

# Critical state desiccation induced shrinkage of biomass treated compacted soil as pavement foundation

**Biomasszával kezelt tömörített járda alap talajának kritikus állapotbeli kiszáradás okozta zsugorodása**

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## Abstract

Volumetric shrinkage critical state induced by desiccation of compacted earth treated and improved with Rice Husk Ash (RHA) and utilized as pavement foundation has been investigated in the laboratory. The critical state study was important to determine at what level of earth improvement with the biomass material can be considered safe in terms of shrinkage behavior of treated soft soil utilized in pavement construction. Rice Husk (RH) is an agricultural waste discharged during rice production and is disposed on landfills. It causes land pollution in places like Abakaliki and Ebonyi State, Nigeria as whole where rice farming is the predominant occupation. Ground and soil improvement with the use of rice husk ash has contributed in the management of solid waste in the developing countries where rice production is a common occupation with its attendant solid waste generation. However, the use of biomass-based binders like RHA has reduced the rate at which oxides of carbon are released into the atmosphere, which contribute to greenhouse emission effects. This exercise is an environmentally conscious procedure that keeps the environment safe from the hazards of carbon and its oxides. The preliminary investigation on the test soil showed that it is classified as an A-7-6 soil group according to AASHTO classification. The index properties showed that the soil was highly plastic with high clay content. The RHA was utilized at the rate of 2%, 4%, 6%, 8% and 10% by weight of treated solid to improve the soil volumetric shrinkage induced desiccation at molding moisture conditions of 2% dry, 0%, 2% wet, and 4% wet of optimum moisture. This was necessary to establish the behavior of hydraulically bound foundation materials subjected to dry and wet conditions during the rise and fall of water tables. Results of the laboratory investigation have shown that at 2% dry of optimum moisture, the volumetric shrinkage (VS) behavior performed best and reduced below the critical line of 4% at 8% by weight addition of RHA and maintained that consistent reduction at 10% addition of RHA. Generally, the critical point was achieved at 8% by weight addition of RHA at all the molding moisture conditions. This is an indication that at molding moisture conditions between -2% to 4%, 8% by weight addition of the admixture, RHA can be utilized as an environmentally conscious construction material to improve the VS of soils for use as hydraulically bound materials in pavement foundation construction. Keywords: critical state, volumetric shrinkage, desiccation, biomass pavement foundation, treated compacted earth, lignocellulosic material  
Kulcsszavak: kritikus állapot, térfogati zsugorodás, kiszáradás, biomassza járda alap, kezelt tömörített föld, lignocelluláris anyag

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## 1. Introduction

Solid waste handling and management around the world and especially in the third world countries have contributed to the alarming amounts of carbon oxides emission and on the threat of global warming. On the other hand, Laterite has served as foundation material for pavement ever since road existed, the need to analyze this material and subsequently improve on the quality of roads has been a serious issue to highway Engineers. One critical concern in the use of laterite is the swell – shrink property of the lateritic material. Expansive soils (lateritic soils with high plasticity index above 17) are prone to large volume changes that are directly proportional to moisture exposure. Therefore, the low bearing strength and compressibility behavior as a result of constant exposure to moisture under hydraulically bound conditions causes severe damage and deterioration to subgrade. Due to the rise and fall of the water table which is triggered by rainfall percolation and subsequent capillary action or suction, the compacted sub-grade layer is constantly subjected to swelling and shrinkage cycle [1-4]. The road embankment is regularly under hydraulically bound condition, and the compacted earth serves as hydraulic barrier in waste containment facilities [5] and also as subgrade/ embankment layer of the road. Swelling and shrinkage properties of laterite have contributed immensely to road failures, and therefore measures to ameliorate these would be of great importance to the Engineer.

The swelling and shrinkage properties of soil are not excluded in stabilized soil but can be minimized, this is due to the physical and chemical properties of soil, swelling occurs during water absorption and shrinks when water dries up. Generally, swelling and shrinking are major factors which affect the development of fissures in lateritic soil [6]. These fissures separate the soil surface and gradually close down into the deeper soil and in turn give rise to different problems of stability. Clayey soil is observed to give different characteristics in wet and dry conditions, it possess desirable sorption characteristics when wet and crack with dust emitted when dry [7]. These cracks break down continuity of soil mass, thereby reducing its strength and soil stability is affected. It grants surface water easy infiltration into the soil. When laterite is soaked with infiltrated water, it collapses and loose strength. Structures built on a soil with stability problem such as this, especially pavements, will in turn collapse with the soil. To a large extent, fissures are closely related with the swell - shrink characters.

