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ชื่อโครงการ Effect of the curing time and leaching of drill cuttings used as a raw material to produce mortar.

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SENIOR PROJECT

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Effect of the curing time and leaching of drill cuttings used as a raw material to produce mortar

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หัวข้อ ผลกระทบของระยะเวลาในการบ่มและการชะละลายของของเสียจากการขุดเจาะที่ใช้เป็นวัตถุดิบในการผลิตมอร์ตา
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บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาการใช้ประโยชน์จากของเสียจากการขุดเจาะ จากกระบวนการขุดเจาะน้ำมัน โดยนำของเสียจากการขุดเจาะใน 4 ชั้นความลึก มาใช้เป็นส่วนผสมทดแทนทรายในกระบวนการผลิตมอร์ตาร์และศึกษาหาระยะเวลาการบ่มที่เหมาะสม ตัวอย่างของเสียจากการขุดเจาะแต่ละชั้นความลึกจะแบ่งออกเป็นตัวอย่างที่ผ่านการล้างน้ำ และไม่ผ่านการล้างน้ำ มาผลิตเป็นมอร์ตาร์ขนาด 5x5x5 ลูกบาศก์เซนติเมตร มีส่วนผสมของปูนซีเมนต์ปอร์ตแลนด์:น้ำ:มวลรวมละเอียด ร้อยละ 1:0.485:2.75 โดยน้ำหนัก ซึ่งมวลรวมละเอียดในการทดลองนี้ประกอบด้วยทรายหยาบและของเสียจากการขุดเจาะ ในสัดส่วนแทนที่ร้อยละ 0 (ชุดควบคุม) และร้อยละ 40 โดยน้ำหนัก ทำการบ่มในน้ำที่อุณหภูมิห้องเป็นเวลา 7 14 และ 28 วัน จากนั้นจึงทำการศึกษาค่าความหนาแน่น ค่าการดูดซึมน้ำ ค่ากำลังรับแรงอัด และการชะละลาย ผลการทดลองพบว่า ระยะเวลาในการบ่มที่น้อยที่สุดที่ให้ค่ากำลังรับแรงอัดผ่านมาตรฐาน คือ 7 วัน ของเสียจากการขุดเจาะที่ไม่ผ่านการล้างน้ำ ชั้นความลึกที่ 3 (A3) มีค่ากำลังรับแรงอัดสูงที่สุดที่ 48.74 เมกะพาสคาล เมื่อเปรียบเทียบกับมาตรฐานพบว่า ความหนาแน่นและค่าการดูดซึมน้ำผ่านตามมาตรฐาน คอนกรีตบล็อกเชิงต้นรับน้ำหนัก (มอก.60) ในขณะที่ค่ากำลังรับแรงอัดของมอร์ตาร์ทุกตัวอย่างมีค่าสูงกว่าเกณฑ์มาตรฐานปูนก่อสำเร็จรูปชนิดแห้ง (มอก.598) และ มอก.60 เช่นกัน เมื่อทำการทดสอบการชะละลายโลหะหนักของของเสียจากการขุดเจาะ พบว่าต่ำกว่าเกณฑ์มาตรฐานตามประกาศกระทรวงอุตสาหกรรม เรื่อง การกำจัดสิ่งปฏิกูลหรือวัสดุที่ไม่ใช่แล้ว พ.ศ. 2548 ดังนั้นจึงสามารถนำของเสียจากการขุดเจาะมาใช้เป็นวัสดุทดแทนทรายในอุตสาหกรรมการก่อสร้างได้

คำสำคัญ: กำลังรับแรงอัด การดูดซึมน้ำ การชะละลาย ของเสียจากการขุดเจาะ มอร์ตาร์

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ABSTRACT

The purpose of this study was to utilization drill cuttings generated from petroleum drilling, which is used as a raw material for mortar production and to find an optimal curing time for mortar. Drill cuttings from 4 depths were divided into as-is samples and cleaned samples. Each mortar was produced in cubic mortar size 5 x 5 x 5 cm^3. The mixture was prepared by Portland cement: water: fine aggregate of 1:0.485:2.75 by weight. The fine aggregate in the experiment consisted of drill cuttings with replaced of coarse sand for 0% (control), and 40% by weight, curing by immersed in water for 7, 14 and 28 days. Mortars were evaluated for density, water absorption, compressive strength, and leachability. The minimum curing time to achieve the standard compressive strength was in 7 days. As-is sample at the third depth had the highest compressive strength of 48.74 MPa. Compared to the standards, it was found that density and water absorption of all specimens was passed the standard of solid load-bearing concrete masonry units (TIS 60) while average compressive strength was higher than the standards of dry mortar for masonry units (TIS 598) and TIS 60 as well. From the leaching test of heavy metals from drill cuttings, it was found that the concentration of heavy metals was lower than that of the standard set by Announcement of the Ministry of Industry, 2005. Therefore, drill cuttings can be used as a fine aggregate in the construction industry.

Keywords: compressive strength, water absorption, leaching, drilling waste, mortar

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Chapter I

Introduction

1.1 Background and rationale

In the present, demand for global energy increases as the population growth increases, causing more oil drilling to compensate for energy loss. Drill cuttings is an environmentally hazardous by-product of drilling process (Mostavi et al., 2015). They use drilling fluids to cool and lubricate the drill bit for easily transport to the surface (Ball et al., 2012). Drilling fluids can be divided into three main groups depending on base liquid i.e., water-based mud, oil-based mud, and synthetic-based mud. Drill cuttings water-based mud are not classified as hazardous waste. However, drill cuttings with synthetic base mud or oil-base mud are classified as hazardous waste by the Announcement of The Department of Mineral Fuels. It is contaminated with petroleum hydrocarbon and heavy metals such as As, Cr, Cu, Pb, Ni, Zn (Kogbara et al., 2016). Drill cuttings can be normally managed by disposal at sea or landfill, thermal treatment and incineration, bioremediation, and solidification/stabilization (S/S). Every treatment method has pros and cons. Thermal treatment generates residue gases that needs to be treated to remove particulates and harmful combustion products such as sulfur oxides, nitrogen oxides. Biological treatment cannot treat the complex molecular structure from contaminated drill cuttings such as the higher molecular weight aliphatic or poly-aromatic organic constituents. Solidification is involving immobilization to transform the waste into a less hazardous form by mixing hazardous waste with cement to hardening. Contaminant migration is restricted by decreasing the surface area exposed to leaching (Ball et al., 2012).

In recent years, the reuse applications have been suggested for drill cuttings management. Many researchers have studied on applications of drilling wastes such as manufacturing of Portland cement, brick and concrete blocks and highway construction materials (Mostavi et al., 2015). There are some researchers studied the possibility of drill cuttings fixed in cement and tested for their characteristic. Compressive strength depends on the growth of crystals from a hydration reaction between cement and water. If there is not enough relative humidity, the crystals cannot grow, and the concrete does not develop the strength as it should. Therefore, curing is an important factor for concrete that impacts the quality of concrete. The use of drill cuttings as raw materials for mortar production should be tested for the toxicity of the material by the leaching test according to Announcement of the Ministry of Industry, 2005. As drill cuttings property from different places vary in size, texture, type of rock, and drilling fluid, hence, this study tried to investigate the potential of using drill cuttings with water-base drilling mud from onshore petroleum drilling in Kamphaeng Phet province to mix with concrete as a replacement of aggregate in mortar. Curing time, one of the main factors, was examined and tested for compressive strength and leaching characteristic of drill cuttings to comply for the application.

1.2 Objectives

1.2.1 To study the effect of curing time of mortar produced from drill cuttings.

1.2.2 To determine leaching characteristic of drill cuttings used as a raw material to produce mortar.

1.3 Benefits

1.3.1 The minimum curing time of mortar with drilling cuttings can reduce the production time.

1.3.2 Drill cuttings can be used as a raw material to construction industry.

Chapter II

Theory and literature review

2.1 Theory

2.1.1 Drill cuttings

Drilling is a major process in exploration and production of petroleum products. One major waste stream generated from drilling operations is the mixture of drilling fluids with a bulk of shale or sandstone fragments, called drill cuttings. Drilling fluids or drill muds are one of the primary wastes generated from drilling operations. Drilling fluids are pumped down through the well. The main purpose of the fluids is to transport the drill cuttings to the surface, cool and lubricate the drill bit, stabilize the wellbore, and control subsurface pressure. To avoid the blow-out of the well, it conducts by controlling the fluid density balance with the pressure of down-hole and adding heavy metal such as barites to counteract the pressure in the hole (Mikos-Szymanska et al. 2018). The composition of drilling fluids can vary widely and may include a different chemical. Drilling fluids can be divided into three main groups depending on base liquid that water-based mud, oil-based mud, and synthetic-based mud.

