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Effect of Rice Husk Ash (RHA) as a Pozzolan on the Strength Improvement of Cement Stabilized Peat

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ABSTRACT

Cement is one of the most effective conventional methods for peat soil stabilization. However, this method is not environmentally friendly because the use of too much cement causes much carbon dioxide to be produced for cement production. Rice husk ash (RHA) is applied as substitution for Ordinary Portland Cement (OPC) in this study. RHA is waste generated from agricultural activities formed from the rice husk combustion process and will help mitigate pollution and disposal problems by recycling this waste in peat soil stabilization. Therefore, the study aims to investigate the basic characteristics of Pontian peatlands and assess the strengths of peat soils by using RHA. Laboratory tests including moisture content, organic content, fibre content, liquid limit, particle size analysis, unconfined compressive strength (UCS) and the Scanning Electron Microscope (SEM) together with Energy Dispersive X-Ray (EDX) analysis were experimented to investigate properties base of peatlands located at Pontian with the proportion of mixing ratio of RHA between 5% to 20%. Based on UCS test, at RHA 5% replacement mixture with cement shows the higher soil strength compared to other RHA replacement mixture with cement with the strength of 185 kN/m^2, 233 kN/m^2, and 278 kN/m^2 for 7, 14 and 28 days of curing periods, respectively. The research found that RHA can promote peat stabilization, particularly in samples with a 95% cement ratio and 5% RHA that can be a countermeasure for environmental issues such as pollution and energy use.

1. Introduction

Generally, organic breakdown and deposition of deceased plants produce peat soil. Peat soils, often referred to as highly acidic soils, exhibit a scarcity of microorganisms, alongside a notable abundance of organic matter. These soils possess a low weight and are visibly discernible under arid circumstances [1]. The peat soil distributions in Malaysia were officially reported to encompass a combined area of 6,073,183 acres, accounting for approximately 7.45% of the country's total geographical area. Malaysia is the top ten of land occupied by Peat Land. The distribution in Malaysia

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shows Sarawak is the biggest area of peat with 4,195,471 acres or 69.08%, Peninsular Malaysia is second largest distribution with 1,588,684 acres or 26.16% and Sabah contributing 289,026 acres with 4.76% dominance [2]. The distributions of peatland in Pontian located in Peninsular Malaysia are quite significance with the low strength of soil structure. Due to the disadvantages, the low strength of the peat soil has affected the agricultural activities in Pontian regarding its infrastructures such as access road and building construction experienced unstable foundation due to the weak soil structure. It is important to enhance the problematic soil structure in order to provide better facilities for agricultural purposes.

The existing peat soil categorization method, which relies solely on organic content and ash content, is deemed inadequate. It is important to consider additional factors including natural water content, structure, level of humidification, organic substance category, and specific gravity in order to achieve a comprehensive classification [3]. In addition, peat is a type of soil formed from the accumulation of plant waste which is partly disintegrated due to insufficient oxygen supply. Peat can give rise to geotechnical challenges in various aspects, including the location of sample collection, deposition, stability, in situ evaluation, stabilization, and building [4]. According to Hashim & Islam [5], peatlands are generally found in thick layers in a limited area. Peat soils also have weak bearing capacity and very high compressibility [6-8]. This is why peat soils often experience difficulties when construction work is carried out on peat soils. Peat is permeable in nature and has the potential to hold significant volumes of water when saturated [9].

A range of stabilization techniques can be employed to enhance the stability of peat soils, with cement frequently utilized as an addition to augment the bearing capacity of such soils. There is a need to look for other alternative technologies which are more environmentally friendly and economical although this type of stabilization is very popular and has been successful in the past. Cement serves as a cohesive agent for peat soils, which exhibit higher porosity in comparison to other soil types. Nevertheless, the utilization of cement for the purpose of stabilizing peat soils poses a significant hazard to the ecosystem by the consequences of carbon dioxide (CO_2) emission throughout the process of cement production resulting in environmental pollution. The use of cement is not economically viable due to large amount of cement required to cover a wide area of peat land [10-11]. Among the other factors influencing this change are the awareness of the environmental impact of the high energy consumption and the emission of CO_2 in the cement production [12].

