and further addition of lime resulted in declined strength. It, therefore, means that the optimum strength was achieved at 0.2% fibre and 5% lime content. This result is similar to the results of the compressive strength, and therefore, the reasons attributed to the compressive strength increase and decrease can also be attributed to the tensile strength. Other reasons responsible for the increased strength are that: (1) the tensile strength of the fibres is greater than that of the soil-cement, and therefore, their addition in the specimen improve the interaction between the soil matrix and the fibres for greater resistance against splitting; (2) there is delay in crack propagation in the specimen due to the bridging of the soil matrix by the fibres [1]. It was also observed during the test that the failure of the specimens was more gradual with the increased fibres content and therefore acting more like a ductile as was also found in earlier studies [43, 48].

Fig. 9 shows the relationship between the compressive strength and the tensile strength of the soil-cement mortar stabilised with coconut fibres and lime. The result shows a positive linear relationship between the compressive and the tensile strengths of all the specimen groups. The coefficient determinant (R^2) obtained are 0.9755, 0.636, 0.6839, 0.5765 and 0.6942 respectively, for 0.0, 0.2, 0.4, 0.6 and 0.8% fibre addition. This implies that as the compressive strength increase, the tensile strength also increased. Earlier studies [25, 49] obtained similar results.

3.5 Erosion resistance

This test is important to determine how the mortar can resist water (rain fall) when applied externally on wall surface. Fig. 10 shows the influence of the coconut fibres and lime on the erosion of the soil-cement mortar. It can be seen that no pit or indent was created by the water dripping unto the surface of the specimens after the test, implying zero (0) mm pitting (erosion). All the specimen tested recorded no erosion. This means the soil-cement mortar stabilised with coconut fibres and lime have resistance against erosion. The result is inconsistent with results obtained by previous studies that stabilised soil matrix with fibres only [16, 26, 50]. These previous studies revealed that the addition of fibres only in the soil has little influence on the erosion resistance of the materials. However, the current study result indicates that the addition of binders (cement and lime) to the soil improved the resistance of the soil against erosion. This is positive as the soil-cement mortar application on external surfaces will be prone to aggressive weather condition such as rainfall.

3.6 SEM and EDS Analysis

The SEM result on the fibre and the specimens are shown in Fig. 11. It can be seen from the fibre image (fibre texture) that the coconut fibre has its surface been rough. This means the texture of the fibre is rough and therefore, has the ability to bond with the soil-cement matrix. A similar result was found in an earlier study [45]. The image of the 0.2% fibre content specimen shows that each fibre is covered with the soil-cement matrix. This ensures that the fibres and the soil-cement matrix interrelate with proportional friction created to generate improve properties of the composite materials. This influenced the improved strength properties of the specimens with 0.2% fibres. The image with 0.8% fibre specimen shows that some of the fibres are crossing and overlapping each other, which prevent the soil-cement interlacing properly with the fibres. This causes some degree of weakness in the specimen, as fibre interfacial contact with soil-cement is reduced. This is responsible for the decreased strength of specimen with high fibre content. The EDS result of the coconut fibres and lime stabilised soil-cement is shown in Table 2. It can be seen that there are high contents of silica (25.82%), aluminium (21.66%) and calcium (20.26%) oxides in the specimen. This is as the result of the lime added to the soil-cement matrix which causes hydration reaction in the composite, thereby sealing some of the pores leading to strength improvement, better resistance to water absorption and erosion, and relatively good density.

4. Summary and Conclusion

This study investigated the influence of coconut fibres and hydrated lime on the properties of soil-cement mortar. Based on the outcome of the investigation, the following summary can be drawn:

1. The addition of 0.2% coconut fibre and 5% lime contents in the soil-cement mortar gained the highest density. This implies that coconut fibres and lime in soil-cement fairly influence the density of the composite material.
2. The soil-cement mortar with the addition of lime, irrespective of the fibre content, recorded decreased water absorption rate. This suggests that lime inclusion in the soil-cement composite influenced the water absorption rate by providing better resistance to water uptake of the material.

