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Soil stabilization of clay with lignin, rice husk powder and ash

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Abstract. This article presents the result of laboratory study conducted on expansive soil specimens treated with lignin, rice husk powder (RHP) and rice husk ash (RHA). The amount of lignin produced from paper industry and RHP were varied from 0 to 20% and RHA from 0 to 10% by weight. The treated specimens were subjected to unconfined compressive strength (UCS),swelling test and Atterberg limit tests. The effect of additives on UCS and atterberg limit test results were reported. It was observed that the additives and curing duration had a significant effect on the strength value of treated specimens. Generally (except the sample treated with 20% RHP for 3-day) with increasing additive and curing duration the UCS value increases. A RHP content of 15% was found to be the optimum with regard to 3-day cure UCS.

Keywords: lignin; rice husk powder (RHP); rice husk ash (RHA); unconfined compressive strength (UCS); Atterberg limits; swelling

1. Introduction

Many buildings are constructed with foundations that are inadequate for the soil conditions existing on the site. Because of the lack of suitable land, homes are often built on the marginal land that has insufficient bearing capacity to support the substantial weight of a structure. Land becomes scarce with growing of cities and it often becomes necessary to construct buildings and other structures on the sites where unfavourable conditions are present. One of the most important characteristic of clayey soils is their susceptibility to the volume change sourced from swelling and shrinkage. Such volume changes can give rise to ground movements which may result in damage to buildings (Bell and Maud 1995).

Expansive soils can be problematic in engineering applications, depending mostly on their interactions with water. Changes in soil volume can cause very significant damage to light weight structures such as cracks on the walls of the single-story buildings, distortion on pavements and pipelines constructed on. Several additives are commonly used for the treatment of expansive clays which include salt, polymers, surfactants, cement, lime, fly ash and mixtures of some of these additives. Lime has, however, been more commonly used for the treatment of expansive clays and other clay soils because it improves the mechanical properties of expansive soils. In

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addition, it is economical and is abundantly available in many parts of the world (Muzahim *et al*. 2012). Lime is mostly used as an additive to stabilize expansive soils. The lime additive reacts with the soil particles, and reduces the swelling potential while increasing the strength and durability of the soil (Du *et al*. 1999, Guney *et al*. 2007, Locat *et al*. 1990).

Several studies are undertaken and reported in the literature to explain the improvements in the mechanical and hydraulic properties of expansive soil due to the addition of stabilizers, mainly from a macroscopic point of view. The focus of most of these researches was on studying the changes associated with the Atterberg limit values (plastic and liquid limits) and the soil properties, such as the volume change (i.e., swell pressure, swell potential, heave), shear strength and the coefficient of permeability of the stabilized expansive soils (Diamond and Kinter 1965, Brandl 1981, Locat *et al*. 1996, Sivapullaiah *et al*. 2000, 2003, Sivapullaiah and Lakshmi Kantha 2005).

Recently, a number of waste materials have been used in the stabilization of soils in order to reduce both environmental problems and the requirement for traditional additives such as lime and cement. Rice husk ash (RHA) and rice husk powder (RHP) are an agricultural residue that is one of these waste materials obtained from the outer covering of rice grains during milling process. RHA includes a huge amount of silica with high specific surface that is very suitable for activating the reaction of soil and lime (Choobbasti *et al*. 2010). Some researchers showed that the RHA was a promising pozzolanic materials to improve lime or cement-stabilized soils (Ali *et al*. 1992, Balasubramaniam *et al*. 1999, Basha *et al*. 2005, Muntohar 2002, Rahman 1987). Muntohar (2004) shows that the addition of 6.0% lime in combination with RHA principally has a significant effect in reducing swell and swelling pressure (Ps) of the clayey soil. Alhassan (2008) stated that the unconfined compressive strength (UCS) of the specimens increased with the addition of lime–RHA in clayey soil. While the use of lime improves the most engineering properties of clay, it brings unfavorable phenomena such as reduction in axial strain at post peak strength (ε), residual strength and plasticity of soil. In recent years, polypropylene fibers have been added into soils to improve the strength, ductility and swelling behaviors of soil (Ikizler *et al*. 2008, Vessely and Wu 2002).