Numerous global initiatives and scientific investigations have been undertaken to mitigate the utilization of cement in diverse domains. Among the popular efforts is to utilize rice husk ash (RHA) as the substitution of cement [13]. RHA refers to the regional agricultural waste material derived from the Paddy Industry in Malaysia. The proper management of ash generated from combustion processes is a significant challenge to several industries, therefore resulting in detrimental environmental consequences. The production process of rice from planting, harvesting and isolation of paddy [14]. The study conducted by Chao-Lung *et al.,* [15] shows the use of Rice Husk Ash (RHA) in the construction material can provide significant benefits such as the compressive strength of concretes with a highest of 20% of RHA in concrete results in comparable values to conventional concrete. Furthermore, the utilization of RHA exhibits significantly higher cement strength efficiency for comparison to the conventional concrete. By virtue of it, the utilization of rice husk ash in peat soil exhibits promising prospects for improving the concrete performance in terms of its clean and stabilized states. The utilization of rice husk ash in concrete has been observed to enhance the workability of plastic concrete, as well as augment the strength and durability of hardened concrete [16]. The use of RHA also presents a cost-effective solution. The addition of RHA into concrete has the potential to decrease the quantity of Portland cement required.

The study aims to improve the strength of the peat by using cement and RHA as the main material. The investigation of the use of RHA materials as an alternative to cement dosage, addressing pollution and energy use issues, aligning with sustainable development principles.

2. Methodology

2.1 Materials

RHA was obtained from Kilang Beras Jelapang Selatan in Muar, Johor. The primary constituents employed in the process of sample preparation encompass peat soils, Ordinary Portland Cement (OPC) and rice husk ash (RHA.) Regarding to the primary constituent, substance such as sodium chloride, can be employed to facilitate the process of stabilization.

2.2 Location and Sampling Method

Based on the scope of the study, peat soil samples used are peat soils taken from Benut, Pontian area. Figure 1 presents the peat sample area used in this study.

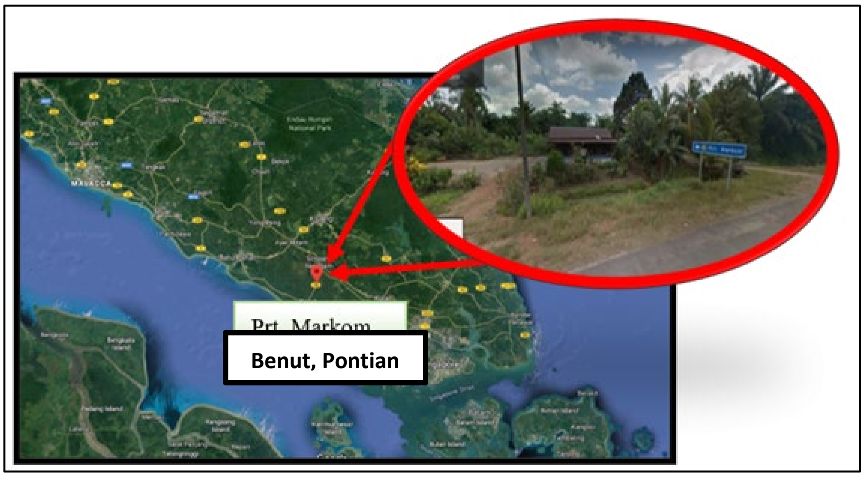

Fig. 1. Sampling location for peat at Benut, Pontian, Malaysia

The peat soil utilized in this investigation was a soil that has undergone disturbance. The sampling method employed in this study involved manual excavation to 1 m depth starting from the surface layer of the ground. 10 cm depth of the soil layer was found to be distinct due to its composition as the uppermost layer, which does not accurately reflect the native peat soil characteristics of the region. Samples of soil taken have been put into containers containing plastic and closed to ensure peat soil was not exposed to the environment. Wet cloth was placed on plastic peat soils to retain the original moisture content of peat soils.

