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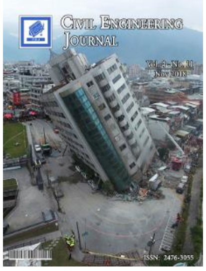

Evaluation of Strength behaviour of Cement-RHA Stabilized and Polypropylene Fiber Reinforced Clay-Sand Mixtures

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Abstract

In this paper, regarding the high availability of rice husk ash (RHA) in Guilan province, also, to decrease the geo-environmental issues caused by dumping RHA in the environment, different clay-sand mixtures are stabilized using the combination of cement and RHA. Polypropylene (PP) fibers are also used to decrease the growth of tensile cracks and increase the overall strength of samples. As the main scope, effect of sand content (in different conditions: with and without presence of RHA) on the compressive strength of stabilized and reinforced samples is investigated. In this regard, 28 day cured clay-sand samples are prepared and unconfined compressive strength (UCS) tests are conducted and the results are compared. It is obtained that with addition of 20% sand to the clay samples, their UCS increases in both cases of non-RHA and RHA-stabilized samples. Moreover, such behavior has been observed with the length of studied PP fibers. As the second scope, based on the conducted UCS tests on the 7-, 28- and 90- day cured clay samples, compressive strength of non-RHA samples are almost completely achieved in a 28-day curing period, while samples containing RHA continue to strengthening after such a period toward a 90-day curing period. Next, a simple relationship for the prediction of UCS of cement-RHA stabilized and PP reinforced clay is presented based on the evolutionary polynomial regression (EPR) technique. This relationship can be efficiently applied by construction engineers to obtain the appropriate mixture design for the stabilization of clay with cement, RHA and PP fibers.

Keywords: Clay; Sand Content; Cement; Rice Husk Ash; Polypropylene Fiber; Unconfined Compressive Strength; Curing Period; Evolutionary Polynomial Regression.

1. Introduction

In recent years, with increasing the rate of civil constructions (e.g. skyscrapers, high dynamic loads, etc.), the site soils should carry higher loads. In this regard, different methods are applied to increase the bearing capacity of soils. Chemical stabilization as a common soil stabilization method has been broadly applied to increase the bearing capacity, decrease the swelling potential and improve the mechanical properties of different granular or soft soils [1-4]. Cement and lime are two conventional constructional material used as binders to stabilize different soils. Some other non-conventional materials such as industrial wastes, fly ash, bottom ash, pond ash, silica fume, ground granulated blast furnace and rice husk ash (RHA) have also been used for such purposes [5-9]. The main role of such binders is initiation of hydration reactions and formation of calcium silicate hydrated (CSH) gel [10]. One of the main reasons for replacing the cement with other waste materials is saving the money in the projects. Also, as other reasons, it should be noted that the total energy consumption in manufacturing the cement is about 5 TJs per 1000 tons. In addition, each ton of cement releases about 1 ton of carbon dioxide into the atmosphere. Among other materials, RHA is a common supplementary material available worldwide as a waste material obtained from controlled burning of rice husks at a temperature of

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600C [11]. On the other hand, dumping RHA in the land is a geo-environmental threat and hence, regarding the high availability of RHA in Guilan province, Iran, its application in the construction projects reduces the project costs and saves the environment.

In the last years, RHA is broadly utilized as a stabilizing material to improve the mechanical properties of soils as a construction material [12-22]. In addition, applications of RHA in the improvement of properties of clayey soils has been investigated by Muntohar and Hontoro (2000) [23], Cai et al. (2006) [24], Tang et al. (2007) [25] and Mtallib and Bankole (2011) [26]. Tripathi and Yadu (2013) studied the bearing capacity of square footing on soft soil stabilized with rice husk ash [27]. Effect of RHA, lime and waste plastic fibers on the engineering properties of silty soils was investigated in Muntohar et al. (2013) [28]. Suksiripattanapong et al. (2017) showed that stabilized spent coffee grounds using RHA and slag geopolymers can be used as sustainable materials in pavement applications [29]. In general, the application of fiber in concrete technology and stabilization of soils has been considered by many researchers. Tang et al. (2007) used the cement and fiber to improve the clayey soil. Based on the obtained results, existence of fiber in the studied clay resulted in an increase in both UCS and shear strength. The assessment of the mechanical properties of cement-stabilized soft clay using fiber and liquid polymer was carried out by Ayeldeen and Kitazume (2017), which resulted in significant improvement in the UCS of the studied soil [30]. Mirzababaei et al. (2018) performed a series of UCS tests to evaluate the stabilization of soft clay using short fibers and poly vinyl alcohol [31]. Despite numerous studies, most of this research has been carried out on clays and less attention has been paid to clay-sand mixtures. In addition, the use of RHA as a waste material for replacement with cement has been evaluated less in such soils. Therefore, there is a lack of detailed studies on the simultaneous effects of RHA, cement and fiber on the behavior of clay-sand mixtures over a long period of time.

In this regard, the present paper aims to study the unconfined compressive strength (UCS) (as a conventional criterion broadly used in QC/QA phases of projects to assess the strength of stabilized soils) of clay and clay-sand mixtures stabilized with different cement and RHA percentages. Polypropylene (PP) fibers are also used to retard the first cracking occurrence and strengthen the studied samples. Since curing period is another affecting parameter in the stabilization of clay samples, in this paper, the role of curing days has been evaluated. In addition, by means of artificial intelligence techniques, the possibility of proposing a simple relationship to predict UCS of stabilized and reinforced samples will be investigated.

2. Materials and Methods

Clay-sand mixture is the common soil of a large area of Guilan province, Iran. Hence, in this paper, combination of clay and sand is selected for further analyses. As the main scope of this paper is investigating the role of the sand content on the strength of stabilized and reinforced samples, Rasht clay is chosen as the host soil (80% of the total soil in the clay-sand combination) and Anzali sand (as a widely available sand in the south of Caspian Sea) consists the remaining 20%.