Modification and stabilization are two basic soil improvement technique [8], these enhance the mechanical behavior to suit construction requirements. Additives such as cement, lime, fly ash and bituminous materials have been used in common practice to improve the strength and other characteristics of laterite [9]. This has kept the cost of roads construction increasingly high due to increasing cost of the stabilizing agents. Thus, the use of agro-industrial wastes (such as rice husk ash) will lead to a considerably reduced cost of construction, minimize environmental hazards and enhance economical value chain of the farmers [10].

Rice husk ash has been validated through several researches

as an effective partial replacement for stabilizing agents such as cement, lime etc. Globally, it is estimated that an average of about 160 million tons of rice husk ash are produced annually [10]. The addition of RHA reduces the plasticity and increase volume stability as well as the strength of the soil [11]. Combined application of RHA and lime can modify the expansive soil by reducing the swelling index and improve its strength and bearing capacity. In the above background analysis, it can be observed that relatively new and sustainable approach, which are environmentally conscious soil improvement has emerged. It is also important to note at this stage that for materials to be considered to be utilized in geotechnical engineering works, a maximum requirement of 4% for the volumetric shrinkage strain is recommended [12].

This paper seeks to study the effect on critical state desiccation of rice husk ash treated soil compacted earth when used as pavement foundation.

## 2. Materials and methods

### 2.1 Materials

**Soil:** The soil utilized in the laboratory experimentation was obtained by disturbed sampling method at depths of 1 to 3 meters from a borrow site located in Amaoba, Ikwuano Local Government Area, Abia State, Nigeria. The map location of the soil sample source is presented in Fig. 1.

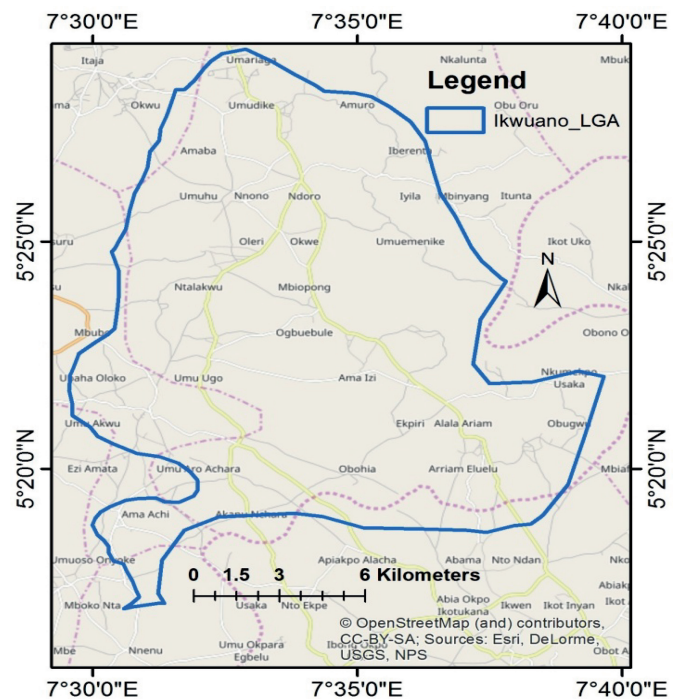


Fig. 1 Test soil sample location map

1. ábra Vizsgált talajminták földrajzi elhelyezkedése

**Rice Husk Ash:** Rice Husk (RH) is an agricultural solid waste belonging to the lignocellulosic biomass discharged from the harvesting and milling of rice. It is normally disposed on landfills and this practice constitute pollution of the environment. The RH used in this laboratory exercise was collected from Rice Mills in Abakaliki, Ebonyi State, Nigeria

where rice farming and production is prevalent and common. Conversely, Rice Husk Ash (RHA) is derived from the direct combustion of the above lignocellulosic biomass released from rice production.

## 2.2 Methods

### Rice Husk Combustion:

Rice Husk (RH) is a biofuel that combusts releasing high amount carbon and its oxides. The method of combustion employed here is the controlled incineration method developed by K. C. Onyelowe *et al.* [13] known as the Solid Waste Incineration NaOH Oxides of Carbon Entrapment Model. In this method, the oxides of carbon released are entrapped in a reaction jar containing 40 v/v NaOH solution, which has very strong affinity with oxides of carbon. At the end of the process, ash is derived and soda ash, baking soda and hydrogen gas are released through the outlet as presented in the waste valorization and gas sequestration cycle (see Fig. 2).