3. Both the compressive strength and the tensile strength of the soil-cement mortar achieved optimum strength at 0.2% coconut fibre and 5% lime content. Implying that, the 0.2% coconut fibre and 5% lime provide better strength properties of the mortar.
4. The erosion test result showed that there were zero indents created in all the specimens. This means that the soil-cement mortar stabilised with coconut fibres and lime have good resistance against erosion, and therefore will be suitable for external application on the wall.
5. SEM analysis of the specimens indicated that the surface of the coconut fibres was rough. The 0.2% fibre content specimen had each fibre covered with a soil-cement matrix which resulted in increased friction of the fibres and the matrix, ensuring increased strength. Higher fibre content, however, led to a reduction in strength due to fibres overlapping each other, thereby reducing the fibre-matrix interactions. The EDS analysis also identified high percentages of silica, aluminium and calcium oxides which behave like a gel by sealing pores in the specimen, contributing to improved properties of the specimen.

The study, therefore, concludes that the addition of coconut fibres and hydrated lime positively influenced the soil-cement mortar properties as a durable construction material. It is, therefore, recommended that 0.2% coconut fibre and 5% lime should be used by practitioners to stabilised soil-cement mortar for construction application.

Conflicts of interest

There is no competing or conflicts or of interest

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Photograph of sample fibres

SEM image of a single fibre

Fig. 1: Coconut fibres

Fig. 2: Experimental procedure (a) curing of specimens (b) Compressive strength testing (c) Tensile strength testing