The different level of drilling in petroleum exploration provides different drill cuttings characteristic. It can be classified drilling into two levels:

1. top-hole section (surface to 1,000 m in depth). In this section, water-based mud serves as the drilling fluid. Therefore, drill cuttings from this section are categorized as non-hazardous waste.

2. bottom-hole section (1,000 m to the target depth). This section uses oil-based mud or synthetic-based mud. Thus, drill cuttings from this section are considered potentially hazardous.

A huge volume of drill cuttings residue becomes waste (Poyai et al. 2020). Hu et al. (2020) analyzed chemical composition of oil-based drill cuttings and found TPH, PAHs (such as naphthalene, acenaphthene, pyrene) and heavy metals (such as As, Cd, Cu, Cr^{6+}, Ni, Zn).

To manage the drill cuttings, disposal at sea or landfill is commonly used. Alternative methods such as chemical/biological treatment, incineration, and thermal treatment are also applied according to geographical constraints. One of the best alternative methods of disposing the petroleum-contaminated soil is to reuse these materials (Mostavi et al., 2015). Several studies have been conducted on substituting multiple typed of waste material such as recycled plastic, fly ash, glass as aggregate and filler in concrete.

2.1.2 Mortar Concrete

Cement is the binding agent with water and aggregates. Coarse and fine aggregates are main of a concrete mixture. The application of cement is shown in Figure 2.1. They help the increase strength of concrete beyond what cement can provide on its own. Sand, gravel, and crushed stone are used as aggregates. Other wastes such as recycled materials, blast furnace slag, glass waste, and by-products can also be used as concrete aggregates.

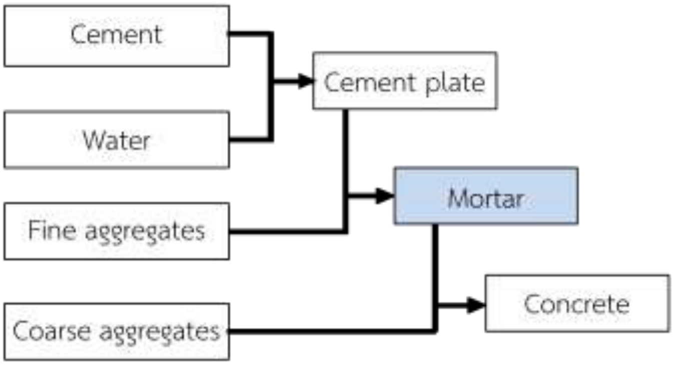

Figure 2.1 The application of cement

Mortar is another building material composed of cement, mixed with fine aggregate and water. Adding water to this mix activates the cement to increase it hardens or cures as concrete. Normally, mortar is not as strong as concrete and is not used as a sole building material.

Concrete is composed of cement, sand, and gravel or other fine and coarse aggregates. The addition of water activates the cement, which is the element responsible for binding the mix together to form a solid. The concrete industry consumes the limited natural resources such as sand and gravel due to this tremendous demand. It is crucial to find surrogate materials which have sustainable features (Noor et al., 2017). Compressive strength depends on the growth of crystals within the matrix of the concrete. These crystals grow from a hydration reaction between cement and water. If there is not enough water, the crystals cannot grow, and the concrete does not develop the strength as it should. If there is enough water, the crystals grow out around the sand and gravel. Therefore, curing is an important factor for concrete production. It has a major impact on the quality of concrete. It retains moisture in concrete that continues to gain strength and delays drying shrinkage until the concrete is strong enough to resist shrinkage cracking. Properly curing concrete improves strength, durability, water absorption and wear resistance. Generally, the concrete and mortar production require curing time 28 days for satisfactory settlement. Quality test on concrete is performed as a part of quality control of concrete structures to meet strict regulations and quality standards. Different quality on concrete such as compressive strength tests, permeability tests must be tested.

2.1.3 Properties of mortar block

1) Particle size distribution

Particle size distribution is an index indicating sizes of particles presented the proportions. The relative of particle amount as a percentage where the total amount of particles is 100% in the sample particle group to be measured. Particle size of a material is importance for understanding its physical and chemical properties. It affects the strength, load-bearing properties of rocks and soils, and reactivity of solids participating in chemical reactions.

2) Density

Density of concrete is the mass or weight of the concrete that required to fill a container of a specified unit volume. In this definition, the volume contains both concrete and voids between concrete particles.

3) Water absorption

Durability of concrete plays a critical role in controlling its serviceability. It is mainly dependent on the capacity of a fluid to penetrate the concrete’s microstructure, which is called permeability. Concrete permeability has a relationship with the characteristics of its pore structure in the cement paste and the intensity of microcracks at the aggregate-cement paste. The water absorption by immersion is also considered to be a relevant parameter about the performance of concrete. Sufficient curing is essential for the concrete to provide its potential performance (Zhang et al., 2014).

4) Compressive strength

Compressive strength of concrete is a measure of ability to resist loads which tend to compress it. It is measured by crushing cylindrical concrete specimens in compression testing machine. The compressive strength of concrete can be calculated by the failure load divided with the cross-sectional area resisting the load. Concrete's compressive strength requirements can vary from 17 MPa for residential concrete to 28 MPa and higher in commercial structures. Higher strengths up to and exceeding 70 MPa are specified for certain applications.

2.1.4 Leaching test

Leaching test is the measure of the concentrations of contaminant that can be released from materials. The leaching tests determine the total amounts of reachable contaminants (leaching rates). The concentration of a trace element depends on the pore water and in the contact (elution) solution. The leaching rate is extremely depended on the concentration and solubility of the contaminants and on the permeability of the matrix (Rankers et al., 1991). To test leaching according to Announcement of the Ministry of Industry, 2005 is shown in Figure 2.2. It must determine total concentration (mg/Kg; wet weight) of hazardous inorganic and hazardous organic contaminant such as Pb, Cd, Hg, Se, Te, Tl, Sb, As, Mn Cr^{6+} and compare with total threshold limit concentration (TTLC).

1) If total concentration is more than TTLC, it classifies as hazardous waste

2) If total concentration is less than TTLC, it will be divided into two cases. Firstly, the concentration of waste is less than soluble threshold limit concentration (STLC) set in law, this waste classifies as non-hazardous waste. Secondly, the concentration of waste is in range concentration between TTLC and STLC, it requires waste extraction test (WET).

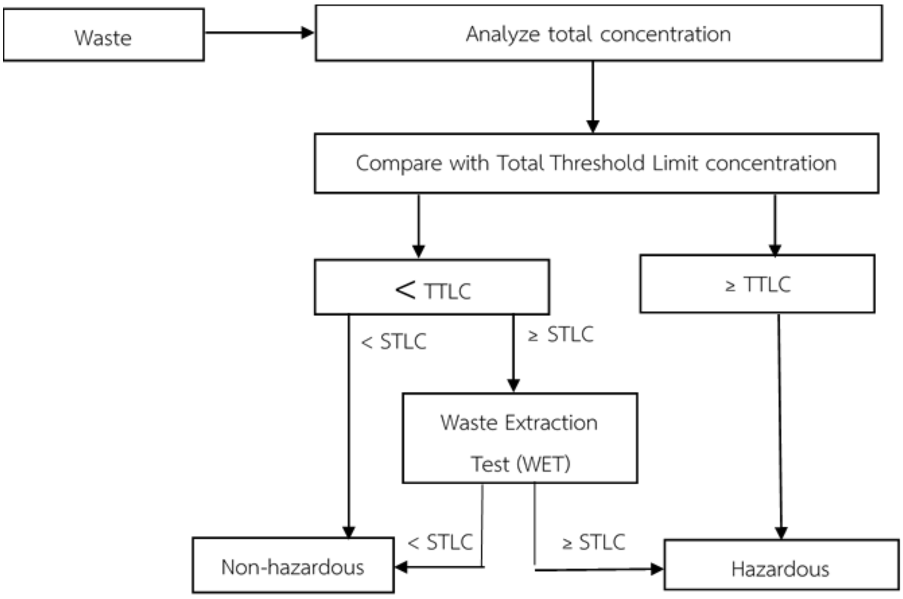

Figure 2.2 Method to classified hazardous and non-hazardous.