Present study aims to evaluate strength behavior of both clay and clay-sand mixtures. Hence, cement (C) in 2%, 4%, 5%, 8%, 10% and 16% (by weight), also, RHA in 2%, 5% and 8% (by weight) are added to the clay samples. The used polypropylene (PP) fiber lengths are 0, 6 and 12 mm. All PP reinforced samples contain 0.2% by weight PP. To study the effect of the curing period, clay samples are made and cured for three different curing periods (7, 28 and 90 days), while clay-sand mixtures are all cured in a 28-day curing period.

2.1. Clay and Sand

The studied clay sample is classified as CL based on ASTM D2487-11 [32] and A-6 according to ASTM D3282-09 [33]. Some of the features of the studied Rasht clay obtained based on ASTM D4318 [34] are presented in Table 1. Also, according to ASTM D698 [35], the standard compaction test is conducted and maximum dry density, MDD, and optimum moisture content, OMC, of samples are attained as 17 kN/m^3 and 17%, respectively.

Table 1. Physical properties and Atterberg limits of the studied clay

Parameter	Value
G_s	2.66
Liquid limit (LL) (%)	35
Plastic limit (PL) (%)	17.1
Plasticity Index (PI) (%)	17.9
Shrinkage limit (SL) (%)	16

According to ASTM D2487-11 [32] and ASTM D3282-09 [33], the studied sand is categorized as SW-SC and A-2-6, respectively. Coefficient of uniformity, Cu, and the coefficient of curvature, Cc, of the studied sand are 8.5 and 1.05, respectively. Also, Gs of tested sand is 2.59. 16% and 18.3 kN/m^3 are, respectively, OMC and MDD of the clay-sand mixtures.

2.2. Cement and Rice Husk Ash (RHA)

Ordinary Portland Cement (OPC) is used in this paper. Table 2 shows the chemical composition of the studied cement and RHA. As a matter of fact, the main factor, which controls the pozzolanic reactions is the formation of CSH and CAH gels. The essential elements for the formation of these gels are silica content of RHA and CaO available in the cement. Reacting these elements in the presence of water, pH of the environment increases and the gels forms.

Table 2. Chemical composition of the studied cement and RHA

Constituents	Cement (%)	RHA (%)
SiO2	22.2	90.6
Al2O3	5.48	0.49
Fe2O3	3.35	0.73
CaO	63.9	1.51
MgO	1.06	0.88
Na2O	0.17	0.22
K2O	0.31	1.8
SO3	2.29	0.43
Loi	1.24	3.34

2.3. Polypropylene (PP) Fiber

In this study, polypropylene fibers with two lengths of 6 and 12 mm, and an average diameter of 34 μm were used as the reinforcement materials. This type of fiber was chosen because it is one of the most common synthetic materials used in other research. Table 3 represents the properties of the used polypropylene, PP, fibers.

Table 3. Properties of studied PP

Properties	Unit	Value
Color	-	White
Cross section	-	Circular
Average diameter	μm	34
Breaking tensile strength	MPa	350
Modulus of Elasticity	MPa	3500
Specific gravity	kN/m^3	9.1
Fusion point	°C	165
Burning point	°C	590
Acid and alkali resistant	-	Very good

2.4. Research Methodology

In this study, to prepare samples of UCS test, the specified values of clay, sand, RHA and polypropylene fiber were combined with each other and then water was added to each sample separately to reach optimum water content. Figure 1 shows soil-fiber mixtures in order to prepare samples. The samples were made using 4.9 cm in diameter and 9.8 cm in height mold based on ASTM D 1633-96. The mixtures were compacted in the mold in three layers with 25 blows/layer to achieve maximum dry density. In order to perform the UCS tests according to D5102-09 [36], unconfined compression testing machine was calibrated by the specialized company and the calibration coefficient was presented. Finally, the results were corrected by this coefficient. The loading was performed with a fixed displacement rate of 1 mm/min and continued until the initial failure of samples. The used mold and the prepared sample are shown in Figure 2.

Figure 1. Addition of polypropylene fiber to a) clay-sand and b) clay mixtures

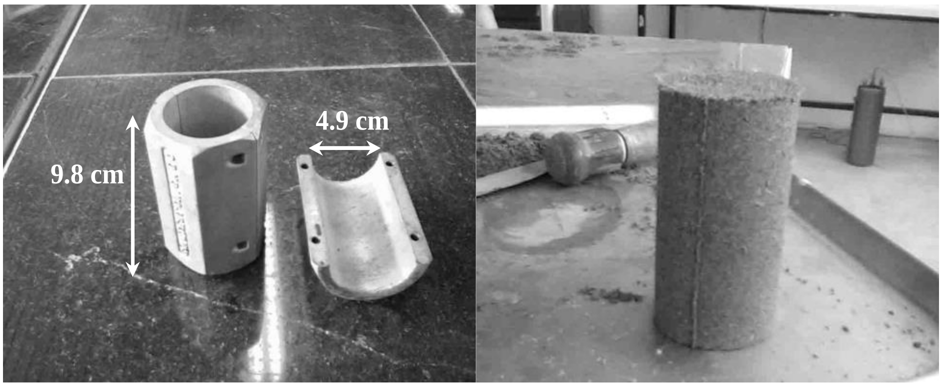

Figure 2. The a) used mold to prepare UCS samples and b) prepared sample

3. Experimental Program

As described, regarding different combinations of the studied materials, different samples are made. Table 4 shows prepared sample numbers along with the constituents in the samples. C as the first term of the sample number, represents for clay samples, while CS is the symbol for the cement-sand mixtures.