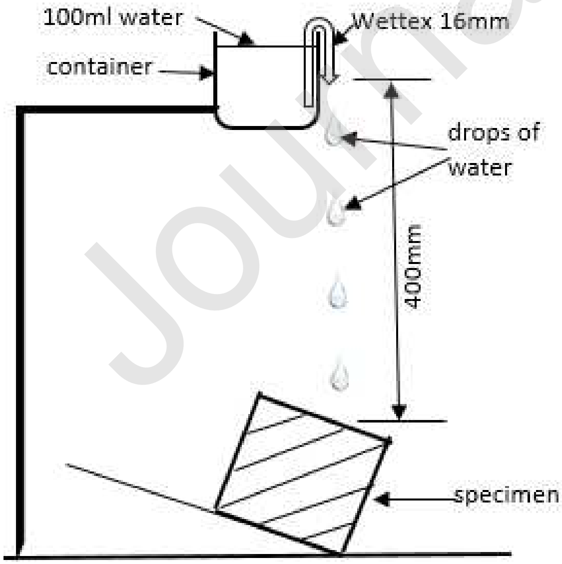


Fig. 3: Geelong erosion test set-up

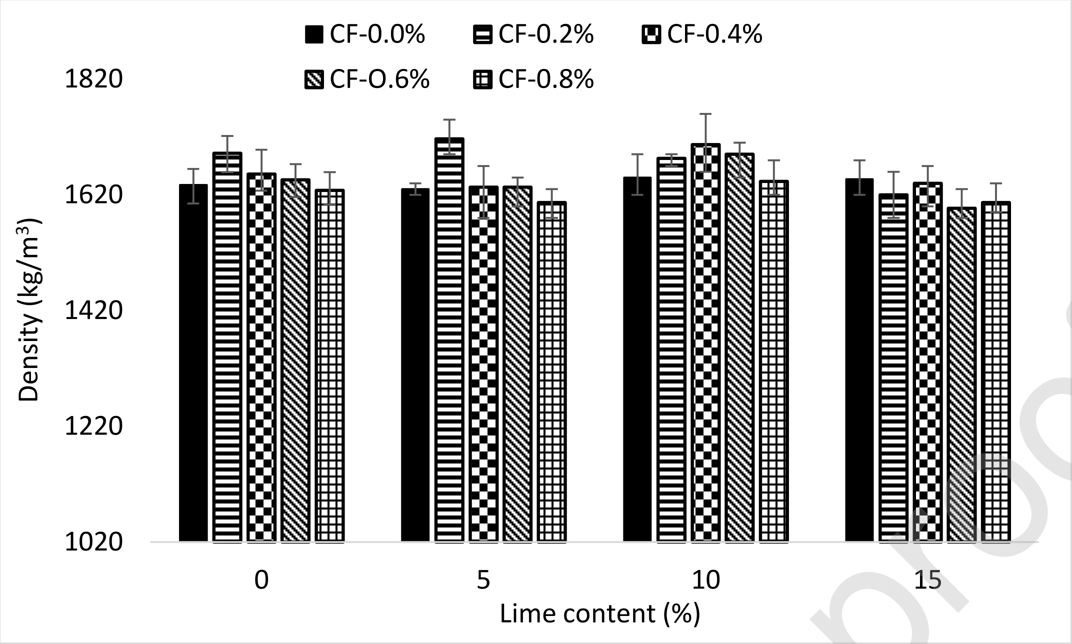


Fig. 4: Density of specimens