The use of recycled materials reduced volume of landfill area and also opens a new gate for sustainable construction practices in engineering applications. This article presents the result of laboratory study conducted for investigating the feasibility of use of waste materials, lignin and rice husk as powder (RHP) and ash (RHA) for improving strength and consistency properties of expansive soil. Geotechnical properties studied in this investigation includes index properties like liquid limit, plastic limit, free swell index and strength characteristics of stabilized soil with replacement of various proportions of lignin, RHP and RHA.

2. Experimental studies

2.1 Materials

2.1.1 The expansive soil used in the study

An artificial, potentially expansive soil used in this study was prepared by mixing 70% red clay (Gs = 2.61, LL = 34.25% and PL = 19) and 30% bentonite (Gs = 2.40) by weight. Laboratory tests related with Atterberg limit, swelling test, standard proctor compaction test were conducted according to ASTM D4318-05 (2005), ASTM D4546-08 (2008), ASTM D698-12 (2012), respectivelly. Physical properties of of the red clay, bentonite and the mixture of expansive soil are

Table 1 Summarizes the various properties of the red clay, bentonite and the mixture of expansive soil

Properties	Red clay	Bentonite	Value
Liquid Limit	40%	275%	148%
Plastic limit	25%	54%	22.4%
Swell percent	5%	64.9%	13%
Degree of expansivity	Medium	Very high	High
Maximum dry density (MDD)	1.643 g/cm³	1.40 g/cm³	1.395 g/cm³
Optimum moisture content (OMC)	15%	35%	25%

shown in Table 1.

2.1.2 The Lignin used in the study

One of the naturally occurring polymers that is achieving significant attention is lignin - a waste product of paper industry. Lignins intuitively should be considered as good wood and paper adhesives since they are the substances that hold plant fibers together. Lignins are the most abundant aromatic plant component in terrestrial ecosystems and represent a significant part of plant litter input (approximately 20%) into soils (Crawford 1981, Kögel-Knabner 2000, Gleixner *et al*. 2001). In taller and more complex plants lignins are chemically connected to cellulose and hemicellulose in the cellulosic fiber walls, providing strength and rigidity to the plant structures as well as resistance to the bio degradation of carbohydrates (i.e., enzymatic hydrolysis) and to environmental stresses (Brown 1961, Kirk and Farrell 1987, Argylopoulos and Menachem 1997, Higuchi 1998, 2006). Lignins are recovered mainly as byproducts from wood pulping operations with about 75 million tons produced annually worldwide. Plant biomass is a lignocellulosic material consisting of cellulose, hemicellulose, and lignin. The various industrial product conversion technologies used with plant biomass can modify natural lignin. The modified lignin can be divided into two principal categories: sulfite lignins (lignosulfonates), derived mainly from the paper industry, and sulfur-free lignins, obtained mainly from biofuel or ethanol production (International Lignin Institute (ILI) 2008). Most lignin-based industrial products in the forms of binder, dispersant, emulsifier, and sequestrant are derived from sulfite lignins (International Lignin Institute 2008). Various studies have also been conducted on the use of sulfite lignin in civil engineering infrastructure applications. Some studies have demonstrated that sulfite lignin is effective in soil stabilization (Nicholls and Davidson 1958). The lignin used as waste material in this study was obtained from Kahramanmaras Paper Industry Incorporation (kmk paper), Turkey.

2.1.3 RHA (*Rice husk ash*) *and RHP* (*Rice husk powder*)

Rice husk is an agro-waste material abundantly available in rice producing countries. It is estimated that rice husk of approximately 20% is obtained from the total rice by the milling process. Rice husk roughly contains 35% cellulose, 35% hemicellulose, 20% lignin and 10-20% ash , by dry weight basis (Luh 1980). In this study rice husk was used as RHA and RHP. Rice husk powder (RHP) was obtained from the grounding of rice husk in a grounding machine for 4 minute under 1000 revolution per minute. The particle size ranges from 0.6 mm to 0.063 mm. The RHP passed through a No. 30 sieve and retain on No. 200. RHA was burnt approximately 1 hour under controlled combustion process. The burning temperature was 600°C. The particles had a

Table 2 Chemical composition of rice husk ash (Ramezanianpour *et al*. 2009)

Consistent	Percentage (%)
Silica (SiO_2)	80.55
Calcium Oxide (CaO)	0.59
Ferric Oxide (Fe_2O_3)	0.24
Sodium Oxide (Na_2O)	0.06
Sulphur Oxide (S_2O)	0.34
Magnesium Oxide (MgO)	0.39
Potassium Oxide (K_2O)	1.65
Titanium Dioxide(TiO_2)	0.02
Loss on ignition (LOI)	15.33

non-uniform shape and its appearance color was grey. The chemical composition of RHA at 600°C are mentioned in Table 2.

