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Shear Strength and Elastic Modulus Behavior of Coconut Fiber-Reinforced Expansive Soil

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Abstract. Shear strength behavior of expansive soil reinforced by randomly placed fiber depends on the added materials' content. This research investigated the effect of the waste coconut fibers content on the stress-strain relationship, the shear strength parameters, and the mixture's elastic modulus. In this study, the coconut fiber content was varied from 0.25% to 1% with 0% fiber as control. The clay samples were tested after mixing by unconsolidated-undrained triaxial test. In general, according to the test result, the inclusion of randomly placed waste coconut fiber has enhanced the peak deviatoric stress, the shear strength parameters, and the elastic modulus. At 0.6% fiber content, the shear strength and the samples' elastic modulus have increased to 79.46% and 153%, respectively, compared with those not reinforced with coconut fiber.

1. Introduction

Many soil improvement methods have been developed to enhance soil's mechanical properties to meet construction's technical requirements. One method that can be carried out is to mix reinforcing material into the soil to enhance bearing capacity, to reduce compressibility, and to reduce lateral deformation [1]. Reinforcing materials that can be used are short fibers mixed into the soil until they become homogeneous. The soil and the fibers will interact with each other through adhesion, thereby increasing the soil's shear and tensile strengths, and the soil becomes more ductile [2]. An alternative that can be used in soil reinforcement is by using coconut coir fiber waste. This natural material has several advantages: light in weight, strong, resistant to microbial decomposition, resistant to salinity, biodegradable, and economical [3-4]. This material is native to the tropics; therefore, it can be found in many Asian countries [5]. Food and Agriculture Organization (FAO) has published that Indonesia is a country that produces the most coconuts in the world. Its product reached 18,555,371 tons in 2018 [6]. An increase in coconut production every year has increased coconut coir waste. So far, the coconut coir waste is commonly used for fuel, household utensils, craft materials, simple water filters, environmentally friendly briquettes, or planting media [7]. This waste has not been widely used in civil engineering projects.

Coconut coir has a tensile strength of 15 to 327 MPa, an elongation of 10 to 75% [8], and has various sizes. Their diameter is from 0.1 to 0.6 mm, and its length is from 50 to 350 mm [1]. It consists of 40% lignin, 54% cellulose, and 6% other water-soluble substances [9]. Due to the high lignin content, coconut coir degradation can occur up to 10 years, taking longer than other natural fibers [1]. Cellulose provides higher mechanical strength (tensile and flexural) and rigidity than other fibers [10]. Coir fibers maintain their tensile strength in wet conditions, have a higher coefficient of friction and are more elastic than synthetic fibers [11-14].



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Many studies have investigated the effect of randomly mixed fibers into the soil, but not many have investigated the shear strength and elastic modulus of expansive soil mixed with fibers using the triaxial test. Kar et al. [14] and Das et al. [16] investigated sandy soils' shear strength using the direct shear test. Several tests of the mechanical properties of expansive soil reinforced with coconut fibers have been carried out. Peter performed the CBR and triaxial test [17], Narendra et al. observed the UCS of expansive soil [18], Himanshu et al. conducted triaxial tests on clay soils [19], while Lal et al. carried out a triaxial test on sandy soil [20-21]. Ayininuola and Oladotun performed a triaxial test on sandy soil (SP-SC and SC) [22], while Gupta et al. performed an unconsolidated triaxial test on clay muds [12]. These studies obtained different results and provided recommendations. The recommended coconut fiber content is 0.25% to 1.2%. The test results revealed that the stabilization with coconut coir waste significantly affected the shear strength characteristics. In this study, a series of tests were conducted to determine the effect of coconut fiber on shear strength and elastic modulus of expansive soil.

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2. Materials and Method

2.1. Soil

The soil used must pass a 4.75 mm sieve. Testing soil samples' engineering properties has been carried out in previous research conducted by Widiarti et al. [23]. The results of these studies are presented in table 1.

Table 1. The physical and mechanical properties of the soil samples [23].