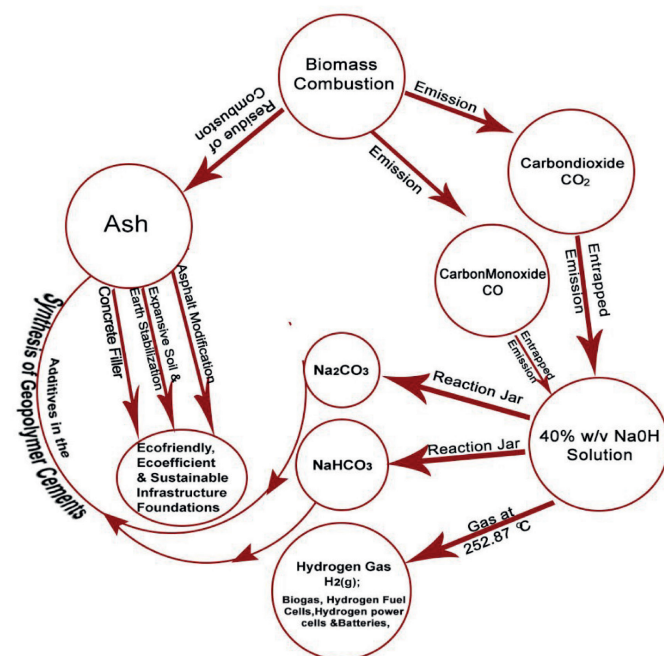


Fig. 2 Biomass valorization, carbon sequestration and hydrogen gas separation and capture cycle

2. ábra Biomassza hasznosítás, szén megkötés, hidrogén gáz elválasztás és megkötés körforgása

**Preparation of Specimens:** 2000 g of crushed open-air dried soil sample passing through sieve number 4; aperture of 4.76 mm was secured and readied for the experimentation. The specimens were prepared by deep and thorough blending and mixing at molding moisture contents of 2% dry, 0%, 2% wet and 4% wet of optimum moisture content, of the soil and varying percentages of the RHA in proportions of 2%, 4%, 6%, 8% and 10% by weight of treated solid. The standard proctor mold was used in this exercise to compact the specimen in accordance with appropriate standards.

**Index Properties:** Moisture content of the natural soil, specific gravity, and gradation characteristics were determined in accordance with experimental protocols presented in British Standard International [14].

**Atterberg Limits:** The consistency limits; liquid limit, plastic limit and plasticity index values were determined for the both the natural and treated soils in accordance with British Standard International [14; 15]. It was observed that the liquid limits decreased from 54% for the natural soil to 31% at the RHA treatment of 8% and increased to 36% at the RHA treatment of 10%. The plastic limit showed similar behavior and decreased from 26% for the natural soil to 17% at 8% treatment with RHA and increased again to 10% treatment of RHA. Generally, the plasticity index consequently showed the same trend and reduced to medium plastic condition of 14% at 8% treatment with RHA from a highly plastic condition of 28% for the natural soil.

**Compaction Properties:** The treated specimens were compacted using the standard proctor mold in accordance with British Standard International requirements presented in BS 1377 [14] and BS 1924 [15] to determine the maximum dry density (MDD) and the optimum moisture content (OMC).

**Volumetric Shrinkage:** In an effort to determine the volumetric shrinkage (%) of the specimens, the compacted materials were extruded from the standard proctor compaction mold and air dried for 12 days under temperature conditions of  $24 \pm 2^\circ\text{C}$  and measurements of diameters and heights were taken every other three (3) with the aid of a Vernier caliper of 0.01 mm precision. The changes in dimensions of the specimens with drying days were observed and recorded.

## 3. Discussion of results

### 3.1 Index and preliminary properties of the natural and treated soil

Table 1 represents the index and preliminary properties of the test soil. From Table 1 the following can be observed and deduced;

**Soil Classification using AASHTO System:** AASHTO soil classification system classified soils in accordance with their performance as subgrade. To classify the soil, laboratory tests including sieve analysis, hydrometer analysis, and Atterberg limits are used to determine the group of the soil. In the AASHTO system [16], the soil is classified into seven major groups: A-1 through A-7 and the soil under investigation is classified as A-7-6 as more than 35% of the sample passed through sieve no 200, i.e., 38%, and its liquid and plastic limits are 54% and 26%, which exceeds 41% and 11% respectively, being the minimum requirements for liquid and plastic limits of soils in this category. However, soils in this category are generally rated for subgrade use as fair to poor.