2.2 Literature review

2.2.1 Mortar production

Zhang et al. (2014) showed recycling glass powder using as material for concrete production can increased up to 20% when replacing glass waste powder. The concrete age 7, 14 and 28 days proven that increasing strength has been observed when replacing of glass waste powder by natural sand.

Foroutan et al. (2018) revealed that well-graded drill cuttings performed better than poorly graded samples. The drilled cuttings at high strength targets (2800, 1200 and 300 psi) have no significant compressive strength reduction. However, at low strength targets (80 and 200 psi) has a significant compressive strength reduction. This may be due that the higher content of cement in high strength concrete mixtures compensates for the lack of strength as result of drill cuttings. It is feasible to replace the fine aggregates up to 20% without significant reducing compressive strength.

Mundra et al. (2020) presented using sandstone cutting waste replacement of natural river sand in concrete producing. Sandstone cutting waste can be utilized in the production of structural concrete as partial replacement of river sand up to 10% replacement level using w / c ratio of 0.35 and up to 30% replacement using w / c ratio of 0.4 &. 0.45.

Table 2.1 shows concrete production process that can be performed in various ways such as mold size, sample preparation. Sample preparation can be done in the sun-dried, dried at room temperature or heat in oven. The replacement range provides the concrete sample with the highest compressive strength is 10-25%

2.2.2 Leachability

Mostavi et al. (2015) analyzed drill cuttings and studied the presence and concentration of Volatile Organic Compounds (VOC), Semi-Volatile Organic Compounds (SVOC), Total Petroleum Hydrocarbon (TPH), and metals. The result compared with Toxicity Characteristic Leaching Procedure (TCLP) regulatory levels determine the mobility of the inorganic phase of drill cuttings. As it can be seen, the drill cutting can be classified as non-hazardous waste.

Wang et al. (2021) analyzed water-based drilling cuttings (WDC). It was tested the leaching performance in general water solution and acid digestion leaching performance. The results were as follows: no detected benzene series and other organic compounds in the lixivium of WDCs in general aqueous solution. However, heavy metals such as arsenic and chromium were detected. Zinc, copper, lead, cadmium, chromium, nickel, mercury, and arsenic were meet the state standards. So, WDC product does not cause any secondary contamination.

Table 2.1 Literature review

Mold Size	Sample	Preparation	Curing (days)	Optimum mixing ratio	% replacement	Maximum compressive strength	Author
4x8 in Cylinder	Drill cuttings (Texas)	Treated mud	28	W/C 0.9	20% drill cuttings	2882 psi (≈19.87 MPa)	Foroutan et al. (2018)
	Drill cuttings (Louisiana)	Untreated mud (vacuum oven at 95 C 48 hr.)					
20x10 cm. Cylinder	drill cuttings	Oven at 100-105 C 24hr.	7	W/C 0.7	20 % drill cuttings +7.5% silica fume + 7.5% fly ash	30 MPa	Mostavi al. (2015)
10x10x10 cm (CS test) 10x10x50 cm (FluxureS test) 15x30 cm Cylinder (tensilS test)	Sandstone cutting	-	28,90	W/C 0.35	10% Sandstone cutting	9.5 MPa	Mundra et al. (2020)
10x10x10 cm (CS test) 10x10x50 cm (FluxureS test)	granite cutting waste (GCW)	dried at room temperature for 48 h	7,28	W/C 0.30	25% GCW	58 MPa	Singh et al. (2016)

Chapter III

Materials and methods

3.1 Materials and equipment

3.1.1 Materials

1) Drill cuttings
2) Portland Cement Type I
3) Coarse Sand
4) Tap water

3.1.2 Equipment

1) Compression strength testing Machine

Figure 3.1 Compression strength testing Machine

2) Cube Mold 5 x 5 x 5 cm^3
3) Mud Mixer, Stanley, Model: SDR1400
4) Laboratory Forced Air Oven, Binder, Model: FD115 E2
5) Laboratory precision balance, Mettler Toledo, Model: ML1602 / 01, Switzerland
6) Precision balance, Kassa, Model: EK3840-WH
7) Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES)
8) Microwave digestion system, Milestone, Ethos One
9) Sieve, Endecotts LTD., English
10) Vernier Caliper

3.1.3 Chemical reagent

1) conc. nitric acid (conc. HNO_3)
2) conc. hydrochloric acid (conc. HCl)

3.2 Methodology

The experimental procedure is shown in the Figure 3.2.

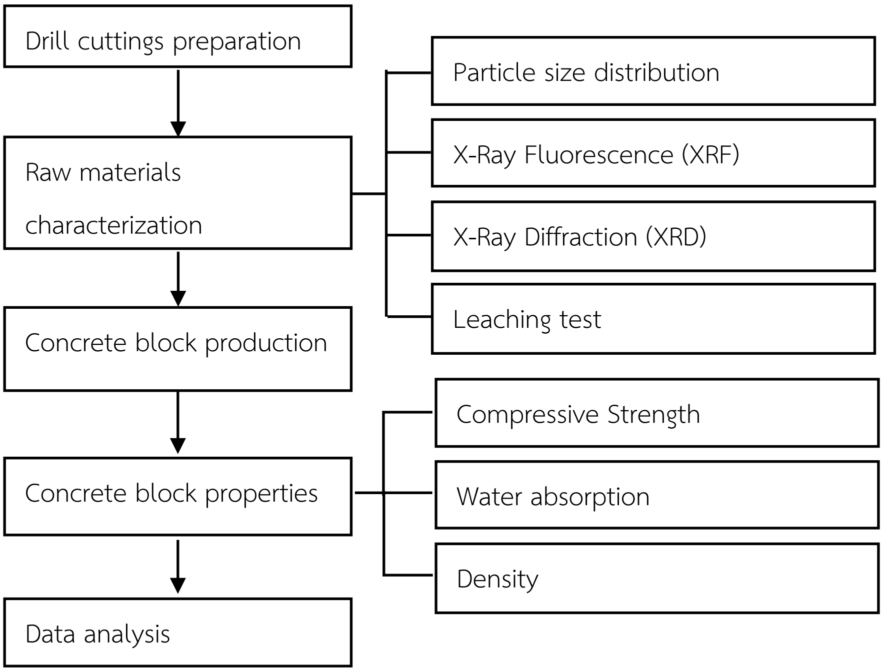

Figure 3.2 Experimental procedure

3.2.1 Drill cuttings preparation

Drill cuttings collected from onshore petroleum drilling in Kamphaeng Phet by the drilling depth layers are divided into 4 depths including 0 – 100 (DC1), 100 – 300 (DC2), 300 – 500 (DC3), 500 – 700 (DC4) meters. Each depth was divided into 2 parts, as-is and cleaned samples. As-is drill cuttings sample (A1-A4) was sun-dried and sifted through a steel mesh. The cleaned drill cuttings sample (C1-C4) was washed 10 times with water and sun-dried. Then, sifted through a steel mesh.

3.2.2 Raw materials characterization

1) Particle size distribution

Particle size distribution test was used according to ASTM C136 (American Society for Testing and Materials, 2014) using sieve shaker No. 1, 4, 10, 16, 40, 100, and 200. Sample was sorted by arranging the sieve with the decreasing size from the top to bottom. Then, material was poured into the top sieve and shake for 15 minutes. After that, the sieves were weighted with the remaining sample in each sieve and calculated a size distribution percentage as the Equations 1-3.

Retained (%) = Weight sample retained (g) x 100 / Total weight sample (1)

Cumulative Retained (%) = Cumulative retained (%) + Retained (%) (2)

Passing (%) = 100 - Cumulative Retained (%) (3)

2) Elemental analysis

Elemental analysis was done using X-Ray Fluorescence (XRF) technique for elemental analysis of materials.

3) Chemical compositions

Chemical composition was analyzed by X-Ray Diffraction (XRD) to identify the crystalline phases presented in materials.