2.2 Methods

2.2.1 Preperation of samples

An artificial, potentially expansive soil (mixture), was prepared by mixing 70% red clay (*Gs* = 2.61) and 30% bentonite (*Gs* = 2.40), by dry mass. The purpose of preparing the mixture soil is to make a more expansive soil. Prior to mixing, the red clays were dried and pass through No. 40 (0.425 mm) sieve (ASTM D422-90 1990). After weighing the constituents, Na-Bentonite and red clay were mixed using a trowel. A preliminary swelling test on (expansive soil) resulted in 13% 1-d vertical swell indicating a highly expansive soil (Seed *et al*. 1962). To increase the strength of the samples, lignin and rice husk powder were added in amounts ranging from 5, 10, 15 and 20% in dry mass to expansive soil, while rice husk ash ranging was 2.5, 5.0, 7.5 and 10% in dry mass. Stabilized specimens were prepared by mixing a pre-calculated amount of additives and expansive soil at a moisture content of 25%.

2.2.2 Swelling test procedure

In this experimental study, the Swelling Method (ASTM D4546-08 2008) was used to determine the amount of swell. Single preparation water content was used for all specimens to simulate routine field compaction specifications. Each specimen was prepared 60 gram dry mass 15 ml water was added to the sample to obtain 25% water content. The total weight of each sample was 70 gram in the consolidation ring of the oedometer apparatus (Height, H = 20 mm and Diameter, D = 50 mm). each specimen was fitted with dry top and bottom porous stones, and loaded with a predetermined surcharge stress σ = 1 psi or 6.9 kPa. After the oedometer was mounted on the loading device, the dial gauge measuring the vertical deflection was set to zero. After compression ceased, each specimen was inundated with water, and swell was monitored for 4 days (96 hours.)

Swell percent was calculated from the equation defined below.

$$\text{Swell (\%)} = 100\ dH/H$$

Table 3 Unconfined compressive strength (UCS), Atterberg limit test and Swelling results of lignin, RHP and RHA treated samples

Additive	Swelling (%)	UCS (kPa)		Atterberg limits		
		3 days	7 days	LL (%)	PL (%)	PI (%)
Control	13	33	113	148	22.37	125.63
% 5 Lignin	5.63	62	120	99.5	21.85	77.65
% 10 Lignin	5	156	291	81.4	22.22	56.9
% 15 Lignin	4.4	324	382	67.9	22.8	45.1
% 20 Lignin	6.35	452	495	66.4	24.5	61.4
% 5 RHP	11	118	254	144	24.72	119.28
% 10 RHP	9.25	310	364	137.5	28.5	104
% 15 RHP	8.55	413	494	133.6	31.78	101.82
% 20 RHP	8.25	412	640	132.22	32.94	99.28
% 2.5 RHA	11.1	126	153	146.4	22.51	123.89
% 5.0 RHA	10.6	167	229	144	24.24	119.76
% 7.5 RHA	10.4	181	321	141.4	26.49	114.9
% 10 RHA	5.65	184	400	137.2	26.1	111.1

Where dH is the change in the initial height of the specimen after it is inundated, and H is the original height of the specimen just before the inundation.

2.2.3 Unconfined Compressive Strength test (UCS test)

The Unconfined compressive strength tests were performed on pure and treated cylindrical samples (46 mm diameter and 100 mm length). Single preparation water content (25%) was also used for all samples. The samples were kept in plastic bags and allowed to cure for 3 days and 7 days in air dried condition at room temperature. The samples were taken out from the plastic bags after curing period. The tests were then carried out in accordance with ASTM D2166-06 (2006), up to failure under constant strain rate (1.2 mm/min).

3. Results and discussion

All test results related with Unconfined compressive strength (UCS), swelling and Atterberg limit test are shown in Table 3.