**Unified Soil Classification System:** On the basis of the Unified Soil Classification System (USCS), soil with  $> 50\%$  of sample mass retained on the 0.074 mm sieve is term coarse-grained and if  $> 50\%$  of the coarse fraction is retained on 4.76 mm sieve, the soil is classified as gravel but if  $\geq 50\%$  of the coarse fraction passes 4.76 mm sieve, such soil is sandy soil. Also the gravelly of sandy soil is classified further as well graded gravel/sand (GW or SW) or poorly graded gravel/sand (GP or SP) if percentage of the soil fines is  $< 5\%$ , but if the percentage of the soil fines is  $> 12\%$ , the soil plasticity index is plotted against its liquid limit and the soil is classified as



gravel/sandy clayey (GC or SC) or gravel/sandy silty soil (GM or SM) depending on its position on the chart. On the other hand, if  $\geq 50\%$  of the sample mass passes the 0.074 mm sieve, the soil is classified as fine-grained soil. The plasticity index of the soil fine-grained is then plotted against its liquid limit on plasticity chart to further distinguish the soil as silt or clay of low, medium, or high plasticity. Based on the Unified Soil Classification System (USCS) results shown in Table 1, the soil is poorly graded (GP) and is a clayey soil of high plasticity (CH). However, it was observed that addition of RHA at 4%, 6%, 8% and 10% improved the soil to clayey soil of medium plasticity (CL).

**Sieve Analysis:** The grain size analysis test results for the soil sample were summarized in Table 1. The values which were obtained from the gradation tests were analyzed with respect to the effect of pre-treatment and soil variations along lateral and depth wise. According to British Standard [14] the %passing the 0.075mm BS sieve should be  $< 35\%$  for subgrade. From the sieve analysis result carried out, 38% of the particles passed through the 0.075mm sieve. Hence the soil is not suitable for use as pavement subgrade.

**Soil Consistency Index:** Soil consistency index examined was Atterberg limit and widely used to differentiate soil types and states. The liquid limit,  $w_L$  and plastic limit,  $w_p$ , plasticity index  $I_p$ , and linear shrinkage of the soil were determined in order to examine the influence of RHA contents used in its treatment. In Table 1 above, the results of Atterberg limits were represented, and it was clearly indicated that the values of the liquid limit  $w_L$  (54%) and plastic limit (26%)  $w_p$  decreased with increasing proportion of RHA, from 54% to 48% and 26% to 23% at 2%, 48% to 42% and 23% to 20% at 4%, 42% to 36% and 20% to 19% at 6% and from 36% to 31% and 19% to 17% at 8% for liquid limit and plastic limit respectively. An increase was also observed in the values of liquid and plastic limits at 10% addition of RHA, from 31% to 36% and 17% to 20% respectively. According to BS 1377 [14], subgrade/fill material should have liquid limit  $\leq 50\%$  and plasticity index  $\leq 30\%$  while for sub-base, liquid limit should be  $\leq 30\%$  and plasticity index  $\leq 12\%$ . However, it can be observed that this soil is unsuitable for use as a pavement subgrade in its original state, but stabilizing same using RHA reduced the liquid limit and plasticity index, making it very suitable for use as pavement subgrade.

**Specific Gravity:** Specific gravity of the soil samples under investigation was determined using AASHTO T22 03, T85-91 procedures [17]. The specific gravity of the soil sample from the result above gave 2.05 and it is perfect for identifying poorly graded soils. It was also observed that addition of RHA at 2%, 4%, 6% and 8% increased the specific gravity of the soil sample to 2.08, 2.25, 2.42 and 2.70 respectively. At 10% addition of RHA, a decrease in specific gravity of the soil from 2.70 to 2.50 was observed. This however shows that RHA is a very good stabilizer for poorly graded soils.

**MDD ( $\text{mg/m}^3$ ) and OMC (%):** Compaction Test was carried out and tabulated to determine the compaction properties i.e., Maximum Dry Density and Optimum Moisture Content of the studied soil. The compaction result shows that the maximum dry density (MDD) of the sample has a value of  $1.85\text{mg/m}^3$  and optimum moisture content (OMC) of 12%. The range of values