3.2.3 Mortar block production

The specimen was made of 5 replications of each proportion for the compressive strength test and 5 replications for the water absorption test. The fine aggregate consisted of drill cuttings with replaced of coarse sand for 0% (control), and 40% by weight. The replacement ratio used in this study was obtained from another study in the related project which found that drill cuttings can replace sand by 0–40% to produce 28 curing days-mortar with no compressive strength reduction. The steps of concrete block production were as follows:

1) Mixed all ingredients together which are cement: water: aggregate 1: 0.485: 2.75 (ASTM C109) by weight for 3 minutes
2) Poured the mixture into the molds (5 x 5 x 5 cm^3).
3) Wrapped the specimens with the plastic wrap for 24 hours.
4) Cured specimens by immersion in water for 7, 14, 28 days.
5) Tested specimens for compressive strength, water absorption, density.
6) Tested leaching of drill cuttings.

3.2.4 Mortar block properties

1) Density

Five specimens of mortar blocks after curing 7, 14, 28 days were measured density. The density was calculated by the Equation 4.

$$\rho = \frac{m}{v}$$

Where ρ is Volumetric mass density (kg/m^3)

m is mass of specimen (kg)

v is volumetric of specimen (m^3)

2) Water absorption

Five specimens of mortar blocks after curing 7, 14, 28 days were measured water absorption according to ASTM C642 (American Society for Testing and Materials, 2016). The procedure was conducted as follows:

1) Dried the specimens in an oven at a temperature of 105±5°C for not less than 24 hr.
2) Removed each specimen from the oven, allowed to cool in dry air.
3) Weighed concrete bricks and designate this value as oven-dry mass (W_d)
4) Immersed the concrete block in tap water at room temperature for at least 48 hours.
5) Wiped the surface of specimens by towel.

6) Weighed dry specimens and designate this value as mass after immersion or saturated mass (W_s).
7) Calculated water absorption of concrete block by Equation 5.

$$\text{Water absorption (\%)} = \frac{Ws\text{-}Wd}{Wd} \times 100 \qquad (5)$$

Where W_s is mass of specimen after immersion (g)

W_d is mass of oven-dry specimen (g)

3) Compressive Strength

Compressive strength of mortar blocks was tested according to ASTM C109 (American Society for Testing and Materials, 2016) after curing 7, 14, 28 days. Three specimens for each sample were placed at room temperature for more than 24 hours and tested with compressive strength testing machine. Compressive strength could be calculated follows Equation 6.

$$C = W/A \qquad (6)$$

Where C is compressive strength of specimen (MPa)

W is maximum compressive load (N)

A is cross-sectional surface area (m^2)

3.2.5 Leaching test by TTLC method

Drill cuttings which are a raw material in this work was tested for leachability follows the method according to Announcement of the Ministry of Industry, 2005. The process was divided into 2 steps: digestion and analysis. For digestion, the sample using microwave extraction, according to US.EPA SW-846 method 3051A: Microwave-assisted acid digestion of sediments, sludges, soil, and oils. The microwave extraction method was designed to mimic extraction using conventional heating with nitric acid (HNO_3) or nitric acid and hydrochloric acid (HCl), according to EPA SW-846 Method 3050 that were specified according to Announcement of the Ministry of Industry, 2005. The procedure was done as follows:

1) Mixed the sample to be homogeneous and sifted through a sieve No.10 (2 mm).

2) Weighed sample 0.5 gram to the vessels.

3) Added 10 ± 0.1 mL concentrated nitric acid in a fume hood.

4) Sealed the vessel according to the manufacturer's directions and properly placed the vessel in the microwave system.

5) Set the microwave program. The temperature of each sample should rise to 175 ± 5 ^{o}C in approximately 5.5 ± 0.25 min and remain at 175 ± 5 ^{o}C for 4.5 min, or the remainder of the 10-min digestion period.

6) Allowed the vessels to cool for a minimum of 5 min before removing them from the microwave system at the end of the microwave program.

7) Filtered and adjusted the final volume to 100 ml.

The analysis of heavy metals can be performed using an Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES).

3.3 Data analysis

The data was analyzed with one-way ANOVA statistics using SPSS program to test statistically significant differences at 95% confidence level of mortar curing to compressive strength.

Chapter IV

Results and discussion

Drill cuttings collected from onshore petroleum drilling in Kamphaeng Phet by the drilling depth layers were divided into 4 depths including 0 – 100 (DC1), 100 – 300 (DC2), 300 – 500 (DC3), 500 – 700 (DC4) meters. The appearances of the raw materials are shown in Figure 4.1. Each depth was divided into 2 parts, as-is and cleaned samples. Characteristics of As-is drill cuttings from 4 depths (A1 - A4) were gray - brown in color, smaller than gravel and coarser than silt. After cleaned the samples from 4 depths with water (C1 - C4), the dust particle was removed. The study testing focused on drill cuttings characterization, mortar block properties produced from drill cuttings and leachability of drill cuttings and mortar.

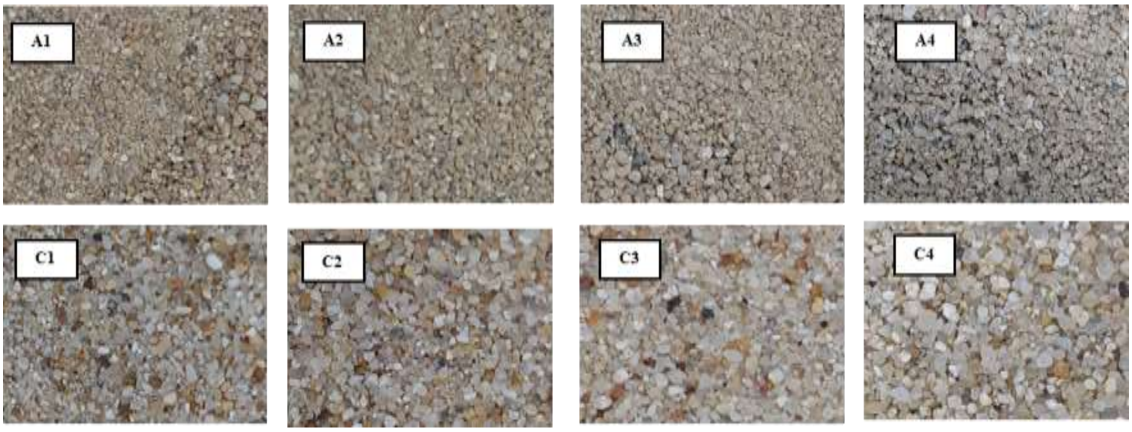

Figure 4.1 Drill cuttings

4.1 Raw materials characterization

The characteristic of raw materials was received by the research project on characterization of drill cuttings from PTT Exploration and Production Public Company Limited (PTTEP) (Imyim et al., 2020) which is a group that participated in research together. The results are as follows:

4.1.1 Particle size distribution

Characterization of the particle size distribution of drill cuttings was investigated by sieve analysis. The calculation results were shown in Table 4.1 and Figure 4.2. Almost all DC1-DC4 samples passed a 4.76 mm sieve and were retained on a 0.074 mm sieve which was the defined size of the fine aggregate. This allows the DC sample to be used to replace fine aggregates or coarse sand. From the particle size distribution of DC1 - DC4, it was found that all samples are compliant with requirements for the size of coarse sand from TIS-598.