Table 4. Experimental program

Sample #	Soil		Additive			Curing period (day)
	Clay	Sand	Cement (%)	RHA (%)	PP (mm)	
C-C4-nR-nP-7	√	-	4	0	0	7
C-C4-nR-nP-28	√	-	4	0	0	28
C-C4-nR-nP-90	√	-	4	0	0	90
C-C4-nR-6P-7	√	-	4	0	6	7
C-C4-nR-6P-28	√	-	4	0	6	28
C-C4-nR-6P-90	√	-	4	0	6	90
C-C4-nR-12P-7	√	-	4	0	12	7
C-C4-nR-12P-28	√	-	4	0	12	28
C-C4-nR-12P-90	√	-	4	0	12	90
C-C2-R2-nP-7	√	-	2	2	0	7
C-C2-R2-nP-28	√	-	2	2	0	28
C-C2-R2-nP-90	√	-	2	2	0	90
C-C2-R2-6P-7	√	-	2	2	6	7
C-C2-R2-6P-28	√	-	2	2	6	28
C-C2-R2-6P-90	√	-	2	2	6	90
C-C2-R2-12P-7	√	-	2	2	12	7
C-C2-R2-12P-28	√	-	2	2	12	28
C-C2-R2-12P-90	√	-	2	2	12	90
C-C10-nR-nP-7	√	-	10	0	0	7
C-C10-nR-nP-28	√	-	10	0	0	28
C-C10-nR-nP-90	√	-	10	0	0	90

C-C10-nR-6P-7	√	-	10	0	6	7
C-C10-nR-6P-28	√	-	10	0	6	28
C-C10-nR-6P-90	√	-	10	0	6	90
C-C10-nR-12P-7	√	-	10	0	12	7
C-C10-nR-12P-28	√	-	10	0	12	28
C-C10-nR-12P-90	√	-	10	0	12	90
C-C5-5R-nP-7	√	-	5	5	0	7
C-C5-5R-nP-28	√	-	5	5	0	28
C-C5-5R-nP-90	√	-	5	5	0	90
C-C5-5R-6P-7	√	-	5	5	6	7
C-C5-5R-6P-28	√	-	5	5	6	28
C-C5-5R-6P-90	√	-	5	5	6	90
C-C5-5R-12P-7	√	-	5	5	12	7
C-C5-5R-12P-28	√	-	5	5	12	28
C-C5-5R-12P-90	√	-	5	5	12	90
C-C16-nR-nP-7	√	-	16	0	0	7
C-C16-nR-nP-28	√	-	16	0	0	28
C-C16-nR-nP-90	√	-	16	0	0	90
C-C16-nR-6P-7	√	-	16	0	6	7
C-C16-nR-6P-28	√	-	16	0	6	28
C-C16-nR-6P-90	√	-	16	0	6	90
C-C16-nR-12P-7	√	-	16	0	12	7
C-C16-nR-12P-28	√	-	16	0	12	28
C-C16-nR-12P-90	√	-	16	0	12	90
C-C8-8R-nP-7	√	-	8	8	0	7
C-C8-8R-nP-28	√	-	8	8	0	28
C-C8-8R-nP-90	√	-	8	8	0	90
C-C8-8R-6P-7	√	-	8	8	6	7
C-C8-8R-6P-28	√	-	8	8	6	28
C-C8-8R-6P-90	√	-	8	8	6	90
C-C8-8R-12P-7	√	-	8	8	12	7
C-C8-8R-12P-28	√	-	8	8	12	28
C-C8-8R-12P-90	√	-	8	8	12	90
CS-C4-nR-nP-28	√	√	4	0	0	28
CS-C4-nR-6P-28	√	√	4	0	6	28
CS-C4-nR-12P-28	√	√	4	0	12	28
CS-C2-R2-nP-28	√	√	2	2	0	28
CS-C2-R2-6P-28	√	√	2	2	6	28
CS-C2-R2-12P-28	√	√	2	2	12	28
CS-C10-nR-nP-28	√	√	10	0	0	28
CS-C10-nR-6P-28	√	√	10	0	6	28
CS-C10-nR-12P-28	√	√	10	0	12	28
CS-C5-R5-nP-28	√	√	5	5	0	28
CS-C5-R5-6P-28	√	√	5	5	6	28
CS-C5-R5-12P-28	√	√	5	5	12	28
CS-C16-nR-nP-28	√	√	16	0	0	28
CS-C16-nR-6P-28	√	√	16	0	6	28
CS-C16-nR-12P-28	√	√	16	0	12	28
CS-C8-R8-nP-28	√	√	8	8	0	28
CS-C8-R8-6P-28	√	√	8	8	6	28
CS-C8-R8-12P-28	√	√	8	8	12	28

As shown in the program of experiments, clay samples were stabilized using 6 cement contents, 3 RHA contents and 3 different fiber lengths. Then, Unconfined Compressive Strength (UCS) tests were conducted on the prepared samples.

4. Results and Discussion

The present manuscript investigates UCS of two different stabilized and reinforced soil types as the main scope. To do this, clay and clay-sand mixtures are stabilized and reinforced. Based on the obtained results, effect of sand content on the UCS of stabilized and reinforced samples is evaluated. These investigations are separately conducted for two cases of stabilization with cement and the combination of cement and RHA. As previously described, the main reason for such a replacement is economic and environmental concerns. In this regard, 28 days cured samples are further studied. As the next step, clay samples are more focused and effects of curing periods on the UCS of cement and cement-RHA stabilized clay samples are elaborated. Some practical and accurate relationships are, also, proposed to obtain the strength of cement-RHA stabilized and PP-reinforced clay based on Evolutionary Polynomial Regression (EPR) technique.

4.1. UCS of Clay-Sand Mixtures: Effect of Sand Content

Clay-sand mixtures are made up of 80% Rasht clay and 20% Anzali sand. Compared to the clay samples (comparing Figures 3-4 with 6-11), in low cement contents (lower than 10%), with addition of sand to the samples, the UCS of samples decreases, while in higher cement percentages (higher than 10%), addition of sand to the samples results in increasing their compressive strength. Such conclusion can also be made for the case of cement-RHA stabilized samples.