2.3 RHA Preparation

The remaining rice husk waste has been dried before blending to facilitate the rooting process. Rice husk used was burned in oven at 700 °C for 6 hours based on the test conducted by Abu Bakar *et al.,* [17] with the aim of moisture removal and yielding smooth husk surface. Ready-dried rice husks are left in a temperature room to shrink hot and sifted with a size of 63 µm size to produce RHA which has uniform ash size.

2.4 Laboratory Testing for Basic Properties Study

Laboratory tests including the experiment of moisture and organic content, pH, liquid limit, specific gravity, fiber content, unconfined compressive strength and particle size analysis have been carried out to determine the characteristic of the peat soil samples in term of basic, chemical, mechanical and physical properties. In this study, the peat soil samples for analysis were partitioned into two groups which is treated peat samples and untreated peat samples. The untreated sample refers to the peat sample that has yet to be undergone any mixing with the binder. All the samples used in this study have been through curing processes for 7, 14 and 28 days. Every experiment done within this study adhered to the approved standards and guidelines. Table 1 presents a comprehensive record of the standards and regulations employed for each testing undertaken in the course of this investigation.

Table 1
Adopted standards for test methods

Experiment	Symbol	Standard
Moisture content	MC	ASTM-D 2974
Organic Content	OC	ASTM-D 2974
PH value	pH	ASTM-D 4972
Liquid Limit	L_L	BS 1377 PART 2: 1990: 4.3
Specific Gravity	G_s	BS 1377 PART 2: 1990: 8.3
Fiber Content	FC	ASTM-D 1997
Unconfined Compressive Strength Test	UCS	ASTM-D 2166
Particle Size Analysis	PSA	ASTM-C 618

2.5 Mix Design

The preparation of peat samples involved categorizing into various groups based on the cement mix and RHA ratio, as outlined in Table 2. The study excluded untreated soil samples, encompassing five different types of mixes. represented by symbol (PC) with peat soil and Ordinary Portland cement (OPC) content was 100%. The abbreviated form for the mixing ratio on peat sample including the symbolic rice husk ash representing the symbol (RHA).

The division of material proportions in this investigation was determined by the volume of the sample, which had height and diameter of 150 mm and 50 mm, respectively. The materials used in the preparation of the samples were peat, cement, and RHA. The sample preparation used the same amount of the mixture for the7, 14 and 28 days of curing process. The process of calculating the quantity of materials used for each specimen tested was based on a previous study from Abu Talib *et al.*, [18]. The determination of peat soil quantities is derived from the bulk density measurement of peat soils, which is established at a value of 10 kN/m^3. The necessary quantity of peat soil for a specimen was determined by multiplying the bulk density data by the specimen volume of 0.000295 m^3.

Furthermore, the specified amount of Ordinary Portland Cement (OPC) necessary for a certain 300 kg/m^3 specimen. The mix ratio amount is subject to variation based on the proportion of cement and the amount of RHA. For example, PCR5 samples containing 95% cement and 5% RHA were multiplied by 300 kg/m^3 for the total quantity of cement and RHA. Every mixture utilized in this experiment was measured in grams (g) as the unit of weight.

Table 2
Laboratory mix design

No. test	Type of test	Test purpose	Curing duration	Binder compositions	Abbreviation
1	Unconfined Compressive Strength Test	To examine the effect of binder composition on the tested specimens	7, 14 & 28 days	100%^{1}OPC: ^{2}PC	PC100
				95%^{1}OPC:5%^{3}RHA	PCR5
				90%^{1}OPC:10%^{3}RHA	PCR10
				85%^{1}OPC:15%^{3}RHA	PCR15
				80%^{1}OPC:20%^{3}RHA	PCR20

*^{1}OPC: *Ordinary Portland Cement*
*^{2}PC: *Peat Cement mixtures*
*^{3}RHA *Rice Husk Ash*

2.6 Unconfined Compressive Strength Test

The sample preparation method employed for carrying out the unconfined compressive strength (UCS) test adheres to the prescribed mix ratio as specified by the ASTM-D 2166 experimental standard. The sample preparation for this study was using PVC pipe as a reference. The mold dimensions employed were 50 mm and 150 mm in diameter and height, respectively. The dimensions of the sample size utilized for the UCS test were 50mm and 100 mm in term of diameter and height, respectively.