Table 4.1 Data of particle size distribution

Particle diameter (mm)	Percentage passed, %			
	DC1	**DC2**	**DC3**	**DC4**
25.4	100	100	100	100
9.5	100	100	100	100
4.76	99.3	99.02	99.81	99.8
2	88.41	75.07	95.64	96.13
1.19	72.69	59.79	88.37	83.86
0.42	31.01	26.11	53.79	37.52
0.149	5.78	11.17	15.28	19.65
0.074	2.84	10.1	9.42	17.73

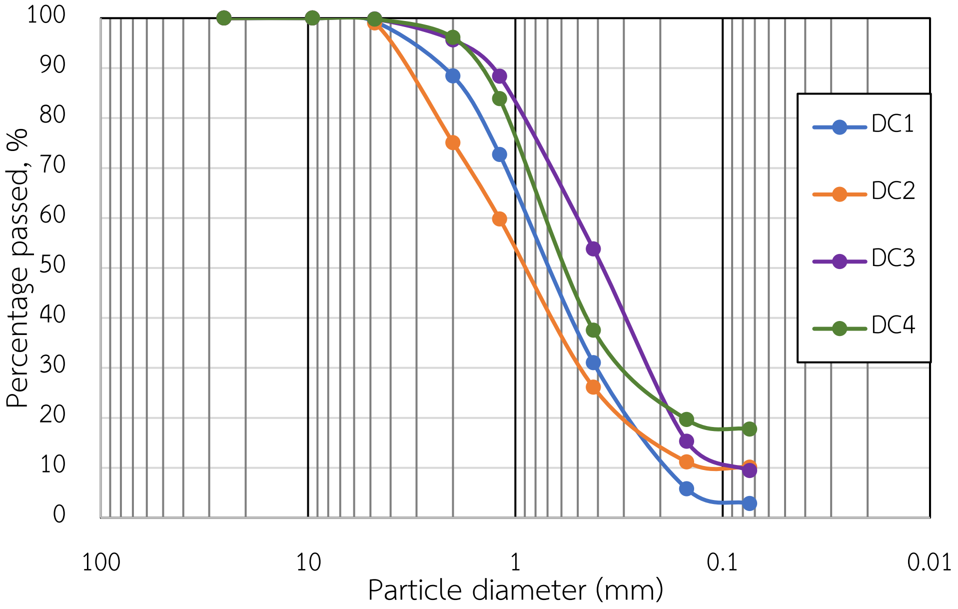

Figure 4.2 Particle distribution curve

4.1.2 Elemental analysis (XRF)

The report of characterization of drill cuttings from PTTEP combined the 4 depths of drill cuttings into two samples i.e., DC1-2 and DC3-4 and analyzed for the XRF. The measurement results are shown in Figure A.1 and A.2. The results found that the major composition of DC1-2 and DC3-4 were SiO_2, accounting for 62 and 77%, respectively as shown in Figure 4.3. SiO_2 is the most common constituent of sand in inland continental settings, usually in the form of quartz. Similar results were reported by Wang et al. (2021), which revealed the three most chemical composition of coarse sands was SiO_2, Al_2O_3 and Fe_2O_3, at 63.49%, 14.04% and 6.63% respectively.

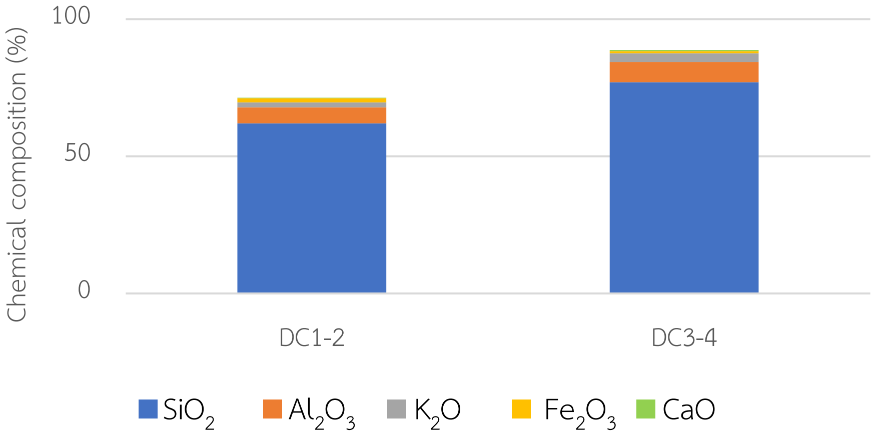

Figure 4.3 XRF analysis results of drill cuttings.

4.1.3 Chemical compositions (XRD)

The chemical elements of the sample validated the presence of the minerals found in the X-Ray Diffraction (XRD) test. The result is showed in Figure 4.4 that the major crystalline phase of drill cuttings was quartz alpha (SiO_2), which the main component of coarse sand. This makes it possible to use drill cuttings instead of coarse sand.

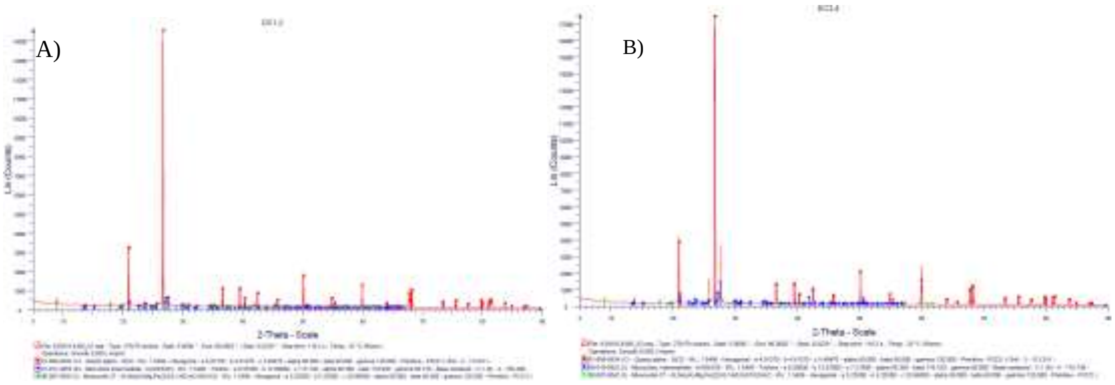

Figure 4.4 X-ray diffraction analysis A) DC1-2 B) DC3-4

4.2 Mortar block properties

The properties of the mortar block which has replaced the coarse sand with drill cuttings 40% by weight was conducted. There were 8 samples of drill cuttings from 4 depths

(DC1, DC2, DC3, DC4) and 2 treatments (as-is and cleaned). The proportion of 5 x 5 x 5 cm^3 mortar is cement: water: aggregate of 1: 0.485: 2.75 by weight. The fine aggregate in the experiment consisted of drill cuttings with replaced of coarse sand for 0% (control), and 40% by weight. The replacement ratio used in this study was obtained from another study in the related project which found that drill cuttings can replace sand by 0 – 40% to produce 28 curing days-mortar with no compressive strength reduction. In our work, after curing time of 7, 14 and 28 days, the mortar samples were then tested for density, water absorption and compressive strength.

4.2.1 Density

Density of mortar blocks of drill cuttings mixes at 7, 14 and 28 days curing time were calculated and shown in Table A.1 and Figure 4.5. The maximum density of curing 28 days presented in C1 (2,188.3 Kg/m^3) which was higher than the control sample (2,170.0 Kg/m^3). In addition, C4 sample gave the lowest density around 2,117.5 Kg/m^3. It was found that density was slightly increased as curing time increased. The statistical analysis showed that it has significant differences of density among 7, 14 and 28 curing days, as shown in Table A.5.