that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall before  $1.44\text{ mg/m}^3$  and  $1.685\text{ mg/m}^3$  and optimum moisture content (OMC) may fall between 20-30%, for silty-clay MDD is usually between  $1.6\text{ mg/m}^3$  and  $1.845\text{ mg/m}^3$  and OMC ranged between 15-25% and for sandy clay, MDD usually ranged between  $1.76\text{ mg/m}^3$  and  $2.165\text{ mg/m}^3$  and OMC between 8 and 15%. Thus, looking at the results of the soil samples, it is observed that the sample is sandy-clay. The low values of the dry density indicate that the natural deposits are loose and accounts for the high void ratio. However, the addition of RHA increased the value of the MDD, while decreasing the value of the OMC respectively from  $1.85\text{ mg/m}^3$  and 12% to  $2.00\text{ mg/m}^3$  and 11% at 2%,  $2.30\text{ mg/m}^3$  and 9% at 4%,  $2.70\text{ mg/m}^3$  and 8% at 6% and  $2.85\text{ mg/m}^3$  and 8% at 8%. A decrease in value of MDD and increase in OMC was also observed at 10% addition of RHA  $2.85\text{ mg/m}^3$  and 8% to  $2.75\text{ mg/m}^3$  and 10% respectively. These substantial improvements recorded on the addition of RHA are due to the high binding strength and the aluminosilicate composition of the additive (see Table 2)

**pH Value:** Soil pH is a measure of the acidity or alkalinity of the water held in its pores. The pH scale goes from 0 to 14, with 7 representing neutral. From pH 7 to 0 the soil is increasingly acidic, while from 7 to 14 it is increasingly alkaline. Table 1 shows that the soil has a pH value of 7.2 and the addition of RHA at higher proportions further increases the soil's alkalinity.

Property	0%	2%	4%	6%	8%	10%
Natural Moisture Content, %	14	-	-	-	-	-
Liquid Limit, %	54	48	42	36	31	36
Plastic Limit, %	26	23	20	19	17	20
Plasticity Index, %	28	25	22	17	14	16
Linear Shrinkage, %	8	6.5	5.5	5.2	4.5	3.2
Percentage Passing BS sieve No. 200 (0.075mm)	38	41	43	47	51	55
AASHTO Classification	A-7-6	-	-	-	-	-
USCS Classification	GP, CH	GP, CH	GP, CL	GP, CL	GP, CL	GP, CL
Specific Gravity	2.05	2.08	2.25	2.42	2.70	2.50
Maximum Dry Density, $\text{g/cm}^3$	1.85	2.00	2.30	2.70	2.85	2.75
Optimum Moisture Content, %	12	11	9	8	8	10
pH Value	7.2	7.4	7.6	7.8	8.1	8.3
Color	Red	Reddish brown	Reddish brown	Reddish brown	Reddish ash	Reddish ash
Dominant Clay Mineral	Illite	-	-	-	-	-

Table 1 Physical properties of the untreated and RHA treated soils  
1. táblázat Kezeletlen és RHA kezelt talajok fizikai jellemzői

Materials	Oxides composition (content wt %)												
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>	LOI	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	IR	Free CaO
study soil	35	12.09	7.36	8.66	5.90	12.0	13.4	-	-	5.5	-	-	-
RHA	86.0	3.3	3.6	3.2	0.45	-	-	-	3.45	-	-	-	-

\*IR is Insoluble Residue, LOI is Loss on Ignition, RHA: rice husk ash.

Table 2 Oxides composition of the materials used in this paper  
2. táblázat A cikkben használt anyagok oxidos összetétele

### 3.2 Effect of Rice Husk Ash (RHA), Drying Time (DT) and Molding Moisture (MM) on the Volumetric Shrinkage of Treated Soil

Up to 10% by weight of RHA was utilized in the treatment of soft soil and the volumetric shrinkage (VS) behavior as a result of this treatment procedure was observed. These blending and mixing were achieved with four various molding moisture conditions of -2%, 0%, 2% and 4% of optimum moisture and subjected to different drying periods to a maximum of 12 days and measurements were recorded on 0, 3, 6, 9 and 12 days. Figs. 3, 4, 5 and 6 and Tables 3, 4, 5 and 6 present the graphical behavior of VS against percentage RHA treatment and tabulated behavior of the soil treated with RHA, molded under different moisture conditions and dried at different days. It can be observed that the VS reduced consistently with increased RHA where the soil was treated under 2% dry of optimum moisture in Fig. 3. Throughout the curing period, the VS also reduced considerably and all fell below VS of 4%, which according to standard requirements is the critical point above which a material cannot be considered good for use as a subgrade foundation under hydraulic bound conditions. This shows that RHA can be used to treat soft soils of similar properties under 2% dry of optimum molding conditions beyond 8% by weight. This behavior is attributed to the highly pozzolanic properties of RHA, which acted as an environmental conscious binder improving hydration reaction, cementation, calcination, and flocculation and reduced consistently the tendency for the treated material to be affected by shrinkage [18; 19]. Another reason for this behavior was because of the cation exchange that took place at the interface between soil polarized ions and those of the admixture within the diffused layer. Thirdly the fineness of the ash material contributed to filling process within the voids, which improved the space-mass index of the treated material. In Fig. 4, the treatment process was achieved under optimum moisture molding conditions i.e. 0% of optimum moisture. This condition is hardly experienced in the field where foundations are subjected to rise and fall of water table like the pavement foundation. This is due to the fact that water table rises when it rains and drops during dry seasons. In Nigeria for example, during spring and fall in many parts of the country, there always rain and this brings about the rise in water table while during winter, the water table falls considerably. So, pavement foundations, which are hydraulically bound structures suffer as a result. It can be observed that at 8% by weight addition of RHA, the VS fell below the critical point (4%), which is safe for treated soil materials to be utilized as subgrade foundation materials. In Fig. 5, wetting moisture condition of molding started where the treated material was molded with 2% wet of optimum moisture. This happens when the water