3.1 Atterberg limit test results

The Liquid limit, Plastic limit and Plasticity index of the untreated and treated samples are shown in Table 1. Figs. 1(a)-(b) show the effect of additivies materials on Liquid limit and Plastic limit. As it is clearly seen in Fig. 1(a), generally LL decreases with increase of all type of the additives. On the other hand PL increases with increase of all type of the additives. It is obvious that all samples show a decrease in Liquid limit. The liquid limit decreased from 148% to 66.4%

with increase in Lignin from 0% to 20%. This can be considered to be as a result of the binding soil particles and dispersion of the clay fraction by Lignin (Which acts a binder to glue the soil particles together). The highest change in LL was obtained at 20% lignin dosage. Thus 20% Lignin caused a decrease of 55.1% in LL when compared to the LL of the control sample. Therefore 20% is considered as the optimum percent of Lignin for this study.

Generally, the Liquid limit decreases with increase in RHP percentage. This can be due to the substitution of swelling soil by RHP that has a small ability for water attraction. It is clear from the Fig. 1 that up to 10% RHP, the reduction in LL is quite significant beyond which become straight line. This result indicates that beyond 10% dosage, the reduction in LL slightly increases. Consequently, the lowest value and maximum reduction in LL is obtained at 20% RHP. As can be seen from Fig. 1(a) the liquid limit decreases with increase of RHA. When the RHA content was increased from 0% to 10%, LL decreases from 148% to 137.2%, respectively. This may be due to the increase in particle sizes for the agglomeration of clay particles with RHA. The reduction in LL is not significant in the used dosage rate compared to the lignin (Sarkar *et al*. 2012).

Fig. 1(b) shows the variation of PL with additive materials. It is clear from the curves that Lignin has a very small effect on the plastic limit of the expansive soil. While RHP and RHA show a considerable effects on PL of the expansive soil. This increase in the plastic limit implies

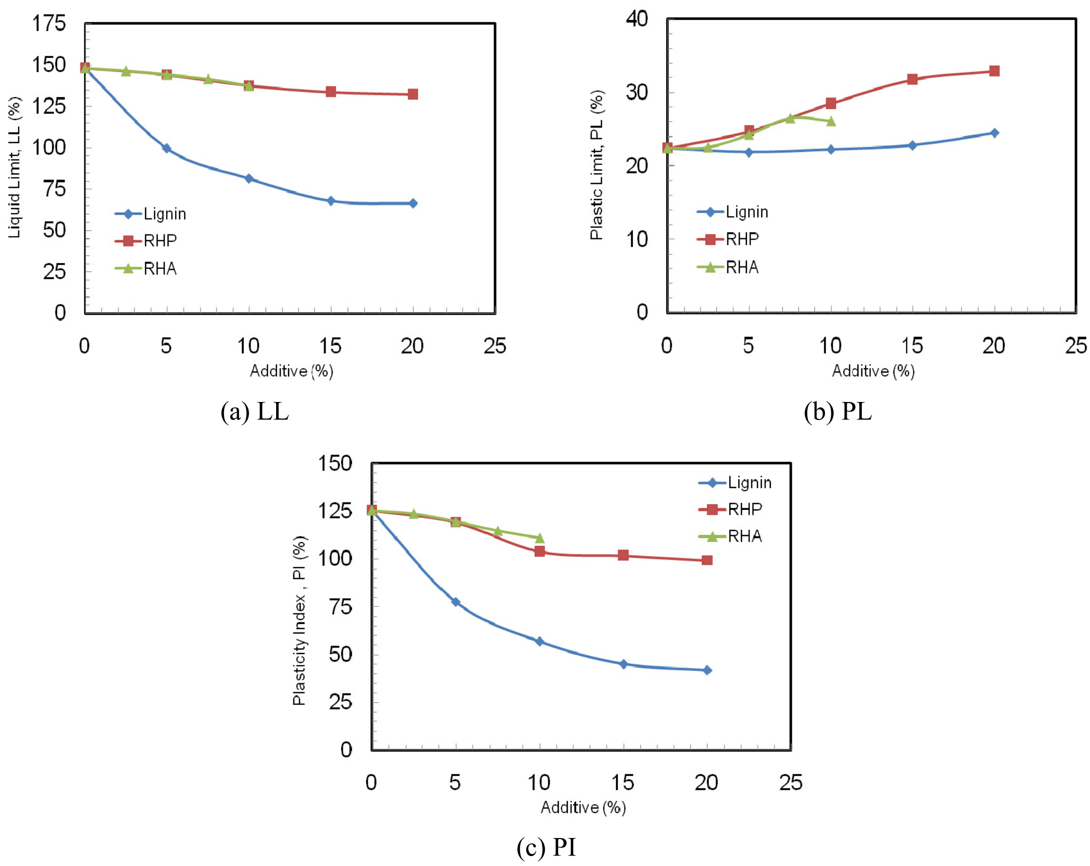


Fig. 1 Variation of LL , PL and PI values of the admixtures treated with Lignin, RHP and RHA