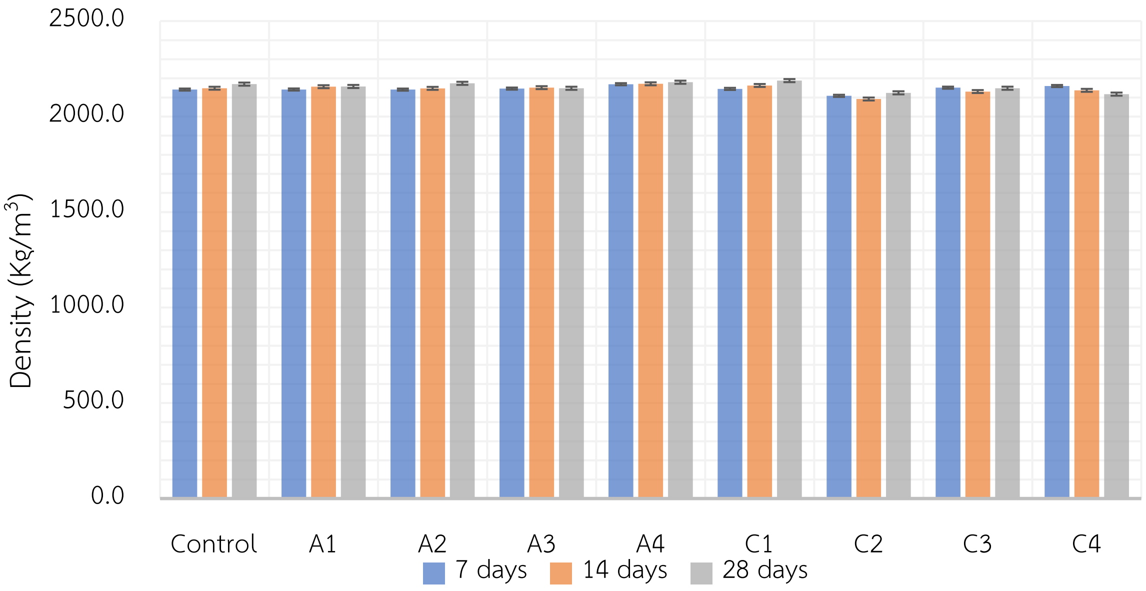

Figure 4.5 The density of mortar block

4.2.2 Water absorption

Water absorption from each treatment of mortar block produced from drill cutting at curing period of 7, 14 and 28 days was shown in Table A.1 and Figure 4.6. The highest water absorption of 28 curing days was achieved by A1 sample, which was found about 164.66 Kg/m^3 compared with 131.58 Kg/m^3 of the control sample. The results from statistical analysis found that the samples with drill cuttings performed higher water absorption than the samples without drill cuttings. This is caused by size of drill cuttings is smaller than coarse sand made it poorly filled in the pore of inside mortar block. Considering the effect of curing time on water absorption, the analysis from one-way ANOVA tests resulted in no significant differences of water absorption among curing times 7, 14 and 28 days, as shown in Table A.9. In general, the water absorption should drop when the curing time increases because of the reaction of hydration. The TIS 60 set the average water absorption value must not be greater than 208 kg/m^3. This means the water absorption of this study was passes as well.

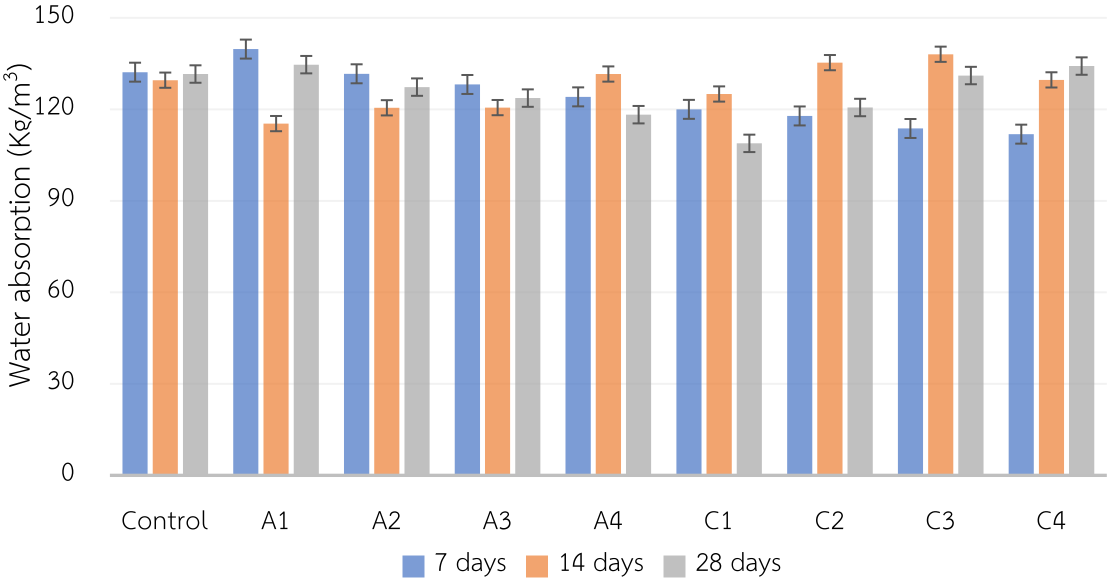

Figure 4.6 The water absorption of mortar block

4.2.3 Compressive Strength

Mortar block produced from drill cutting with curing period 7, 14 and 28 days was tested for compressive strength as shown in Figures 4.7 and 4.8.

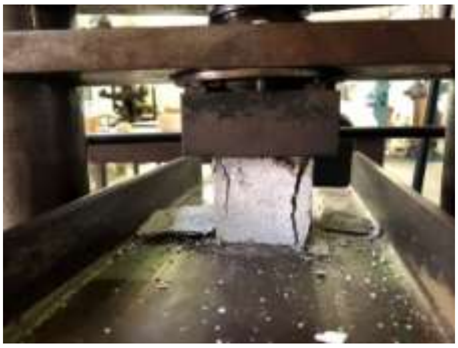

Figure 4.7 Compressive strength test

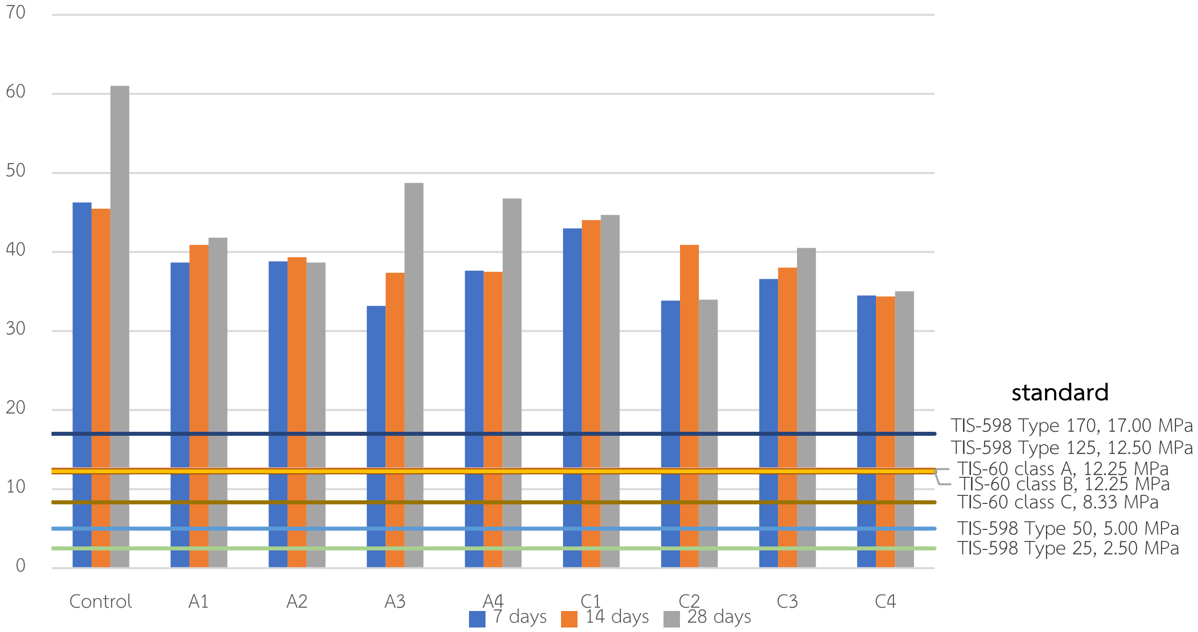

Figure 4.8 Compressive strength of sample compares with standards.

The maximum compressive strength of curing 28 days was 48.74 MPa from A3 which lower than the control sample (61.02 MPa). In addition, C2 sample gave the lowest compressive strength around 33.97 MPa. The result found that the compressive strength of most mortar block slightly increased as curing time increased. Exception for compressive strength of sample mixed with drill cuttings from second depth (A2 and C2) which was highest at 14 curing days.

From the two-way ANOVA statistical comparison among curing times (7, 14 and 28 days) and compressive strength (MPa), it was found that the curing time affecting the compressive strength values at 28 days were significantly different from 7 and 14 days as show in table A.13. The curing time was also affected on compressive strength of mortars prepared by as-is drill cuttings (A1-A4) as shown Table A.15. Compressive strength between 7 and 14 days was not significantly different ($p>0.05$) in each depth, while at 28 days was significantly different ($p<0.05$) from others. The statistical test showed no significant difference among depth of drill cuttings at 95% confidence level as shown in Table A.16. For the mortar with cleaned drill cuttings sample (C1-C4), it was found that the curing time was not affected to the compressive strength as shown in Table A.19. The result in Table A.18 shows that depth layers were affecting the compressive strength values at 95% confidence level.

The increase in compressive strength over the curing time occurs due to the formation of a dense matrix formed by the hydration reactions. Calcium silicate hydrate (C-S-H) is the most important product of hydration reaction. It governs the overall strength of concrete as it binds the cement and aggregates into a compact matrix. A higher concentration of C-S-H gel leads to the higher compressive strength of concrete (Wang et al., 2018).