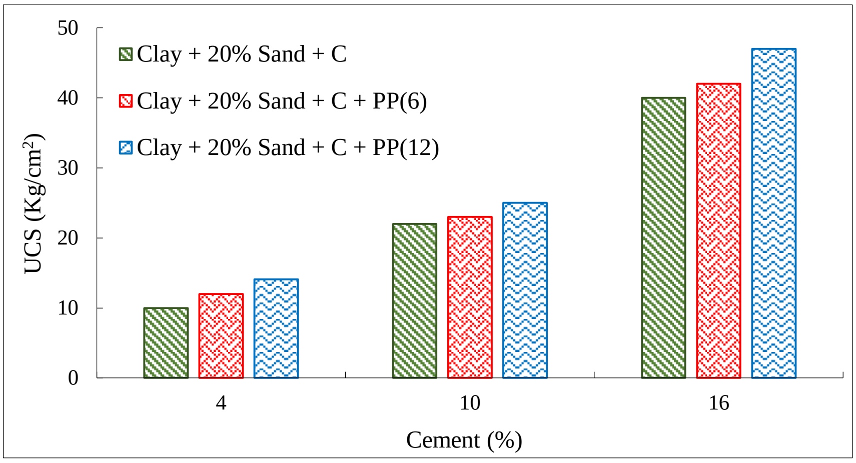

Figure 3. Effect of sand content on the UCS of non-RHA clay-sand samples

As shown in Figure 3, the soil compressive strength increased significantly with increasing cement content, so that the UCS of samples containing 4 and 16% cement was about 10 and 40 Kg/cm^2, respectively. The addition of polypropylene fiber also slightly increased the strength of the samples, which these changes was higher in samples containing 12 mm fiber length compared to 6 mm ones. UCS of samples containing 4, 10 and 16% cement and fiber with a length of 12 mm was equal to 14, 25 and 47 Kg/cm^2, respectively.

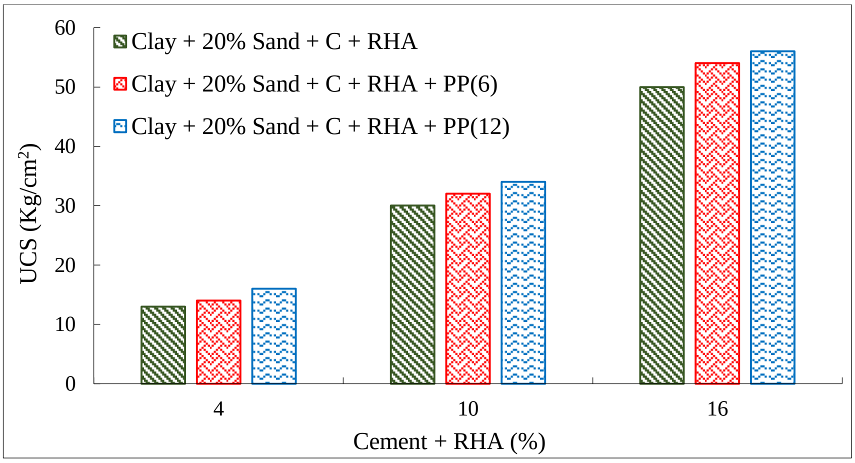

Figure 4. Effect of sand content on the UCS of RHA stabilized clay-sand samples

As shown in Figures 4, with increasing the binder percentage, UCS increases. Compared to the cement stabilized samples, such increases in the strength of cement-RHA clay-sand samples are slightly higher. The UCS of non-fiber samples containing 4, 10 and 16% cement and RHA showed an increase of about 30, 36 and 25%, respectively, compared with non-RHA samples. Also, the direct relationship between the length of PP and UCS is clearly observed. In addition, in clay-sand mixtures, effect of PP fibers on the UCS of both cement and cement-RHA samples is not significant. Meanwhile, its effect in higher binder percentages is more considerable.

Figure 5 shows the stress-strain variations of a sample containing 16% cement-RHA mixture and polypropylene fiber with length of 6 mm. As can be seen, yielding in the fiber-reinforced sample did not occur suddenly and showed a softening behavior, so that it had more flexibility and no rupture was observed in the sample. While non-fiber samples had a sudden rupture and longitudinal cracks in the samples were created during yielding.

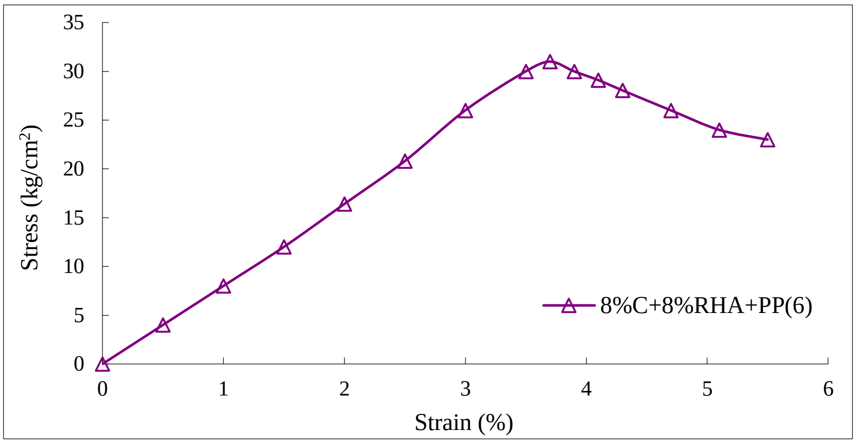

Figure 5. Stress-strain changes for a clay-sand sample

4.2. UCS of clay Samples

In order to investigate the effects of curing period on the UCS of clay samples, non-RHA (cement) and cement-RHA stabilized clay samples are more studied. Such investigation can help to find the mechanism behind the strengthening of stabilized samples, also, will help to attain the optimum curing period while using cement or RHA for stabilization purposes.