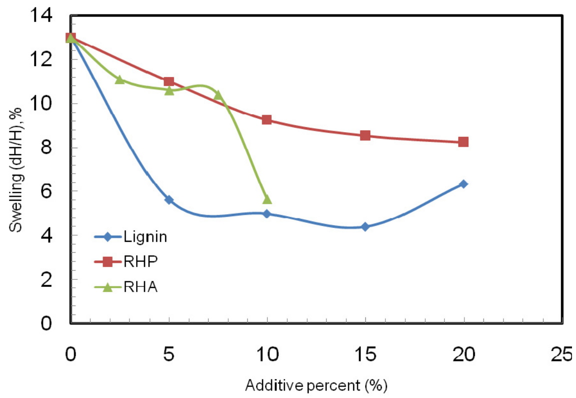


Fig. 2 Effect of Lignin, RHP and RHA on swelling percent of expansive soil

that RHP and RHA treated soil required more water to change it plastic state to semi-solid state. Similar behaviour was reported by Sarkar *et al*. (2012).

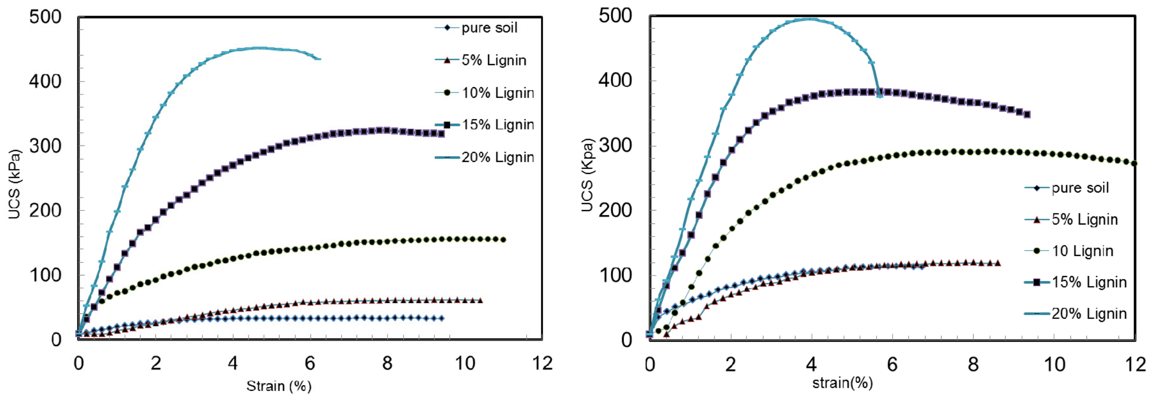
It is indicated from Fig. 1(c) that Plasticity ındex (PI) of all treated samples showed a decrease at any additive content. However in the case 20% Lignin PI slightly increases. According to Fig. 1(c) it is clear that the Lignin has most influence on the expansive soil related with PI when it is compared to the other additive materials. Also, according to the PI results, 20% Lignin, 20% RHP and 10% RHA have most effect on the PI of the expansive soil.

3.2 Swelling test results

Swelling percent test was carried out on the pure expansive soil to measure swelling parameter in order to examine the effect of various additives on the eliminating of the swelling potential of the soil. The swelling value for the control sample was 13%. Swelling potential results of untreted and treated specimens are presented in Table 3. According to Fig. 2 swelling percent decreases with increase in Lignin percentages (except 20%). The reason due to the dispersion of clay fraction by lignin, the binder (lignin) caused to plugging of voids and increasing the effective surface area of the binder fraction. Gow *et al*. 1961 has demonstrated that the dispersion of clay fraction benefits stability of the soil (decreases swelling percent). Consequently, it can be seen that the swelling percentage decreased from 13% to 5% when the Lignin content increased from 0% to 15%. Further increase of lignin the swelling percentage slightly increased. Thus, the most decreasing in swelling potential was obtained for the soil treated with 15% lignin (Fig. 2). Therefore 15% lignin content may be considered as optimum percentage.