Parameters	Values	Method Standard
Specific Gravity, G _s	2.63	ASTM D854-10
Particle sizes distribution:		
Sand (%)	13.36	ASTM D422-63
Silt (%)	70.58	ASTM D6913-04
Clay (%)	16.06	
Consistency limits:		
Liquid Limit, LL (%)	89.91	
Plastic Limit, PL (%)	38.86	ASTM D4318-10
Shrinkage Limit, PL (%)	16.33	
Plasticity Index, PI (%)	51.05	
Proctor standard compaction:		
Maximum Dry Density, MDD (kN/m ³)	12.64	ASTM D698-12
Optimum Moisture Content, OMC (%)	29.90	
Soil Classification (USCS)	CH (inorganic clays of high plasticity, fat clays)	ASTM D2487-11
Soil Classification (AASHTO)	A-7-6 (clayey soils)	ASTM D3282-09
Activity	3.18 (> 1.25, active clays/montmorillonite)	

2.2. Coconut coir fibers

Coconut coir fibers were mostly obtained from waste in the traditional market. The tensile strength of coconut fibers is displayed in table 2. The fibers were cut into small pieces, from 30 to 50 mm in length, and then were randomly mixed into the soil until it was homogeneous.

Table 2. Tensile strength of coconut fibers.

Sample number	Length (mm)	Average diameter (mm)	Tensile strength (MPa)
1	100	0.28	92.20
2	100	0.28	72.50
3	100	0.21	110.36
4	100	0.23	143.39
5	100	0.32	107.41
6	100	0.21	121.86
Average			107.95

2.3. Mix design

The number of samples used for each variation was three pieces with a cell pressure of 98.1 kPa, 196.2 kPa, and 294.3 kPa, respectively. The coconut fiber content variations used were 0.25%, 0.5%, 0.60%, 0.75%, and 1.0% of the mixture's total weight. Mixing is carried out at conditions of maximum dry density and optimum moisture content. The mixture of soil and coconut fibers is depicted in figure 1.



Figure 1. The mixture of soil and coconut fiber.

2.4. Testing procedures

The main test carried out in this study was triaxial in unconsolidated-undrained conditions concerning ASTM D2850-03 [24]. A cylinder mold with a diameter of 36 mm and a height of 72 mm was used to make the triaxial sample. Loading was given until the sample failed. Triaxial testing and specimen samples after testing can be seen in figure 2.

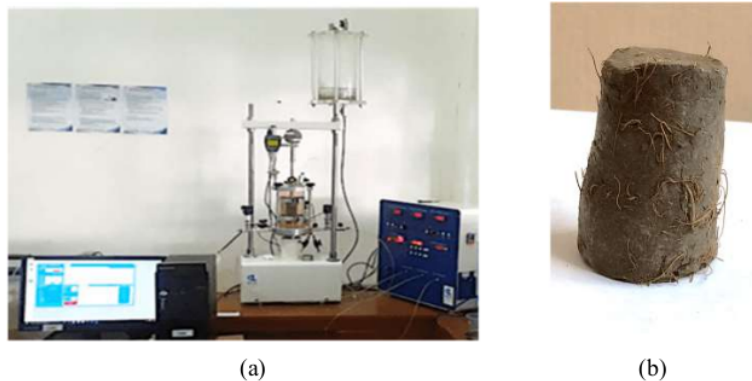


Figure 2. (a) Unconsolidated-undrained triaxial test (b) Specimen after testing.

3. Results and Discussion

3.1. The relationship between deviatoric stress and axial strain

In the unconsolidated-undrained triaxial test, the specimen was first loaded with a certain value of cell pressure, i.e., 98.1 kPa, 196.2 kPa, and 294.3 kPa. The specimen was then added with the deviatoric stress, which increased the value until it caused the specimen to fail. Figure 3 demonstrates the relationship between deviatoric stress and axial strain of the coconut fiber-reinforced expansive soil for various cell pressures. From these figures, it appears that the deviatoric stress at failure increases with the increase in applied cell pressure. The reinforced soil has a higher peak of deviatoric stress than the peak of deviatoric stress of unreinforced soil.