4.2.1. Effect of Curing Period on non-RHA and RHA Stabilized Clay Samples

Figures 6-8 show the UCS of clay samples stabilized with cement using different PP lengths and cured in different periods of 7, 28 and 90 days. As seen, the rate of increasing UCS from 4% to 10% cement is higher than that of from 10% to 16% in all curing periods. In addition, almost the optimum UCS values of stabilized and reinforced samples are attained in a 28-day curing period since there is not a meaningful increase in the UCS of all the investigated samples from a 28 to 90-day curing period. The reason is that most of the pozzolanic reactions occurred in the first 28 days. This means that the stabilization phase in the cemented clay is almost a fast phenomenon.

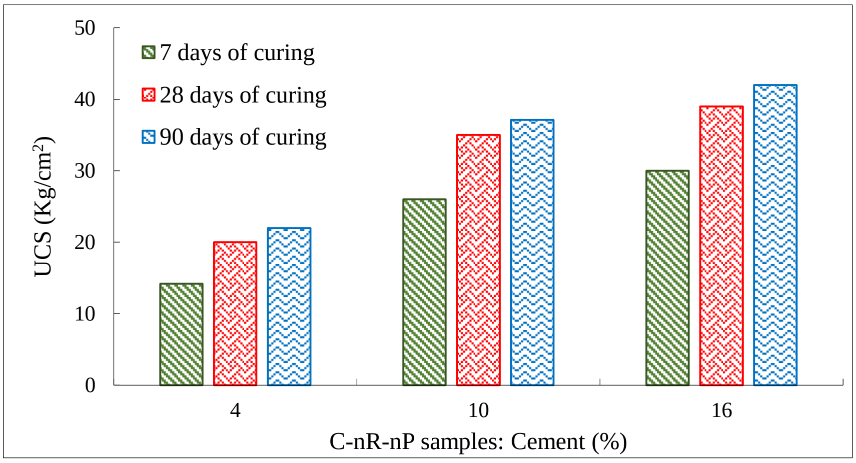

Figure 6. Effect of curing period on the UCS of nP, non-RHA stabilized clay samples

In general, the increase in compressive strength of samples can be attributed to an increase in pozzolanic reactions. The addition of cement to the soil and performing these reactions creates calcium silicate hydrate (CSH) and hydrated calcium aluminate (CAH) gels, which is the main reason for increasing the UCS of the samples [10]. These reactions are time-dependent and therefore, in the first 7 days, a slight strength increase was observed in all samples. However, the strength of the samples increased sharply with increasing curing time up to 28 days and the completion of long-term pozzolanic reactions. It is important to note that the increase in UCS up to 28 days in samples containing more cement was higher; because there is not enough cement to complete the pozzolanic reactions in lesser percentages.

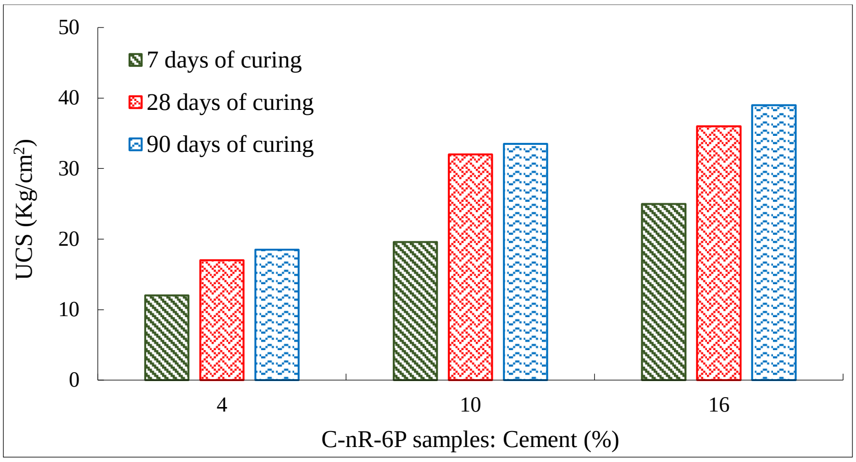

Figure 7. Effect of curing period on the UCS of 6P, non-RHA stabilized clay samples

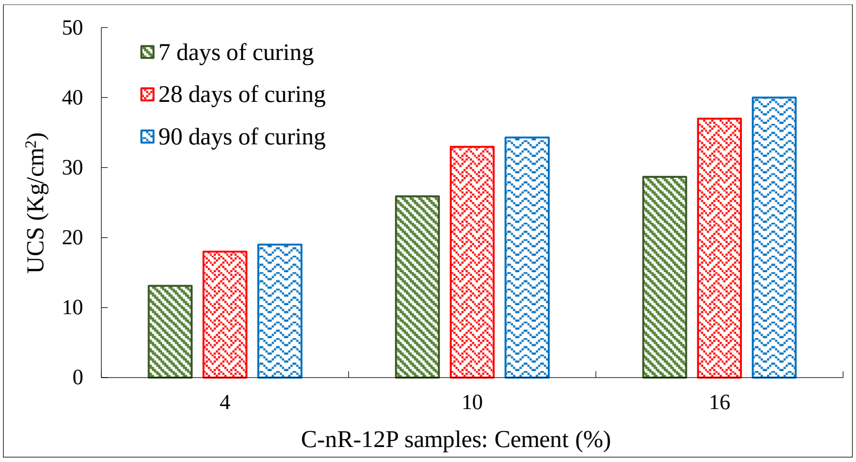

Figure 8. Effect of curing period on the UCS of 12P, non-RHA stabilized clay samples

On the other hand, as shown in Figures 9-11 for cement-RHA stabilized clay samples, the main portion of strengthening phenomenon is occurred in a 90-day curing period. The considerable increase form 28-day to 90-day UCS for cement-RHA stabilized clay samples show that in presence of RHA, the speed of hydration reactions decreases. Hence, RHA retards the strengthening period, meanwhile increases the value of UCS of samples. Such behavior can be obviously observed comparing Figures 6-8 with their corresponding figures in Figures 9-11.

As shown in Figure 9, the compressive strength after 90 days of treatment in sample containing 16% cement-RHA mixture was about 96% higher than that of 4% cement-ash mixture, which was equivalent to 57 and 29 Kg/cm^2. These values for the samples with 7-day treatment period were reported to be 34.7 and 15.5 Kg/cm^2, respectively. As previously stated, this is due to the completion of pozzolanic reactions and the formation of CSH and CAH gels [10].