The first stage in the peat sample preparation involved the arrangement of ingredients, specially cement and RHA amount. After accurately measuring every ingredient, a conventional mixing machine was utilized to combine the ingredients for a duration of one minute. This procedure was conducted in order to achieve a meticulous and all-encompassing mixing of the ingredients before being added into peat soil specimens. Following the end of the preparation of the material mixture, the peat samples have undergone a mixing process for a period of 3 minutes by using a mixer. The duration of the peat soil sample mixing procedure was prolonged by adding the previously produced binders into the identical mixing apparatus. In order to obtain a uniform combination, each sample underwent a process of homogenization, accomplished by thorough mixing for a period of 6 minutes. The complete mixed samples were then poured into molds, with a maximum of three layers. A rigid metal retainer with 20 bumps per layer and a constant height of 10 cm was used to compress each layer. Following the sample's insertion and compacting within the mold, it was submerged for 7, 14, and 28 days in a water-filled container to begin the curing process.

2.7 Compression Test

This compression test is one of the most important tests in this study as it determines whether the resulting mixture to treat peat soils is capable of achieving the expected strength target or otherwise. The strength test used in this study was UCS with the ASTM-D 2166standard as a reference to the treated peat strength determination. Treated peat samples were preserved with curing for 7, 14 and 28 days. The molds applied in this compression test were 50 mm and 100 mm in diameter and height, respectively for each sample.

Deformation dial values were recorded for each 0.25 mm interval at the load dial. The deformation dial value will reach the maximum value and will decrease after shear failure occurs on the tested sample. The value of the drop was recorded to get the overall graph of the sample. The average value of the two samples tested for each different mix ratio were used to obtain an optimum mix ratio for the entire study.

2.8 Characterization of Chemical and Physical Structure

The purpose of the Energy Dispersive X-ray (EDX) study was to determine the chemical or elemental composition underlying the mixture strengthening on treated peat. Scanning Electron Microscopy (SEM) was used in addition to this chemical evaluation to provide microstructure proof of the stabilized soil's cementation and void refining. The sample preparation must be done specifically for SEM/EDX analysis. The treated peat samples were put through a 150 micron screen using sieve apparatus before being coated with thin layer of conductive material such as gold to avoid charging during analysis before undergoing SEM/EDX.

3. Results

3.1 Basic Properties of Peat Soil

Moisture, organic and fibre content, potential of hydrogen (pH) values, specific gravity, liquid limit, particle size analysis (PSA), microstructure, and chemical composition of the peat samples have been conducted to determine the characteristics of peat soil.. The findings of studies done to ascertain the fundamental characteristics of peat soils are shown in Table 3. The findings prove that the peat exhibits a range of fiber content spanning from 31% to 77%, organic content ranging from 50% to 97%, and a pH value of 3.03. Consequently, the peat can be classified as hemic peat due to its elevated organic composition and high acidity. Hemic peat typically acidic, intermediate range of fiber content and high organic content due to the slow decomposition process of organic matter [19]. The investigation found that the peat exhibited low strength and instability, which may be attributed to factors such as low strength, water content, and liquid limit. Consequently, these factors have a negative effect on the peat shear strength of the peat [20].