Fig. 2 illustrates the variation of swelling percent with RHP content. The results show that the swelling percent was affected by RHP content and the effect decreased by increasing of RHP. This due to the addition of RHP that it is a none plastic material and has a highly resistant to moisture penetration and contain high silica (SiO_2) contents. The maximum reduction percent of the swelling percent is found as 37% in the case of 20% RHP as shown in Fig. 2.

In general swelling percent decreased with increase in RHA content. Thus, swelling percent decreased from 13% to 5.65% when RHA increased from 2.5% to 10%. This can be explained by chemical effect due to presence of around 85% and 90% amorphous silica. RHA caused maximum decreasing in swelling (36%) at the addition of 10% RHA (Fig. 2). It is interesting to note that



(a) at 3-days curing (b) at 7-days curing

Fig. 3 Effects of Lignin on UCS of mixtures

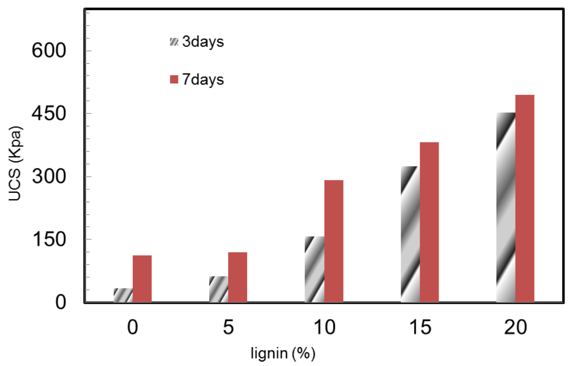
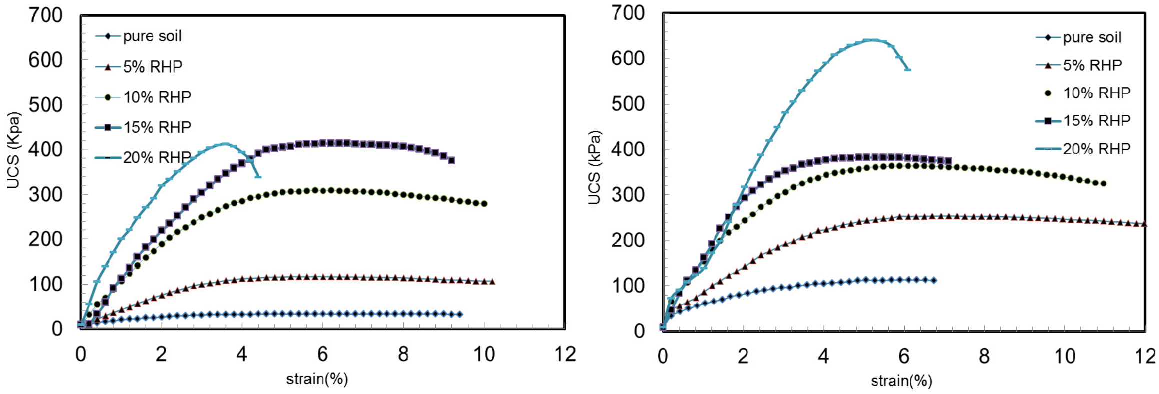


Fig. 4 The UCS values of treated clayey soil with Lignin in 3 and 7-days curing time

with the addition of 5% and 7.5% RHA, the swelling percent values were very close ranging from 10.6 to 10.4, respectively.

3.3 UCS test results

Unconfined compressive strength tests were conducted on specimens with and without additives (lignin, RHP and RHA) for 3- and 7-days curing. Figs. 3(a)-(b) show the development of unconfined compressive strength of stabilized soils with various percentages of lignin (%0, %5, %10, %15 and %20) for 3 and 7 days curing. Generally, UCS increases with respect to increase in lignin content. Thus, UCS for 3-and 7 days cured specimens added with 20% lignin increases to 452 kPa and 495 kPa, respectively. These values are the maximum values of UCS that represent the most increasing percent in all UCS values. Increase in the strength of the expansive soil is due to increase in cohesiveness of the specimen through binding of soil particles by glue material (lignin), adding lignin to clay soils increases the soil stability by causing dispersion of the clay fraction (Gow *et al*. 1961, Davidson and Handy 1960). The lignin used as co-product has also been thought to have a positive role in soil stabilization (Kozan 1955, Nicholls and Davidson