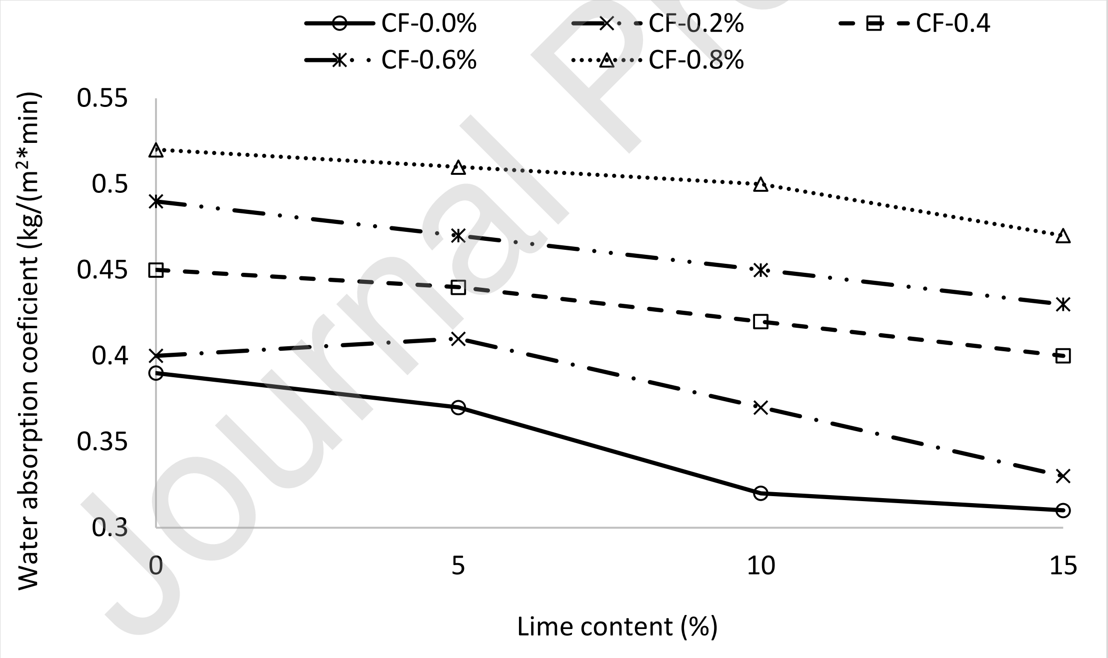


Fig. 5: Water absorption coefficient of specimens

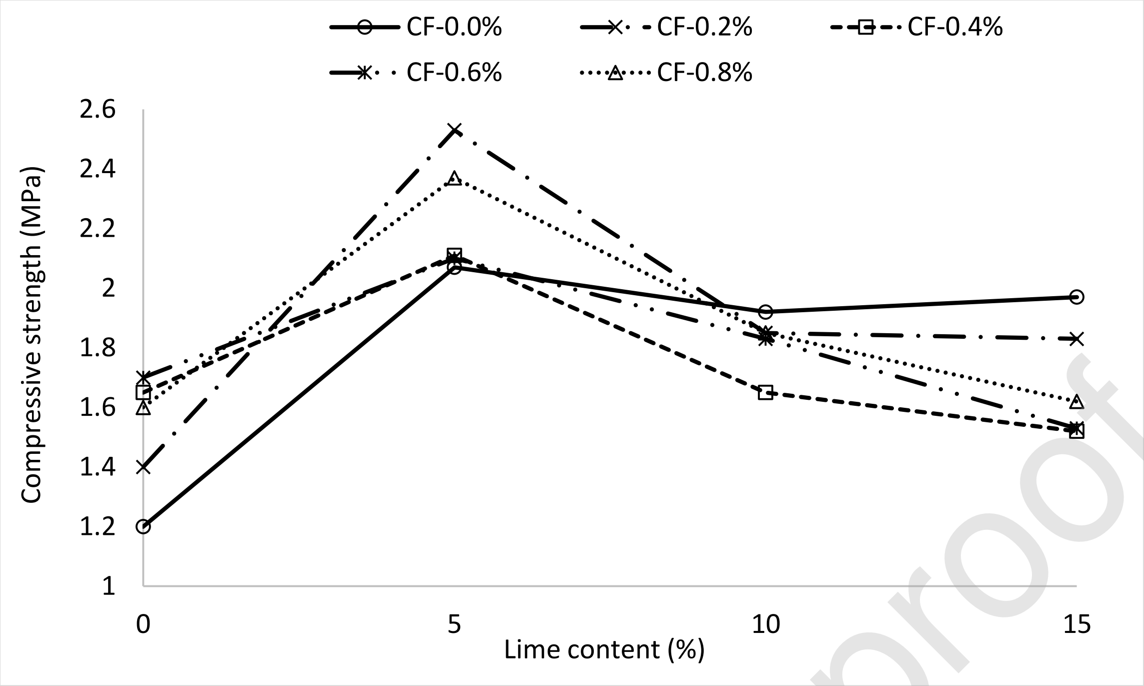