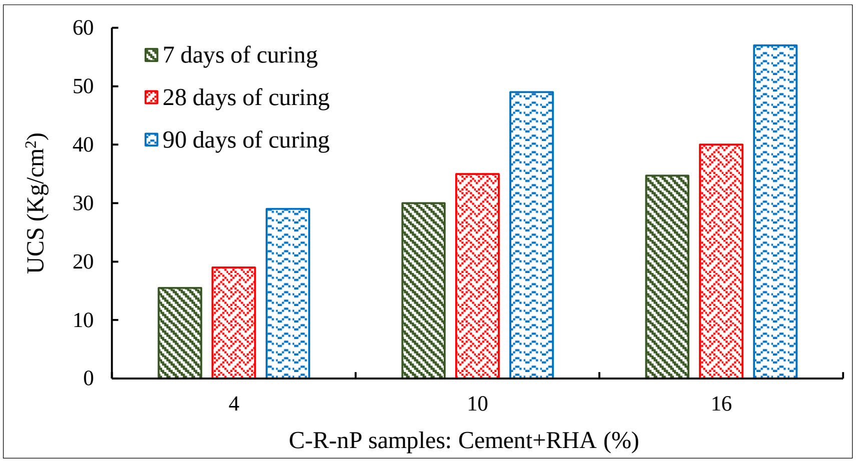

Figure 9. Effect of curing period on the UCS of nP, RHA stabilized clay samples

The UCS variations of samples containing fiber were similar to those of non-fiber samples. As shown in Figure 10, UCS values after the 90-day treatment in samples containing 4 and 16% chemical additive and fiber with length of 6 mm were reported as 27 and 52 Kg/cm^2, respectively. The increase in fiber length up to 12 mm slightly increased the UCS to about 28 and 54 Kg/cm^2, respectively, as shown in Figure 11.

Stress-strain changes in the sample made with clay are the same as those expressed in clay-sand mixtures. The presence of fiber in the clay sample changed the behavior of the failure in post-peak from the brittle state to the softening state, which is shown in Figure 12. Based on observations from broken samples, it was found that the non-fiber samples had deep cracks and openings, whereas fiber samples exhibited a lot of flexibility.

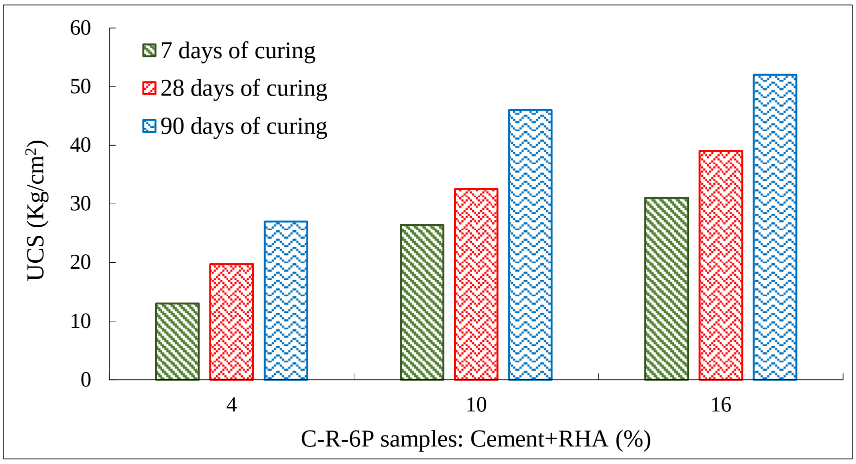

Figure 10. Effect of curing period on the UCS of 6P, RHA stabilized clay samples

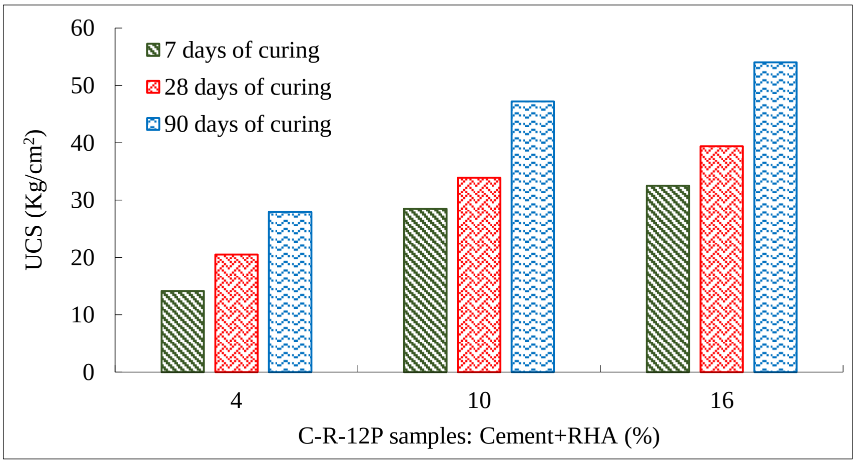

Figure 11. Effect of curing period on the UCS of 12P, RHA stabilized clay samples

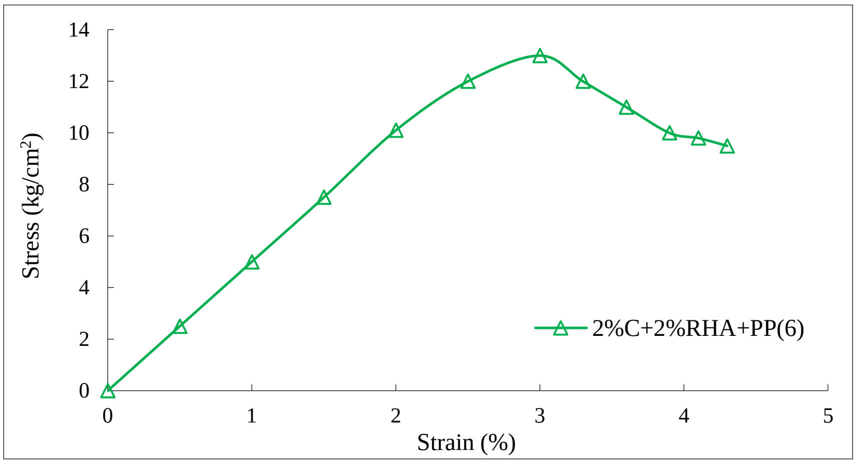

Figure 12. Stress-strain changes for a clay sample

4.2.2. EPR-Based Relationship for the Prediction of UCS

This section aims to present a new relationship for the prediction of UCS of cement-RHA stabilized and PP reinforced clay samples. Such a relationship will considerably help practitioners and design engineers in selecting the optimum mixture design without spending significant time and money.