(a) at 3-days curing (b) at 7-days curing

Fig. 5 Effects of RHP on UCS of mixtures

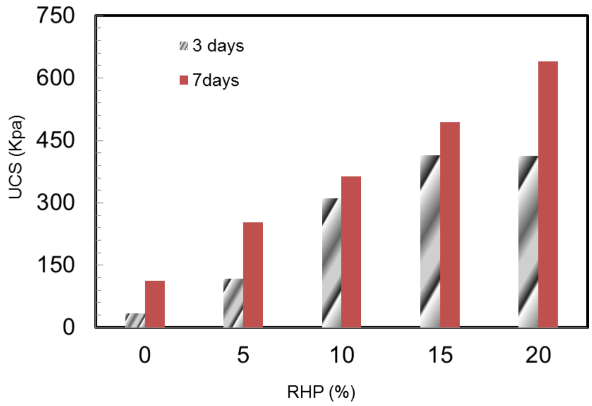
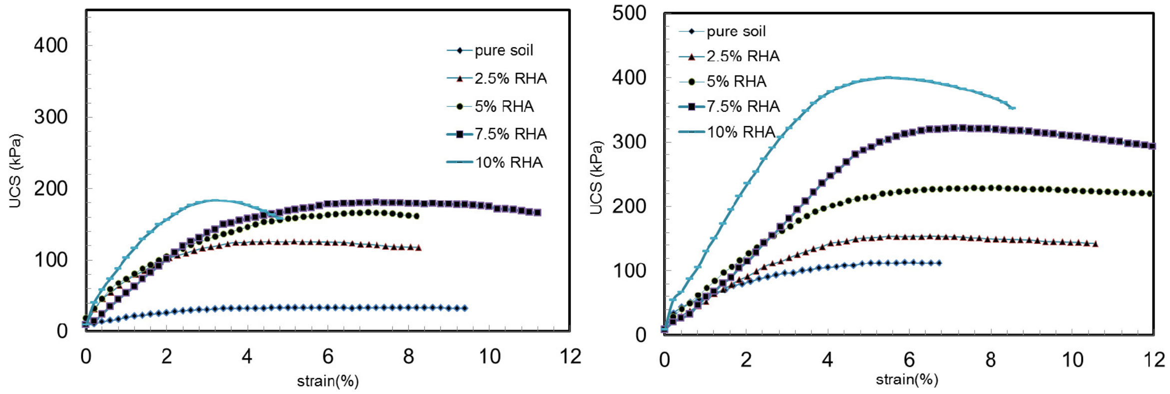


Fig. 6 The UCS values of treated expansive soil with RHP in 3 and 7-days curing time

1958, Johnson *et al*. 2003, Ceylan *et al*. 2009, 2010).

Fig. 4 shows the maximum values of unconfined compressive strength for various percentages of lignin at 3-day and 7-days cure. It is observed that the UCS values of treated soil increase further with increase in curing time, in other words, the UCS values for 7-days cured soil is higher than the 3-days cured specimens. For example, UCS for 3-days and 7-days cured samples added with 10% lignin increases to 156.7 kPa and 291 kPa, respectively.

Figs. 5(a)-(b) present the maximum values of UCS (3-day and 7-day) for various percentages of RHP content (%0, %5, %10, %15 and %20). As can be seen, the 3-day UCS is found to increase with an increase of RHP content from 0 to 15%. 7-day UCS is shown to increase for all percentages of RHP. This result can be attributed to improved compatibilization between RHP and expansive soil that increases the cohesiveness of the RHP treated expansive soil. In the case of 20% RHP, the 3-day compressive strength slightly decreases. In this case (20% RHP) the sample became brittle. The 3-day compressive strength of soil treated with 20% RHP is 412.5 kPa, compared to 640 kPa of 7-day compressive strength of the same content of RHP. This indicated that the curing further improved strength of RHP treated soil (Fig. 6).