Fig. 6: Compressive strength of specimens

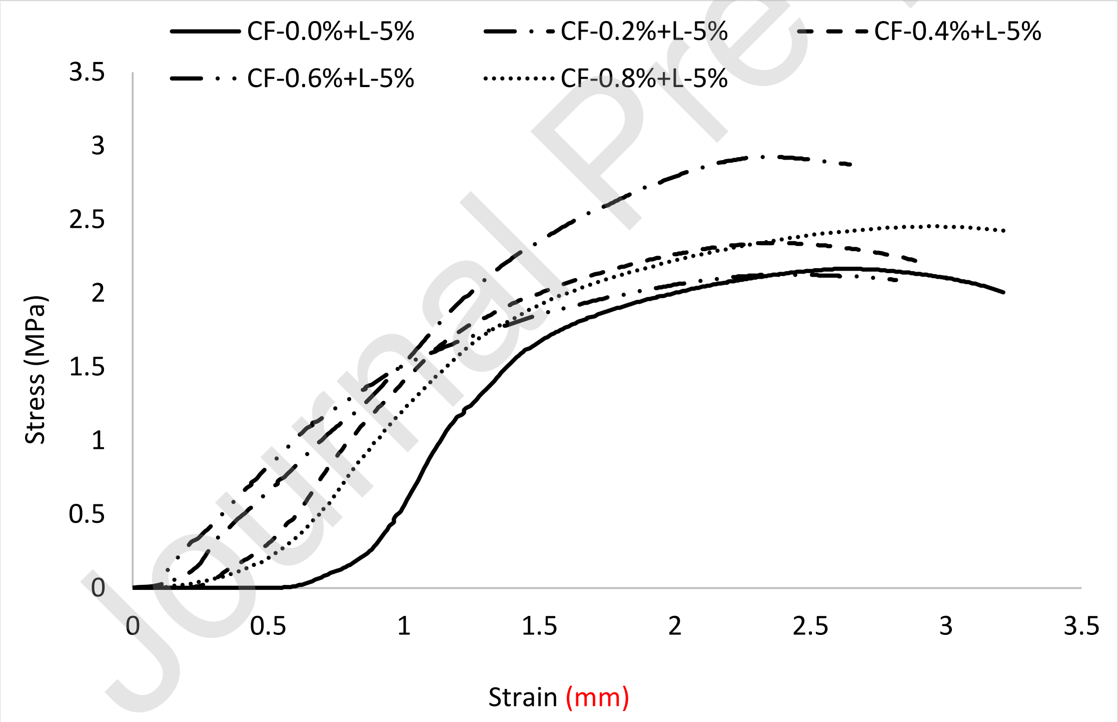


Fig. 7: Stress-strain relationship of the specimens