For the calculation of average compressive strength of mortar block, it revealed that as-is samples (A1-A4) presented higher average compressive strength than the cleaned samples (C1-C4). This is expected to occur from the washing of water that causes the removing of small particle and drilling muds. The small particle can fill in the pore of mortar resulted in lower water absorption and higher density than the as-is samples, which leads to high compressive strength. However, the statistical test showed no significant difference between as-is sample and cleaned sample at 95% confidence level as shown in Table A.11. Moreover, the analysis of the effect of drill cuttings’ depth revealed (Table A.12) that the compressive strength of mortar blocks was no significant difference among different depths of drill cuttings.

From the results in this work, it can be concluded that the compressive strength of all specimens was higher than the compressive strength required by the standards of dry mortar for masonry units (TIS 598-2547 all type, ≥ 17 MPa) and solid load-bearing concrete masonry units (TIS 60-2516 all type, ≥ 8.34 MPa). In addition, mortar that has been cured at 7 days can be used as construction e.g., materials foundation wall material, load-bearing wall, traffic surface, and sidewalk. This can reduce the production time of mortar.

4.3 Leachability by TTLC method

To test the leachability of drill cuttings used as a raw material and mortar samples, the method according to Announcement of the Ministry of Industry, 2005 was conducted. The method was divided into 2 steps i.e., digestion and analysis. In this work, all samples were digested with microwave extraction and the solution was ready for analysis the targeted heavy metals by an Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES). Due to COVID 19 pandemic, it was obstructed to analyze the heavy metals and no own results from this research.

However, this work revised the results from Imyim et al. (2020) which works together in parallel on analysis of leaching characteristics. It can be seen from Figure 4.9 that the leaching of inorganic contaminants (As, Be, Cd, Cr, Cu, Mo, Ni, Pb, Sb, Se, Ti, V, and Zn) from drill cuttings samples generally presented lower concentrations compared to the authorized limits fixed by the Announcement of the Ministry of Industry (2005). However, it found extreme concentration of non-heavy metal compounds i.e., Fe and Ca concentrations was 16,016 and 2,598 mg/kg, respectively, but these two elements have not been established in the standards. Therefore, it can be assured that the drill cuttings used as a raw material to produce mortar is safe to use.

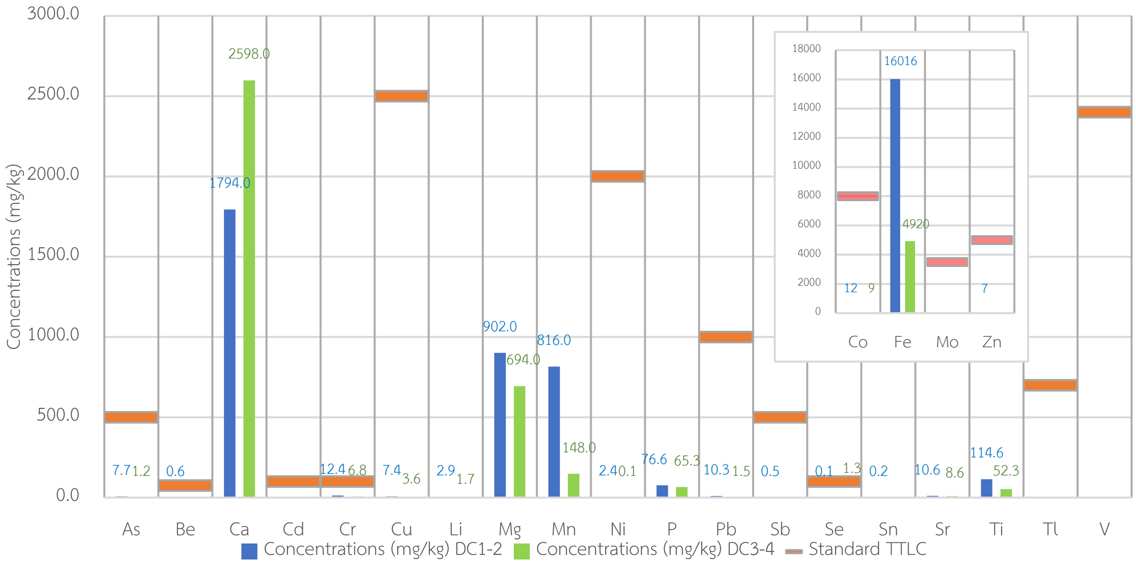

Figure 4.9 Concentrations of released metals

Chapter V

Conclusions and recommendation

5.1 Conclusions

The study focuses on the utilization of drill cutting generated from petroleum drilling, which is used as raw material to replace sand in mortar production. The result of the experiment showed:

- All replacement drill cuttings samples passed the requirement of compressive strength standard according to the TIS-598 and TIS-60. Thus, drill cuttings perform physical property to use as raw materials for mortar production.
- The compressive strength of 28 days curing time in mortar block production was higher than 7 and 14 days curing time.
- Seven days of curing time was adequate for producing mortar.
- The concentration of inorganic contaminant leaching from drill cuttings samples was lower than the limited concentration set by the Announcement of the Ministry of Industry (2005).
- Preparing the drill cuttings sample by washing off the drilling mud did not make a significant difference in compressive strength as well as the depth layer.

The results from this work can be concluded that drill cuttings from onshore petroleum drilling in Kamphaeng Phet can be used as a substitution material for mortar production.

5.2 Recommendation

The utilization of solid waste to produce mortar block can be one of an alternative way to manage petroleum drilling waste. Further studies to enhance the quantity and quality of concrete block from drill cuttings should expand size of mortar concrete to suit with the other required standard of TIS. Mortar with 40% replacing coarse sand with drill cuttings also passed TIS standards. Therefore, the replacement ratio should be increased to reduce the amount of drill cuttings waste. More characteristic of drill cuttings should be investigated, particularly the chemical composition of the reaction with cement during the curing phase in the manufacturing of mortar blocks.

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Appendix

Figure A.1 XRF of DC1-2

SiO2	Al2O3	K2O	Fe2O3	Na2O	MgO	CaO	TiO2	BaO	MnO	P2O5
662.2 KCps	66.2 KCps	50.2 KCps	228.8 KCps	1.5 KCps	3.3 KCps	5.4 KCps	4.1 KCps	0.9 KCps	6.9 KCps	0.3 KCps
62.0 %	5.89 %	1.79 %	1.50 %	0.282 %	0.240 %	0.206 %	0.138 %	638 PPM	572 PPM	335 PPM

Cl	SO3	Rb2O	ZrO2	ZnO	Cr2O3	SrO	CuO	NiO	PbO	V2O5
0.7 KCps	0.3 KCps	11.9 KCps	13.8 KCps	2.4 KCps	0.3 KCps	5.7 KCps	1.0 KCps	0.7 KCps	1.0 KCps	0.3 KCps
300 PPM	233 PPM	76.8 PPM	69.6 PPM	50.6 PPM	48.9 PPM	35.4 PPM	27.5 PPM	23.7 PPM	22.7 PPM	0.0 PPM