table rises and expose foundation materials to moisture ingress or migration through the poorly compacted or cracked layers. It can also be observed that at 8% by weight addition of RHA, the VS dropped to below 4% point safe for materials to be used but beyond that to 10% addition, the VS abruptly increased again beyond the critical line. This shows that, at the molding moisture condition of 2% wet of optimum, the RHA cannot be utilized beyond 8% again (see Table 3). This behavior was due to the added moisture which restarted the hydration reaction and created space for volume changes thereby increasing the shrinkage properties again in a renewed cycle. In Fig. 6, the molding moisture was increased and the condition wasn't encouraging as the behavior of the VS resided above the critical line except also at 8% by weight addition of RHA and at 12 days drying time. This is due to excessive molding moisture within the clayey mass of treated soil, which increase swelling properties and VS properties. On the hand, Figs. 7, 8, 9 and 10 show the response of VS with respect to the various drying periods in days. It can be observed that the VS reduced with increased exposure to drying conditions corresponding also to increased addition of RHA. The best result was obtained at 2% dry of optimum molding moisture condition and at the RHA treatment rate of 8% by weight. This shows that the longer the foundation materials treated with RHA stay through the drying period, the better and more reliable the strength development and a corresponding improvement in the volumetric shrinkage (VS) [20]. It is also important to remark that the VS obtained at the optimum moisture condition is reliable but beyond that line, on the molding moisture side, the treated material start to suffer the effect of moisture exposure. It is obvious that at molding moisture of 4% wet of optimum, the treated soil fails to meet the VS requirements.

Volumetric Properties	Air Drying Period (Days)	RHA treated soil compacted at 2% dry (-2%) of optimum (%)					
		0	2	4	6	8	10
Volumetric Shrinkage Strain (%)	0	10	9	7.5	5.5	4	3.5
	3	9.5	8	7	5.2	3.8	3.2
	6	8.5	7.5	6.5	5	3.5	3
	9	7.8	7.2	6	4.8	3.3	2.8
	12	7.5	7	5.5	4.5	3.1	2.5

Table 3 Desiccation of RHA treated soil compacted at 2% dry (-2%) of optimum  
3. táblázat RHA-val kezelt talaj száradása az optimálisnál 2%-kal szárazabban tömörítve

Volumetric Properties	Air Drying Period (Days)	RHA treated soil compacted at 0% of optimum (%)					
		0	2	4	6	8	10
Volumetric Shrinkage Strain (%)	0	12	10	7.5	5.5	4	5.2
	3	11	8.5	6.5	5	3.8	4.8
	6	9	7.5	6	4.5	3.5	4.5
	9	7	6.8	5.5	4.2	3.2	4.3
	12	6	5.5	5	4.1	3	4.2

Table 4 Desiccation of RHA treated soil compacted at 0% of optimum  
4. táblázat RHA-val kezelt talaj száradása az optimálisan tömörítve

Volumetric Properties	Air Drying Period (Days)	RHA treated soil compacted at 2% wet (+2%) of optimum (%)					
		0	2	4	6	8	10
Volumetric Shrinkage Strain (%)	0	15	12	8	6.5	4.1	5.5
	3	11	9	7.5	5.8	4	5.2
	6	8	7.5	6	5.2	3.8	4.8
	9	6	5.5	5	4.5	3.5	4.5
	12	6	5	4.5	4.3	3.5	4.3

Table 5 Desiccation of RHA treated soil compacted at 2% wet (+2%) of optimum  
5. táblázat RHA-val kezelt talaj száradása az optimálisnál 2%-kal nedvesebben tömörítve

Volumetric Properties	Air Drying Period (Days)	RHA treated soil compacted at 4% wet (+4%) of optimum (%)					
		0	2	4	6	8	10
Volumetric Shrinkage Strain (%)	0	18	14	12	9	7	5.5
	3	17	13	10	7.5	6.5	4.5
	6	15	12	9.5	6.8	5.5	4.2
	9	11	8.5	7.5	5.5	4	4
	12	8	7.5	5.8	4.5	4	4.2