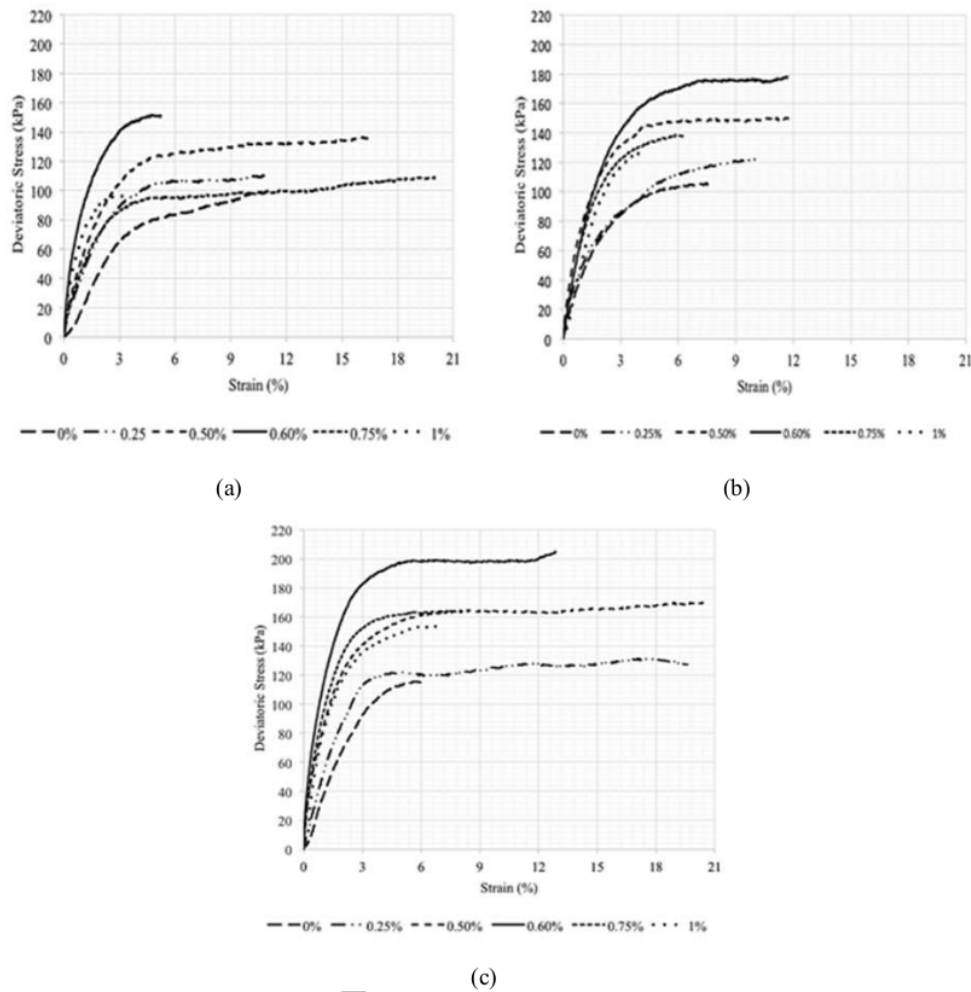


Figure 3. Relationship between deviatoric stress and axial strain of the mixture for various cell pressures: (a) 98.1 kPa; (b) 196.2 kPa; (c) 294.3 kPa

3.2. The effect of coconut fiber on peak deviatoric stress

The peak deviatoric stress values from the soil reinforced with various coconut fiber content are presented in figure 4.

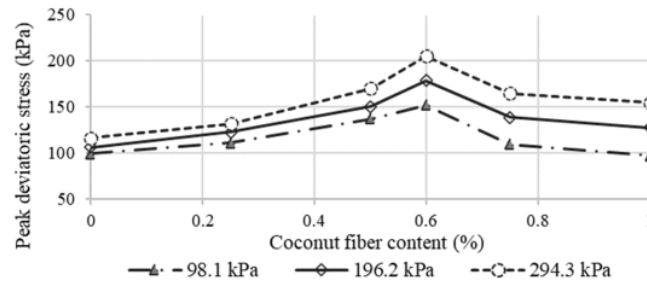


Figure 4. Peak deviatoric stress with various coconut fiber content.