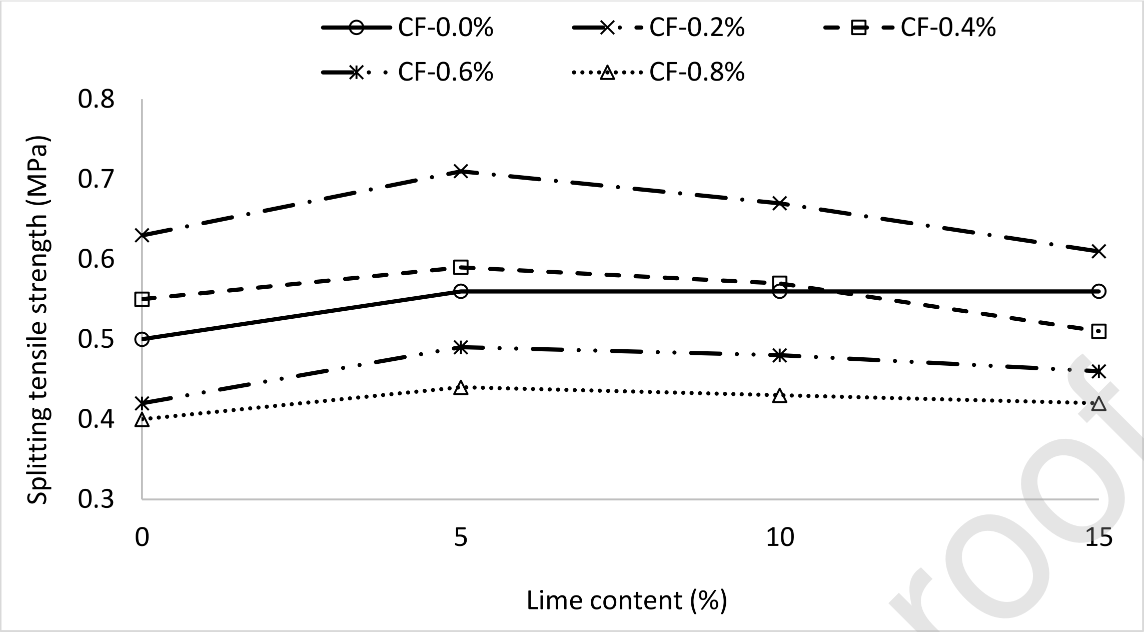


Fig. 8: Tensile strength of the specimens

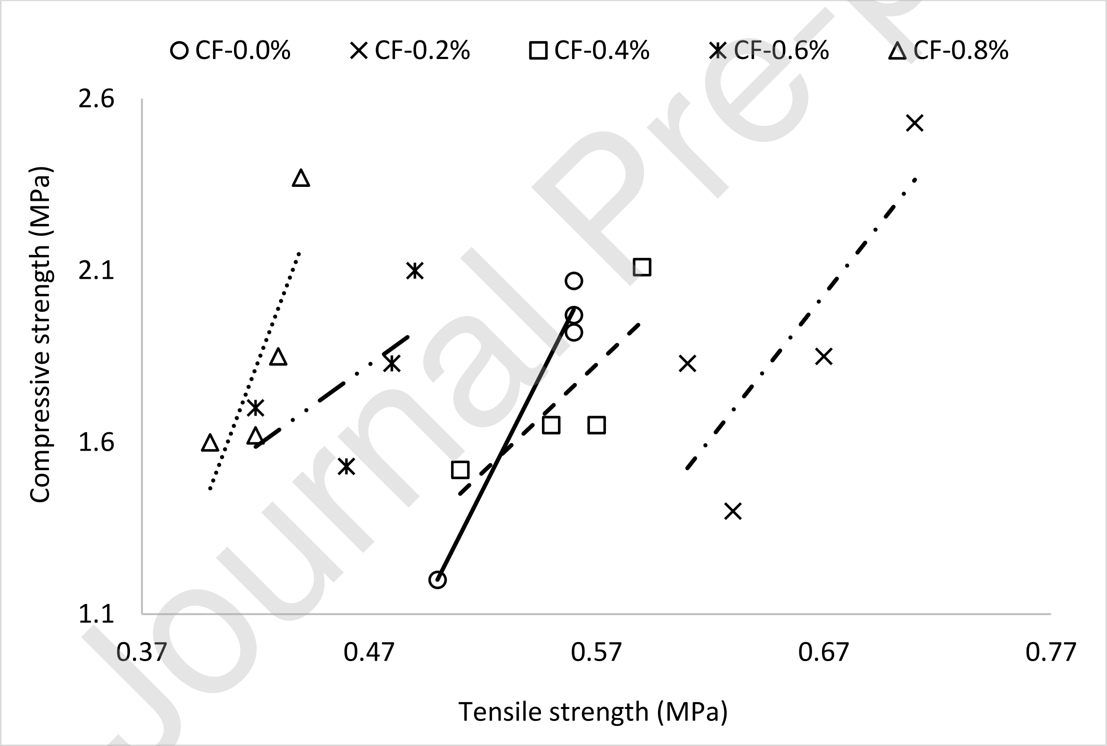
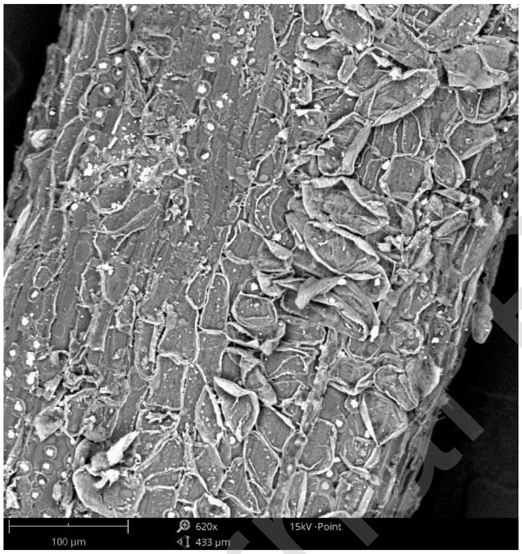