Table 3
Summary of analysis of the basic properties of Benut, Pontian

Laboratory test	Values	Published Data
Moisture content (*w*), %	602.73	200-2200
Organic content (OC) %	84.17	50-97
Acidity, pH	3.03	3-7.2
Specific gravity, G_s	1.65	1.07-1.8
Fibre content (FC), %	47	31-77
Liquid limit (L_L), %	199.5	190-550

3.2 Effect of RHA Replacement in OPC on the Strength Characteristics

The investigation involves the substitution of cement with varying proportions of RHA, ranging from 5% to 20% (as shown in Table 3). The optimal UCS can be determined by relationship between the UCS analysis of stabilized peat and the mixing ration of RHA, as illustrated in Figure 2. The findings of the stabilized peat were found to be influenced by the utilization of RHA as a substitution for OPC. The test specimen with a 5% substitution of OPC with RHA has the highest UCS rate of 278 kPa, slightly surpassing the UCS of the PC specimen. In general, the reaction between cement and water (H_2O) results in the formation of Calcium silicate hydrates (CSH), also known as tobermorite, along with calcium hydroxide (CH) [21]. The cohesive substance responsible for the interconnection and stabilization of soil particles is derived from CSH. Nevertheless, the interaction between humic acid found in peat and calcium ions results in the formation of calcium humic acid, which is insoluble [22].

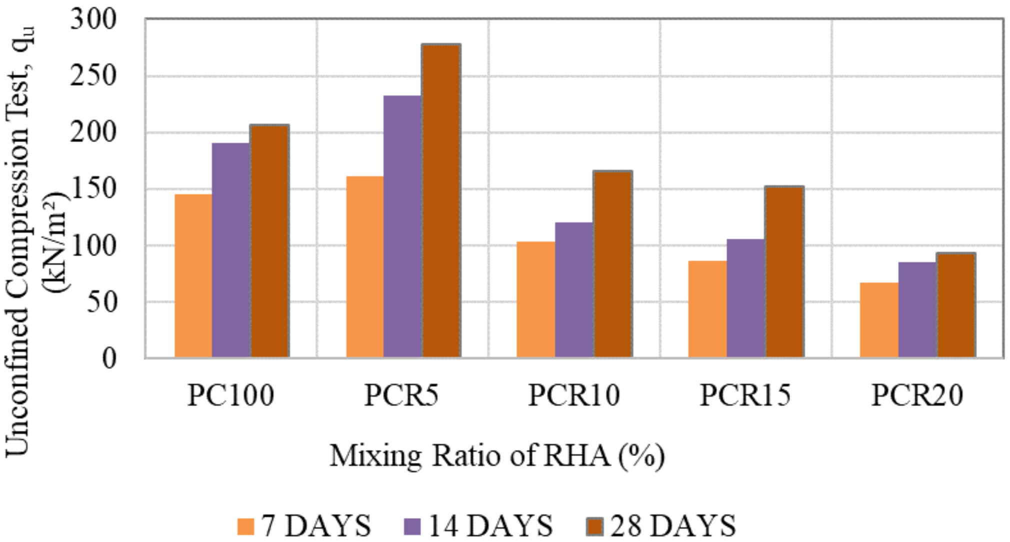

Fig. 2. Effect of RHA percentage replacement on the UCS on stabilized peat

The modest enhancement in strength found in the soil-cement composite can be ascribed to the inhibitory consequences arising from the subsequent pozzolanic reaction between CH and peat. This reaction occurs after the optimal effects of cement hydration have already taken place. It can be hypothesized that the soil-cement mixture with a 5% content of rice husk ash exhibits improved values of UCS, thereby contributing to this explanation. The application of RHA into the soil-cement mixture technique resulted in enhanced cement hydration. The interaction between the pozzolan, CH, and water results in the generation of supplementary secondary tobermorite gels with calcium alumina silicate hydrates (CASH) [23]. The factor contributing to the formation of an alkaline condition that facilitates the reaction of secondary pozzolanic in cemented peat soil is the inclusion of pozzolan, which possesses higher concentrations of silica and alumina. The cement has activated the components that are capable of neutralizing acidity, thereby equalizing the acid levels. Consequently, the incorporation of CSH and CASH serves to enhance the compaction of stabilized peat and enhance the strength of the peat structure.