Figure 4 shows that peak deviatoric stress increases with increasing fiber content. The maximum increase occurred in a mixture of coconut coir fibers by 0.6%, namely 52.97% at 98.1 kPa, 68.51% at 196.2 kPa, and 76.93% at 294.3 kPa. Then, there was a decrease in the peak deviatoric stress value in a mixture of 0.75% and 1% coconut fiber. It indicates that the fiber will strengthen the bonds in the soil matrix and contributes to the shear resistance through friction and cohesion between the soil and the fiber. Therefore, to cause a failure in the soil, a greater load is required. However, excessive amounts of fiber cause the soil's strength to decrease because the coconut fibers interact more with other coconut fibers than with soil.

3.3. The effect of coconut fiber on friction angle (ϕ) and cohesion (c)

The friction angle (ϕ) and cohesion (c) values for various fiber are depicted in figures 5 and 6.

Figure 5 shows that expansive soils have a friction angle of 2.35° . The friction angle increases as the fiber content increases. According to Muntohar [18], [2] and Sujatha et al. [25], the tensile strength possessed by the fibers will help the soil withstand the tensile stress that occurs. The fibers in the soil will increase the contact and friction between the fiber surface and the soil so that it helps the soil to withstand shear forces due to loads.

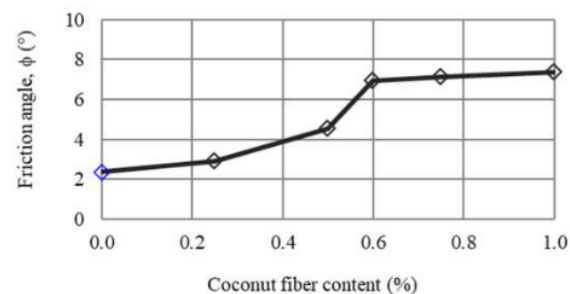


Figure 5. Friction angle with various coconut fiber content.

Figure 6 presents that expansive soils have a cohesion of 43.26 kPa. The addition of coconut fiber increases the cohesion. The cohesion achieves a maximum increase of 28% at the fiber content of 0.6%. The addition of coconut fibers exceeding 0.6% decreases the cohesion value. The cohesion is

obtained by the attractive force between the bonds of the soil grains. The increase in cohesion value occurs because coconut fibers increase bonds between soil grains. The addition of fiber over the optimal amount can reduce soil strength effectiveness because fiber is a non-cohesive material to reduce lubrication. The fibers will interact with each other, not with the soil. Besides, the addition of coconut fibers causes the percentage of soil grains to decrease and, therefore reducing the soil's strength [2, 10, 26-27].

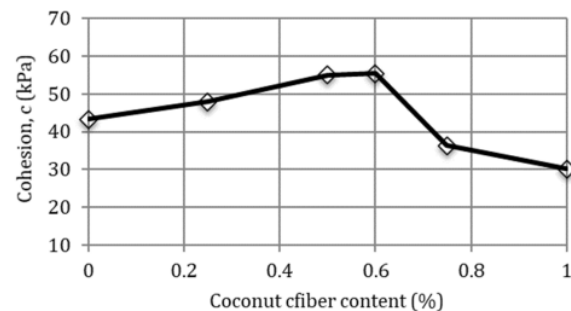


Figure 6. Cohesion with various coconut fiber content.

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3.4. The effect of coconut fiber on shear strength

The shear strength of different fiber content is depicted in figure 7. The value of shear strength is determined by the value of cohesion, normal stress at failure, and friction angle. The maximum enhances in shear strength occurred in the coconut fiber mixture by 0.6%, with an increase of 79.46% in the cell pressure of 294.3 kPa. The shear strength will be reduced if more than 0.6% of coconut fiber is added. This decrease is due to a decrease in the cohesion value. A significant decrease in cohesion will decrease the soil shear strength value even with an increase in friction angle.

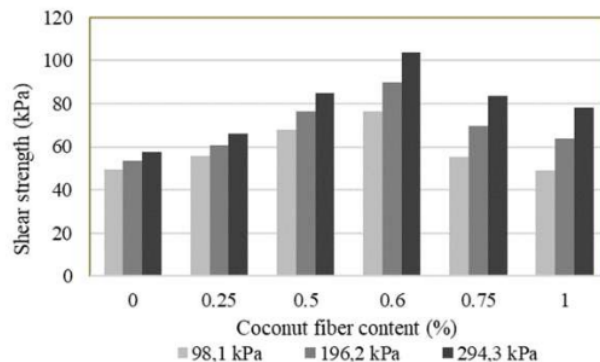


Figure 7. Shear strength with various coconut fiber content.