Fig. 9: Relationship between tensile and compressive strengths

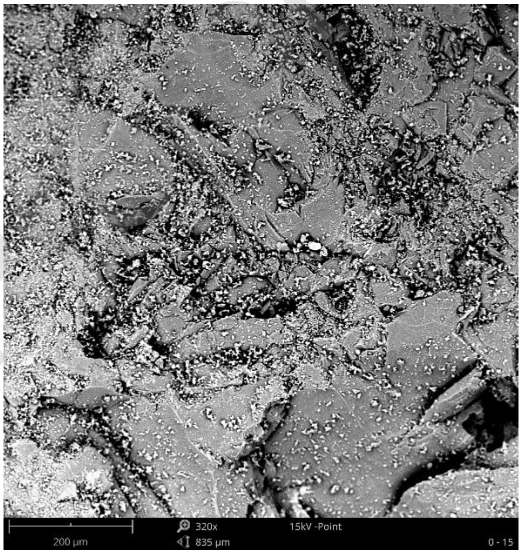
0.4% fibre + 5% lime specimen

0% fibre + 10% lime specimen

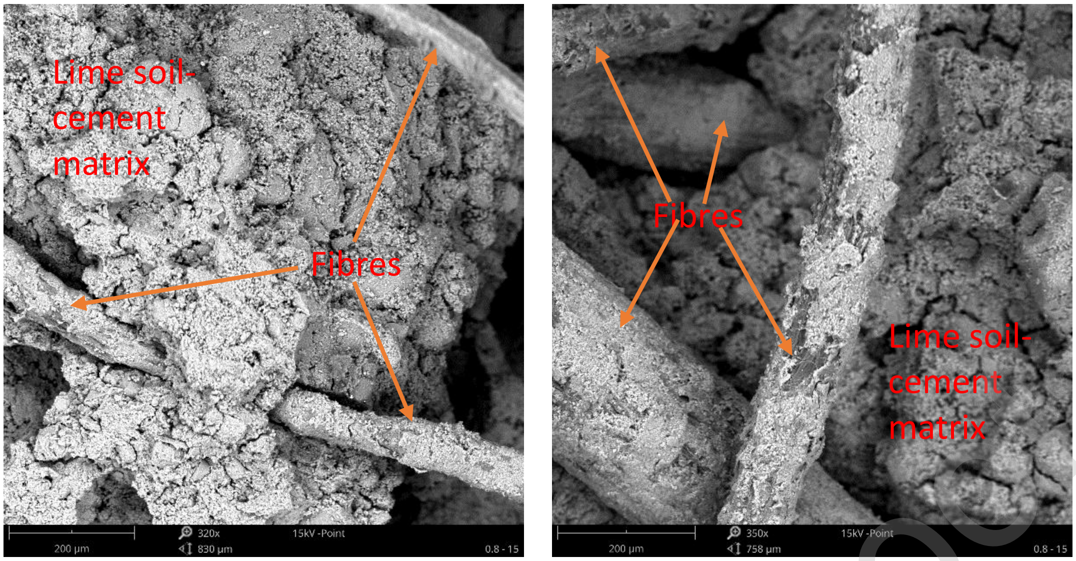
Fig. 10: Erosion test result (a) (b)



Fibre texture



A specimen without (0%) fibre



0.2% fibres specimen

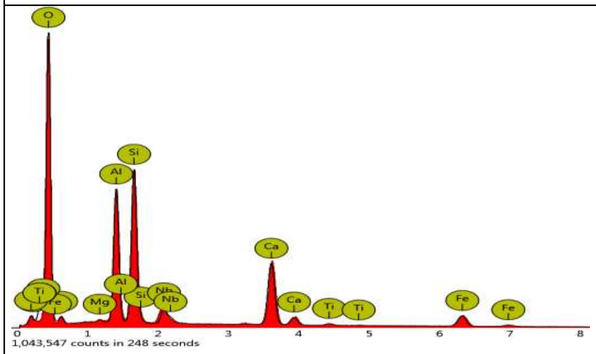
0.8% fibres specimen

Fig. 11: SEM images of fibre, different fibre content and 5% lime specimens

Table 1: Properties of soil

Properties	Values
Standard Proctor test	
Optimum moisture content (%)	11.19
Maximum dry density (Mg/m^3)	1.46
Atterberg limits	
Liquid limit W_L (%)	57.2
Plastic limit W_P (%)	28.5
Plasticity index I_P	28.7
pH	
Value	6.5
Particle size distribution	
Gravel (>2 mm) (%)	5
Sand (2 - 0.063 mm) (%)	47
Silt (0.063 - 0.002 mm) (%)	4
Clay (<0.002 mm) (%)	44

Table 2: EDS Result (0.2% fibre + 5% lime specimen)

Element content	Oxide	Concentration (%)
	Si	25.82
	Al	21.66
	Ca	20.26
	Fe	12.33
	C	9.49
	Nb	9.08
	Ti	0.88
	Mg	0.49