Evolutionary Polynomial Regression (EPR) is a new hybrid regression technique of Artificial Intelligence (AI) known as a grey box predictive tool used to predict target functions based on the transfer functions and the relationships with the concerning input parameters [37-38]. It combines the best features of the conventional regressions with the genetic programming and least squared error methods. It uses different functions, sentences and constants to predict the complicated output targets. Figure 13 shows the typical flow diagram of EPR method. In this method, type of functions, number of terms, range of exponents, number of generations, etc. are constraints to control the target [39-41].

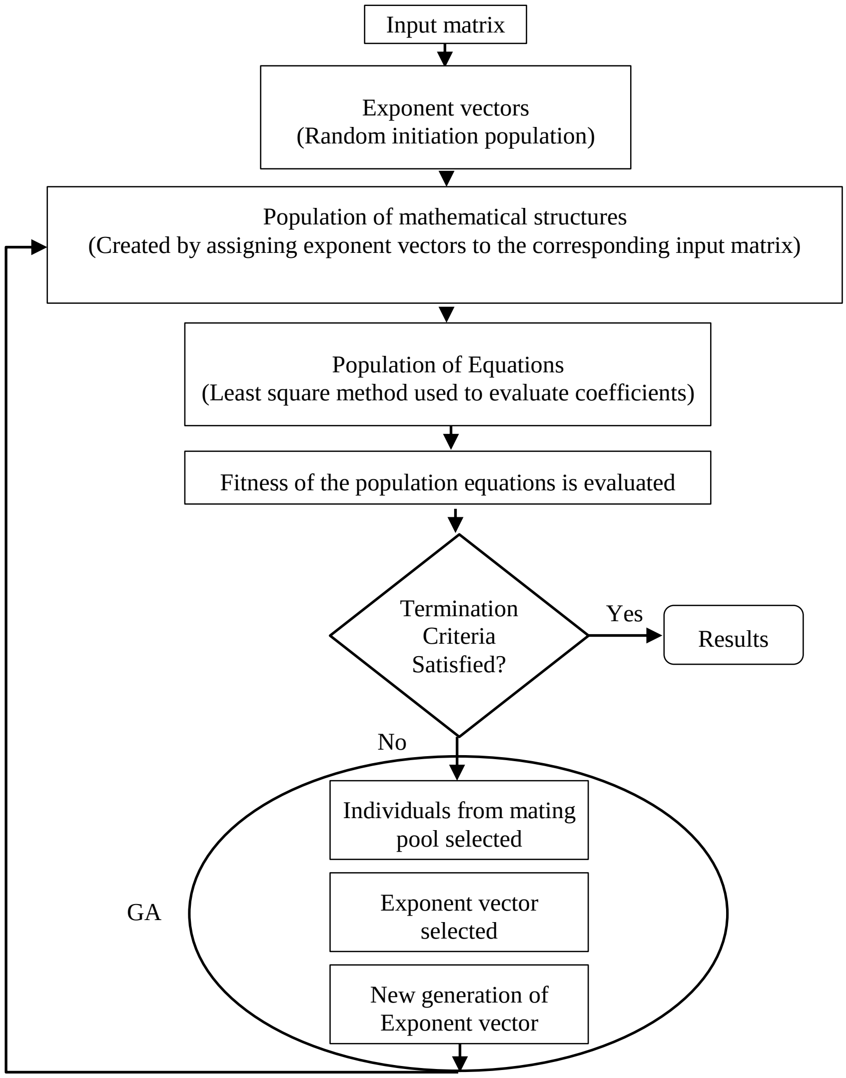

Figure 13. EPR flow diagram [32]

This technique is applied to the prepared databank to predict the UCS of stabilized and reinforced clay based on the cement percentage (C), RHA percentage (R), PP percentage (P) and curing days (CD) as input parameters. Equation 1-2 show two of the obtained relationships. The first equation, which is the best relationship corresponds to the logarithmic base functions.

Logarithmic: $$UCS = 9.7451 \times [Ln^{0.25}(R+1)] + 32.4523 \times \left[\sqrt{Ln(C+1)} \times Ln^{0.25}(CD+1)\right] - 0.82984 \times \left[CD^{0.25} \times Ln(P+1)\right] + 0.00092049 \times \left[CD^{2} \times \sqrt{Ln(R+1)}\right] + 0.024259 \times [P^{2}] - 35.995 \qquad R^2 = 98.41\% \qquad (1)$$

Exponential: $$UCS = 7.9586 \times 10^{-10} \times \left[\sqrt{R} \times e^{0.25\mathrm{CD}}\right] + 4.3166 \times [\mathrm{R}] - 0.3953 \times [\mathrm{R}^2] + 23.2778 \times [(\mathrm{C} \times \mathrm{CD})^{0.25}] - 4.0956 \times [\mathrm{C}^{0.25} \times \sqrt{CD}] - 25.2527 \qquad R^2 = 97.28\% \qquad (2)$$

Figure 14 shows the predicted and measured UCS values for different samples. Also, Figure 15 represents the coefficient of determination of the proposed relationship.