Table 6 Desiccation of RHA treated soil compacted at 4% wet (+4%) of optimum  
6. táblázat RHA-val kezelt talaj száradása az optimálisnál 4%-kal nedvesebben tömörítve

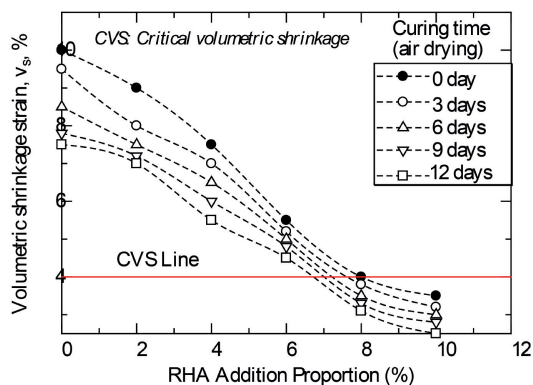


Fig. 3 Volumetric shrinkage of RHA treated soil compacted at 2% dry (-2%) of optimum moisture  
3. ábra Optimális víztartalomnál 2%-kal szárazabban tömörített RHA kezelt talaj térfogati zsugorodása

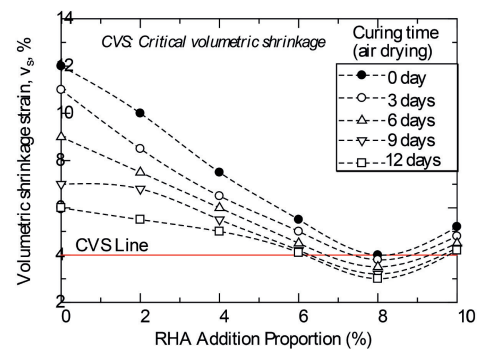


Fig. 4 Volumetric shrinkage of RHA treated soil compacted at optimum moisture  
4. ábra Optimális víztartalom mellett tömörített RHA kezelt talaj térfogati zsugorodása

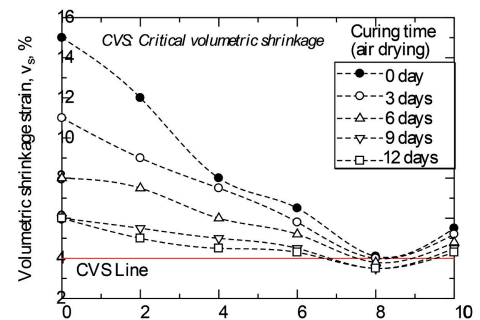


Fig. 5 Volumetric shrinkage of RHA treated soil compacted at 2% wet (2%) of optimum moisture  
5. ábra Optimális víztartalomnál 2%-kal nedvesebben tömörített RHA kezelt talaj térfogati zsugorodása

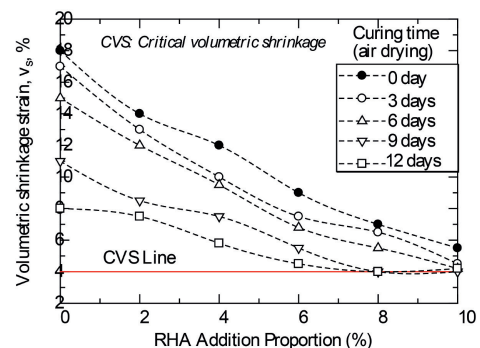


Fig. 6 Volumetric shrinkage of RHA treated soil compacted at 4% wet (+4%) of optimum moisture  
5. ábra Optimális víztartalomnál 4%-kal nedvesebben tömörített RHA kezelt talaj térfogati zsugorodása

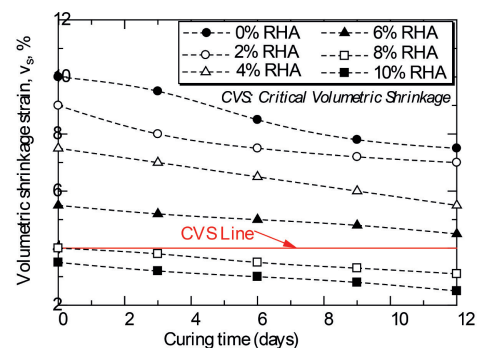


Fig. 7 Volumetric shrinkage against curing time of soil treated with RHA at 2% dry of optimum moisture molding condition  
7. ábra RHA kezelt talaj térfogati zsugorodása az utókezelési idő függvényében optimális nedvességtartalomnál 2%-kal szárazabban készítve