3.3 Effect of RHA Replacement in OPC with SEM and EDX

SEM tests were conducted to prove the microstructure changes occurring in peat soil after stabilization. The samples used in this test were PC100 and PCR5 with a duration of 28 days representing the sample after stabilization. The selection of a 28 days curing sample is due to the reaction between binders and peat soils and produce high strength in longer periods. The results of the SEM analysis indicate the sample state upon stabilization, as depicted in Figure 3, for the purpose of conducting comparisons. This phenomenon can be further clarified by observing the increased compaction of soil microstructure following stabilization, achieved by maintaining a consistent focal point on the lens. A comparison between the soil following stabilization for the PC100 mixture and the PCR5 mixture revealed a gradual reduction in fibrous particles and porous particles with empty spaces, leading to an increasing density of the soil structure. Due to the nature of the pozzolan material RHA has reacted as filler in the cavity space [24]. The SEM and EDX experimental results charts show the average value of the chemical for the sample after the stabilization is plotted. The value of the chemical is taken from 3 different points of the area as labelled in Table 4 for soil after stabilization using PC100 and PCR5.

Furthermore, in terms of changes in chemicals can be seen in Table 4 which shows that the difference in oxide compounds in terms of carbon values carbon (C), oxide (O), Alumina (Al), Silica (Si), Calcium (Ca) and Iron (Fe). Due to the minimum mix of 5% RHA, the peat soil strength can be improved than the use of 100% of PCs in peat stabilization. Cement and its hydration products are frequently related to C, O, Al, Si, Ca, and Fe and significantly affect the UCS value. Hydration is the process by which cement chemically combines with water to create a matrix that is both strong and persistent. The stabilised peat develops the required strength and stability during the curing stage because it gives the hydration process sufficient time to take occur. Indirectly, RHA is a good pozzolan material to enhance cement strength by mixing with specific ratio. By comparing to EDX outcomes in Figure 4, the findings indicate that stabilized peat, specifically PC5, exhibits enhanced strength when the C content is reduced, and the Ca content is increased. It was clearly shown the highest intensity (peak) of the elements of Ca, Si, Al and O if compared to PC100. It is imperative to acknowledge that the presence of the four elements is crucial in facilitating the formation of CSH and CASH crystals. These crystals serve as the primary cementation products in stabilized soil [25]. Obvious decrement of carbon elements percentage was observed after Pontian peat was stabilized. For instance, by comparing PC100 mixtures with mixtures PCR5, the carbon elements fell dramatically from 42.78% to 36.76%. This finding proves that neutralization of organic matter in peat by peat-cement-rice husk ash combinations are significant.

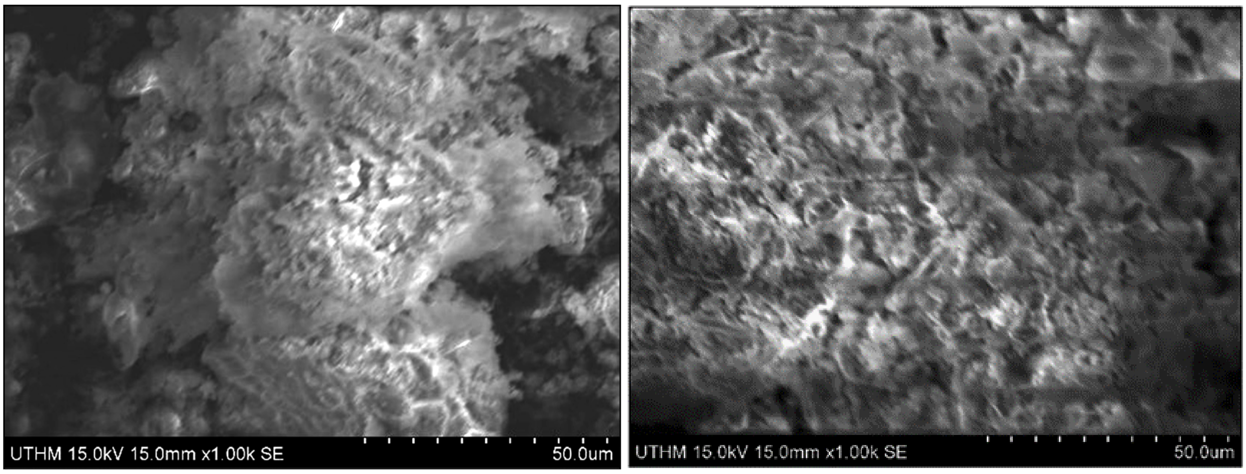

Fig. 3. Scanning-electron microscopy (SEM) for PC100 and PCR5

Table 4
Element compositions in PC100 and PCR5 samples.