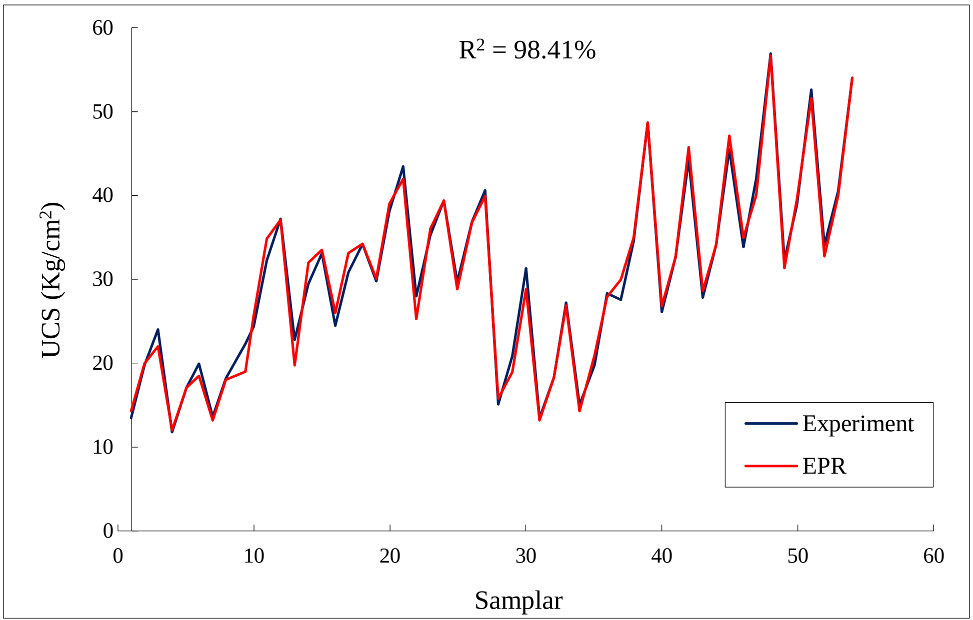

Figure 14. Predicted and measured UCS values for different samples

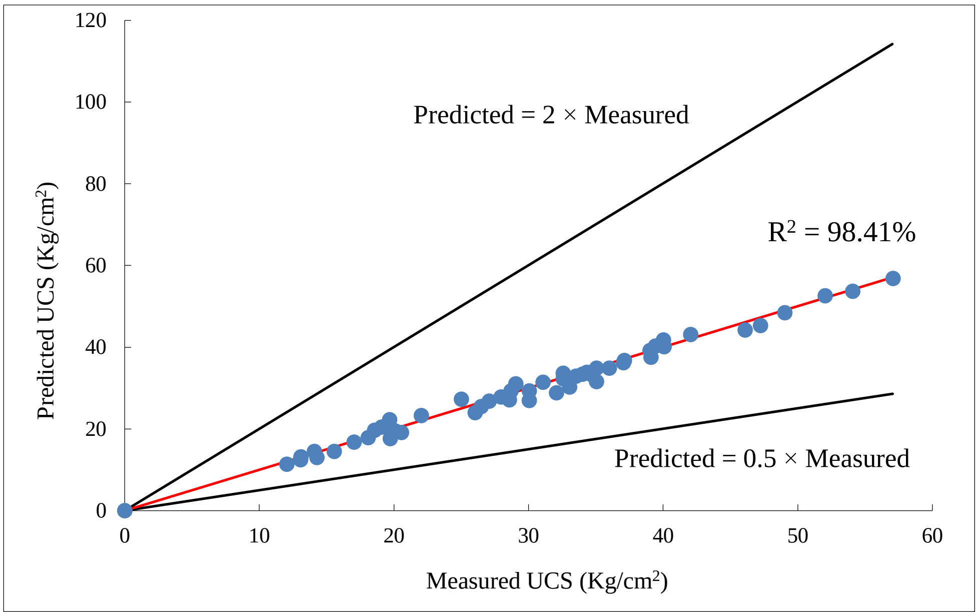

Figure 15. Coefficient of determination for prediction of UCS of tested samples

The proposed relationship can be effectively applied for the prediction of UCS of both non-RHA and cement-RHA stabilized clay samples reinforced with PP fibers. Regarding the acceptable coefficient of determination of the proposed relationship (98.41%) in the prediction of the UCS values, its accuracy is accepted.

5. Conclusion

This paper presents results of unconfined compressive strength tests on the clay and clay-sand mixtures stabilized with different cement and RHA percentages, also, reinforced with different lengths of PP fibers. Replacement of cement with RHA enhances the strengthening of the samples, also, economically and environmentally are beneficial to the projects. In this paper, effect of the replacement of 20% of clay with the sand was investigated. Clay-sand mixtures were cured in 28 days, while clay samples experienced three different curing periods (7, 28 and 90 days). Based on the conducted tests and post-testing analysis, following conclusions are presented:

- For C < 10%, with addition of 20% sand to clay samples, the UCS of samples decreases, while for C > 10%, addition of the sand to the samples results in increasing their compressive strength. Such conclusion can, also, be made for the case of cement-RHA stabilized samples.
- The rate of increasing UCS values with addition of cement from 4% to 10% is higher than the corresponding UCS value for the case of increasing cement content from 10% to 16% for the both non-RHA and RHA stabilized clay samples (for all the curing periods).
- 28-day is introduced as the optimum curing period for non-RHA stabilized clay samples since there is not a meaningful increase in the UCS of all the investigated samples from a 28 to 90-day curing period.
- There is a considerable increase in the UCS value of RHA stabilized clay samples from the 28-day to 90-day curing period since RHA causes hydration reaction slow. Although RHA retards the strengthening period, it increases the value of UCS of samples.
- A simple, high accuracy relationship for the prediction of UCS of RHA stabilized clay sample, reinforced with PP fibers is presented based on the EPR technique.
- The proposed relationship can be used as a basis for selecting the mixture design for the stabilization of clay.

6. Conflicts of Interest

The authors declare no conflict of interest.

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