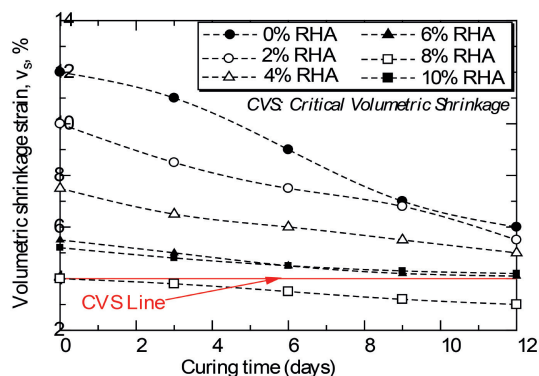


Fig. 8 Volumetric shrinkage against curing time of soil treated with RHA at optimum moisture molding condition

8. ábra RHA kezelt talaj térfogati zsugorodása az utókezelési idő függvényében optimális nedvességtartalom mellett készítve

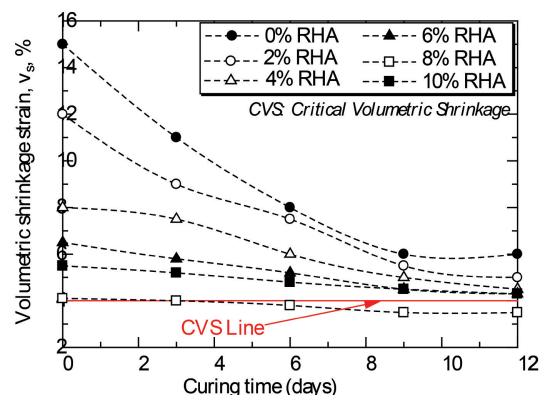


Fig. 9 Volumetric shrinkage against curing time of soil treated with RHA at 2% wet of optimum moisture molding condition

9. ábra RHA kezelt talaj térfogati zsugorodása az utókezelési idő függvényében optimális nedvességtartalomnál 2%-kal szárazabban készítve

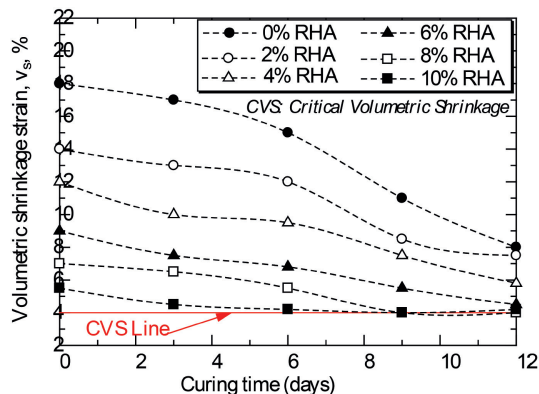


Fig. 10 Volumetric shrinkage against curing time of soil treated with RHA at 4% wet of optimum moisture molding condition

10. ábra RHA kezelt talaj térfogati zsugorodása az utókezelési idő függvényében optimális nedvességtartalomnál 4%-kal szárazabban készítve

## 4. Conclusion

The following remarks can be made from the laboratory investigation of the critical state volumetric shrinkage of compacted earth treated and improved with rice husk ash;

a. The index properties of the test soil showed that it is an A-7-6 soil group according to AASHTO method, it is highly plastic with the  $I_p$  above 17%, it is poorly graded and expansive with high shrinkage properties, which

made it undesirable to be used as a pavement foundation soil subjected to hydraulically bound conditions.

- b. The RHA as a lignocellulosic and amorphous material has high pozzolanic reaction on the treated soil thereby improving the shrinkage properties under different molding moisture conditions.
- c. The VS of the treated soil reduced consistently with the addition of RHA and with the days of exposure (drying) and important to note is that the VS reduced below the critical line 4% at 8% by weight addition of RHA and was established as the proportion that met the condition for the soil material improvement under varying molding moisture conditions between -2% and 4%. Meanwhile, the drying period proved that the longer the days within the drying conditions, the better the VS. it shows that water migration and ingress during rise in water table for hydraulically bound structures like the pavement foundation causes the VS to increase above the critical level thereby causing failures of the pavement facilities.
- d. Finally, and once again, Rice Husk Ash (RHA) has proven to serve as an environmentally conscious construction material with the potentials to improve soils and the ground for use as foundation materials. With the above results, it can comfortably replace the conventional cement and completely rid our planet with the sources of greenhouse emission for a healthier world of construction activities.

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