Element	Symbol	Percentage (%)	
		PC100	PCR5
Carbon	C	43	37
Oxygen	O	40	42
Aluminum	Al	1	2
Silica	Si	2	2
Calcium	Ca	13	16
Fe	Iron	2	1

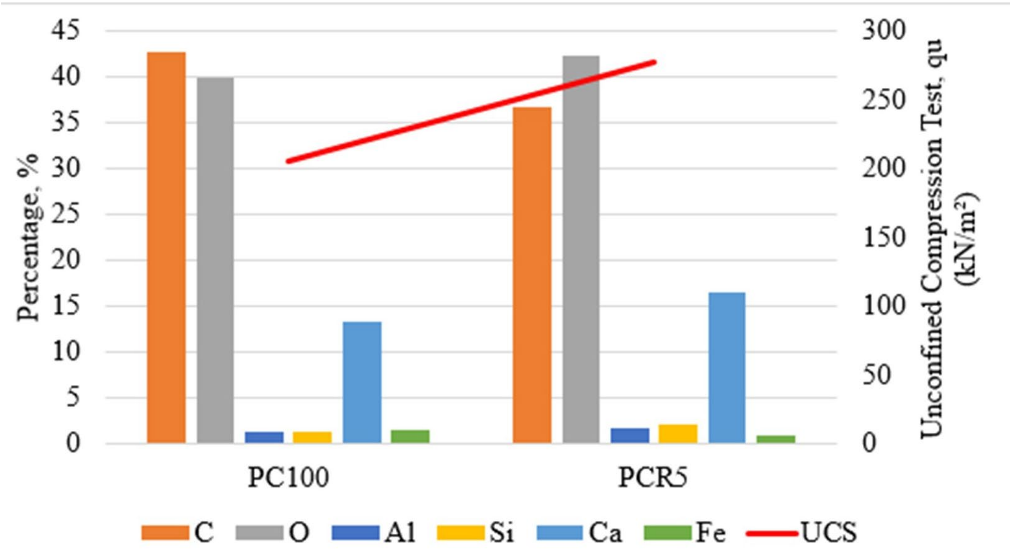

Fig. 4. The relationship trends for EDX and UCS

4. Conclusions

The employment of RHA to improve the strength of Pontian Peat was investigated significantly. The result of this study is derived from the analysis, data, and explanation provided in this research, which suggests that the utilisation of RHA can promote the stabilization of peat. Peat soil in Benut, Pontian was classifying as hemic peat based on the H4 class in fiber content test, Von Post scale table due to the capacity to retain a significant quantity of water. It also classifies as highly acidic with high ash content. This proves that peat soil in targeted location was produced from decayed organic matter. From the peat stabilization treatment using RHA as pozzolan, it was observed that the samples of PCR5, which had a cement ratio of 95% and included 5% RHA were determined to be the optimal choice for the research conducted. The PCR5 sample demonstrated optimal strength throughout the curing process, reaching maximum values of 185 kN/m^2, 233 kN/m^2, and 278 kN/m^2 after 7, 14, and 28 days, respectively. In conclusion, the implementation of a 5% reduction in cement material yields significant environmental benefits in terms of sustainability. This reduction directly addresses the adverse effects associated with cement manufacture, such as the generation of diverse forms of pollution, notably carbon dioxide emissions and excessive energy use. Hence, it is imperative that the emerging sector in Malaysia actively promotes and adopts the utilization of RHA materials as a viable alternative to a portion of cement dosage. This initiative aligns with the principles of sustainable development, thereby requiring further attention and implementation.

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