(a) at 3-days curing (b) at 7-days curing

Fig. 7 Effects of RHA on UCS of mixtures

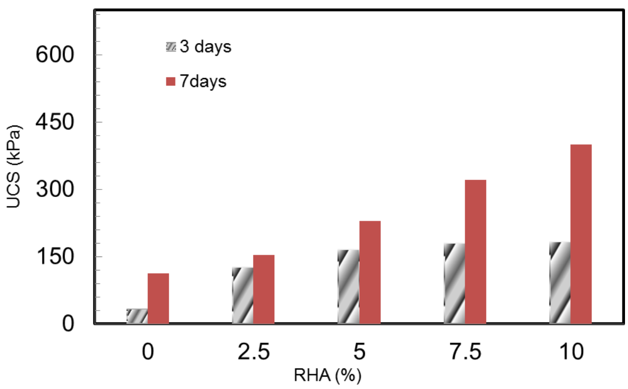


Fig. 8 The UCS values of treated expansive soil with RHP in 3 and 7-days curing time

Figs. 7(a)-(b) show the influence of RHA on UCS of the specimen for 3 and 7-days curing. The results show that the stress- strain behavior was markedly affected by the RHA and the effect increased by increasing RHA content. It can be concluded that the RHA has a significant effect on the mechanical properties of the expansive soil and the strength of the soil increases with increasing the RHA content. The results indicate that there is a direct relationship between the strength and amount of RHA in soil mass (at the range of the experimental work carried out in this study). Similar behavior was found by (Brooks 2009, Phani Kumar and Sharma 2008) who concluded that when the RHA content was increased from 0 to 12%, unconfined compressive strength increased by 97%. Increase in strength of RHA treated specimens is due to the pozzolanic action.

Fig. 8 presents the peak values of the UCS (3-days and 7-days) for various percentages of RHA. The results indicating that the increasing in UCS when length of curing is increased. The 3-day compressive strength of soil treated with 10% RHA is 184 kPa, compared to 400 kPa of 7-day compressive strength of the same content of RHA. This is indicated that curing period has a positive role in increasing UCS of the samples.

4. Conclusions

Laboratory study conducted on expansive soil specimens treated with lignin, rice husk powder (RHP) and rice husk ash (RHA) has been proposed in this study.

- The significant improvement on the unconfined compressive strength was obtained by using lignin, RHP and RHA. The UCS of the samples proportionally increased with above additives for all samples except 20% RHP. 3-day UCS increased with increase RHP content from 0 to 15%, further addition of RHP the 3-day UCS slightly decreased. While the 7-day UCS was shown to increases for all percentages of RHP.
- Curing further improved strength of treated soil. For example, the 3-day UCS soil treated with 10% lignin, 10% RHP and 10% RHA were 156 kpa, 310 kpa and 184 kpa, respectively, compared to 291 kpa, 364 kpa and 400 kpa of 7-day UCS at the same content of lignin, RHP and RHA, respectively.
- In both cases of 3 and 7 days curing, the addition of 5% lignin had low effect on UCS. Above this amount improvement being more.
- RHA more affected by curing when compared to lignin and RHP. Maximum percentage change recorded as 117% with addition of 10% RHA.
- The Liquid limit, Plastic limit and Plasticity index of the untreated and treated samples were studied. LL decreases with increase of all type of the additives. On the other hand PL increases with increase of all type of the additives.
- The liquid limit decreased from 148% to 66.4% with increase in Lignin from 0% to 20%. The most decreasing (percentage change) in LL was obtained for the expansive soil treated with 20% lignin. Thus 20% Lignin caused a decrease of 55.1% in LL when compared to the LL of the control sample (artificial soil).
- The Liquid limit decreases with increase in RHP percentage.The lowest value and maximum reduction in LL is obtained at 20% RHP.
- The liquid limit decreases with increase of RHA. When the RHA content was increased from 0% to 10%, LL decreases from 148% to 137.2%, respectively.
- Lignin has a very small effect on the plastic limit of the expansive soil. While RHP and RHA show a considerable effects on PL of the expansive soil.
- Plasticity ındex (PI) of all treated samples showed a decrease at any additive content. The Lignin has most influence on the expansive soil related with PI when it is compared to the other additive materials. Also, according to the PI results, 20% Lignin, 20% RHP and 10% RHA have most effect on the PI of the expansive soil.
- The swelling value for the control sample was 13%. The swelling percentage decreased from 13% to 5% when the Lignin content increased from 0% to 15%. Further increase of lignin the swelling percentage slightly increased. Thus, the most decreasing in swelling potential was obtained for the soil treated with 15% lignin.
- The results show that the swelling percent was affected by RHP content and the effect decreased by increasing of RHP.
- In general swelling percent decreased with increase in RHA content. Thus, swelling percent decreased from 13% to 5.65% when RHA increased from 2.5% to 10%.

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