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3.5. The effect of coconut fiber on the elastic modulus

The elastic modulus can determine soil stiffness elasticity from the relationship between axial strain and deviator stress [25]. The elastic modulus can be determined from the deviatoric stress-axial strain curve using the secant modulus method, where the deviatoric stress is divided by the strain. In this study, the elastic modulus is shown in figure 8.

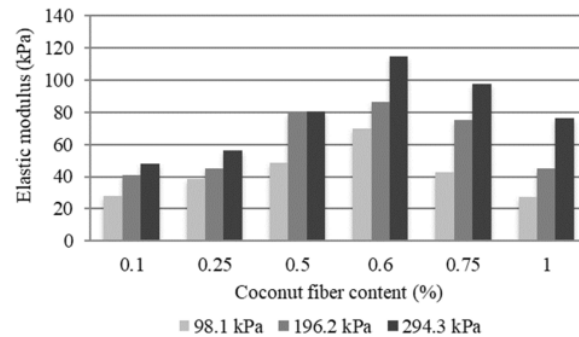


Figure 8. Elastic modulus with various coconut fiber content.

If more fibers are added, the elastic modulus value will be higher, meaning that the soil is getting more rigid. The results reveal that the soil's elastic modulus increases from 27.70 kPa to 70.09 kPa in the coconut fiber mixture of 0.6% at a cell pressure of 98.1 kPa. It has increased by 153% than those without added fiber. However, if the fiber content is more than 0.6%, the elastic modulus will decrease. One of the factors influencing the elastic modulus value is the bond between the soil grains. Hence, too many fibers will reduce the bonds between the grains.

4. Conclusions

- The addition of coconut fiber increased the value of peak deviatoric stress. The highest value was obtained in a mixture with a coconut fiber content of 0.6%, increasing by 52.97% at the cell pressure of 98.1 kPa, 68.51% at the cell pressure of 196.2 kPa, and 76.93% at the cell pressure of 294.3 kPa.
- The highest increase in cohesion (c) was discovered in expansive soils with a fiber percentage of 0.6%.
- The friction angle (ϕ) increased with the addition of the coconut fiber mixture. The highest increase in friction angle was found in expansive soil with a fiber percentage of 1.0%.
- Soil with a coconut fiber percentage of 0.6% produced the highest increase in shear strength and elastic modulus.

5. References

- Hejazi S M, Sheikhzadeh M, Abtahi S M and Zadhoush A 2012 A simple review of soil reinforcement by using natural and synthetic fibers, *Constr. Build. Mater.* **30** 100–116
- Muntohar A S, Widianti A, Hartono E and Diana W 2013 Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber, *J. on Mater. in Civ. Eng.* **25**(9) 1260-1270
- Ahmad Lone I and Bawa A 2018 Utilization of fly-ash and coir fibre in soil reinforcement, *Int. J. Civ. Eng. Technol.* **9**(8) 341–346, 2018
- Sivakumar Babu G L, Vasudevan A K, Vinod P and Ajitha B 2009 Discussion: Evaluation of strength and stiffness response of coir-fibre-reinforced soil, *Proc. Inst. Civ. Eng. Gr. Improv.* **162**(4) 205–207
- Vinod P, Bhaskar A B, Pillai G S and Sereemy S 2009 Use of Sand–Coir Fiber Composite Columns in Stabilization of Soft Clay Deposits, *J. Nat. Fibers* **6**(6) 278–293
- Food and Agriculture Organization of United Nation 2019 Top 20 Countries, Net Production Value of Coconuts 2018 Retrieved on July 1, 2020 from http://www.fao.org/faostat/en/#rankings/countries_by_commodity

- [7] Trikarlina E, Sigalingging R and Munir A P 2018 Penambahan Sikacim Concrete Additive Pada Pembuatan Batako, *J. Rekayasa Pangan dan Pert.* **6**(1) 38–43
- [8] Ali M 2010 Coconut fibre - A versatile material and its applications in engineering,” *2nd Int. Conf. Sustain. Constr. Mater. Technol* **2**(9) 1441–1454
- [9] Khatri V N, Dutta R K, Venkataraman G and Shrivastava R 2016 Shear strength behaviour of clay reinforced with treated coir fibres, *Period. Polytech. Civ. Eng.* **60**(2) 135-143
- [10] Gowthaman S, Nakashima K and Kawasaki S 2018 A state-of-the-art review on soil reinforcement technology using natural plant fiber materials: Past findings, present trends and future directions, *Materials (Basel)*. **11**(4) 553
- [11] Upadhyay P and Singh Y 2017 Soil Stabilization Using Naural Fiber Coir, *Int. Res. J. Eng. Technol.* **04**(12) 1808-1812
- [12] Gupta H K, Maurya M C and Gupta A K 2017 Shear Strength Enhancement of Soil by Using Coconut Fiber, *Imperial J. of Interdisciplinary Research* **3**(6) 366–372
- [13] Maurya S, Sharma D A K, Jain D P K and Kumar D R 2015 Review on Stabilization of Soil Using Coir Fiber, *Int. J. Eng. Res.* **4**(6) 296–209, 2015
- [14] De Menezes L C P, De Sousa D B, Sukar S F and De M Ferreira S R 2019 Analysis of the Physical-Mechanical Behavior of Clayey Sand Soil Improved with Coir Fiber *Soils and Rocks* **42**(1) 31–42
- [15] Kar R K, Pradhan P K and Naik A 2014 Effect of randomly distributed coir fibers on strength characteristics of cohesive soil, *Electron. J. Geotech. Eng.* **19** G 1567–1583
- [16] Das D, Kaundinya D, Sarkar R and Deb B 2016 Shear Strength Improvement Of Sandy Soil Using Coconut Fibre, *Int. J. Civ. Eng. Technol.* **7** 297–305
- [17] Peter L, Jayasree P K, Balan K and Raj S A 2016 Laboratory Investigation in the Improvement of Subgrade Characteristics of Expansive Soil Stabilised with Coir Waste, *Transp. Res. Procedia* **17**(December) 558–566
- [18] Narendra Goud G, Hyma A, Shiva Chandra V and Sandhya Rani R 2018 Expansive soil stabilization with coir waste and lime for flexible pavement subgrade, *IOP Conf. Ser. Mater. Sci. Eng.* **330** 012130
- [19] Ayininuola G M and Oladotun P O 2016 Geotechnical properties of coconut coir fiber soil mixture, *Civ. Eng. Res.* **6**(4) 79–85
- [20] Himanshu B, Jauhari N and Varshney H 2017 Performance and Analysis of Coir Fibre as Soil Reinforcement *Int. J. Res. Appl. Sci. Eng. Technol.* **V**(XI) 62–72
- [21] Lal D, Sankar N and Chandrakaran S 2019 Triaxial test on saturated sands reinforced with coir products,” *International Journal of Geotechnical Engineering* **13**(3) 270–276
- [22] Lal D, Sankar N and Chandrakaran S 2017 Effect of reinforcement form on the behaviour of coir geotextile reinforced sand beds, *Soils Found.* **57**(2) 227–236
- [23] Widiyanti A, Diana W and Hasana M 2020 Direct Shear Strength of Clay Reinforced with Coir Fiber, *UKaRsT* **4**(2) 151–162
- [24] ASTM D2850-03 2003 *Standard Test Methods for Unconsolidated Undrained Triaxial Compression Test on Cohesive Soils* (Pennsylvania: ASTM International, USA)
- [25] Sujatha E R, Sai S, Prabalini C and Aysha Z F 2017 Influence of random inclusion of coconut fibres on the short term strength of highly compressible clay, *IOP Conf. Series: Earth and Environmental Science* **80** 012056
- [26] Kamaruddin F A, Nahazanan H, Huat B K and Anggraini V 2020 Improvement of marine clay soil using lime and alkaline activation stabilized with inclusion of treated coir fibre, *Appl. Sci.* **10**(6) 2129
- [27] Sachin. D, Mujeeb A and Dr. Sowmya N J 2016 Effect of Coconut Coir Fibres on Black Cotton Soil Blended with Fly Ash, *Int. J. Eng. Res.* **05**(10) 505–508

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