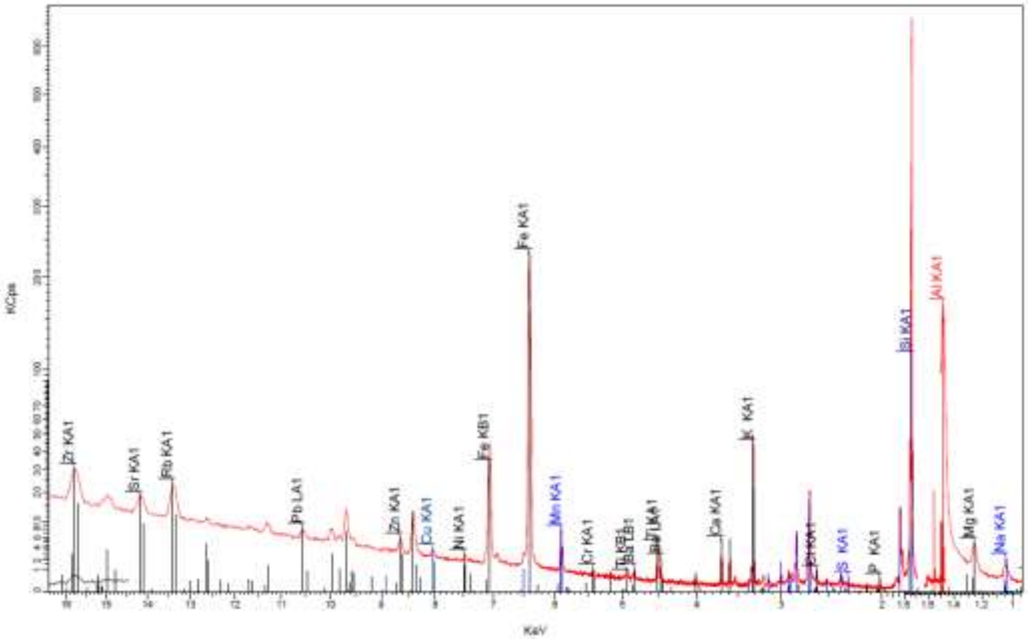


Figure A.2 XRF of DC3-4

SiO2	Al2O3	K2O	Fe2O3	CaO	Na2O	MgO	TiO2	BaO	P2O5	MnO
658.3 KCps	66.2 KCps	71.6 KCps	91.9 KCps	7.9 KCps	1.3 KCps	2.7 KCps	2.5 KCps	0.8 KCps	0.2 KCps	1.6 KCps
77.0 %	7.37 %	3.21 %	0.762 %	0.387 %	0.295 %	0.245 %	0.106 %	758 PPM	262 PPM	170 PPM

Cl	SO3	Rb2O	ZrO2	SrO	ZnO	NiO	PbO	Cr2O3	CoO	CuO
0.3 KCps	0.2 KCps	17.8 KCps	12.4 KCps	7.5 KCps	1.2 KCps	0.6 KCps	0.9 KCps	0.1 KCps	0.6 KCps	0.5 KCps
158 PPM	150 PPM	138 PPM	73.3 PPM	56.1 PPM	29.6 PPM	27.0 PPM	23.8 PPM	0.0 PPM	0.0 PPM	0.0 PPM

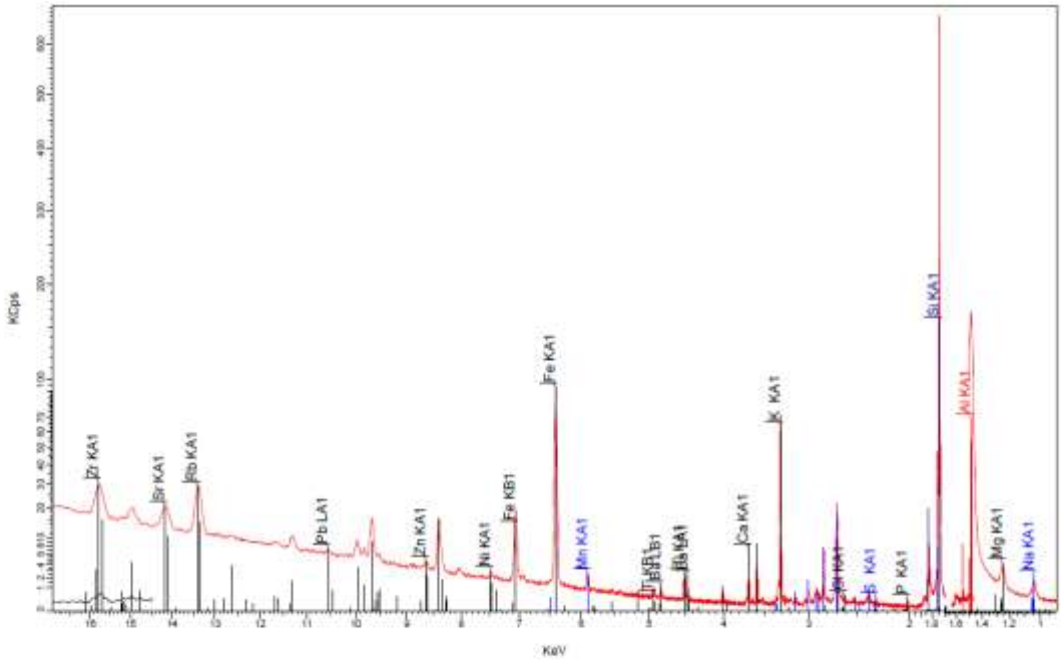
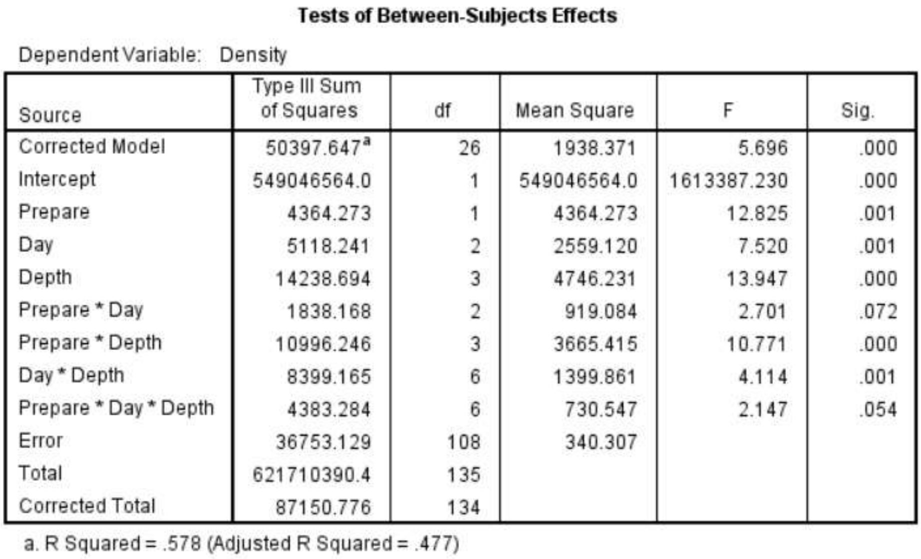


Table A.1 Data of Density, Water absorption and Compressive strength

Sample	Curing (Days)	Density (Kg/m^3)	Water absorption (Kg/m^3)	Compressive strength (MPa)
Control	7	2141.34 ± 20.99	132.19 ± 25.40	46.26 ± 1.41
	14	2148.42 ± 19.58	129.57 ± 41.94	45.47 ± 3.78
	28	2169.95 ± 16.20	131.58 ± 14.15	61.02 ± 0.23
A1	7	2141.74 ± 11.79	139.76 ± 28.18	38.68 ± 5.04
	14	2156.53 ± 18.52	115.33 ± 101.52	40.90 ± 4.12
	28	2157.63 ± 23.45	134.66 ± 37.71	41.81 ± 4.90
A2	7	2141.17 ± 23.44	131.66 ± 56.70	38.81 ± 2.57
	14	2147.74 ± 16.16	120.51 ± 72.65	39.33 ± 8.00
	28	2174.03 ± 23.51	127.30 ± 52.44	38.68 ± 4.68
A3	7	2146.40 ± 10.45	128.16 ± 58.94	33.19 ± 0.45
	14	2151.44 ± 21.75	120.58 ± 102.66	37.37 ± 2.61
	28	2148.11 ± 20.63	123.70 ± 29.70	48.74 ± 1.20
A4	7	2169.46 ± 15.47	124.10 ± 45.71	37.63 ± 8.00
	14	2171.66 ± 15.86	131.58 ± 61.38	37.50 ± 7.78
	28	2179.76 ± 7.30	118.26 ± 53.95	46.78 ± 4.19
C1	7	2144.94 ± 13.99	120.00 ± 46.54	42.99 ± 4.30
	14	2162.90 ± 12.75	125.04 ± 38.51	44.03 ± 1.81
	28	2188.34 ± 23.94	108.85 ± 100.33	44.69 ± 3.74
C2	7	2108.54 ± 17.60	117.84 ± 45.61	33.84 ± 4.68
	14	2092.00 ± 5.14	135.32 ± 47.76	40.90 ± 0.99
	28	2124.36 ± 12.29	120.61 ± 57.22	33.97 ± 7.25

Sample	Curing (Days)	Density (Kg/m^3)	Water absorption (Kg/m^3)	Compressive strength (MPa)
C3	7	2151.25 ± 12.96	113.73 ± 72.40	36.59 ± 12.19
	14	2131.04 ± 12.36	138.06 ± 21.74	38.02 ± 1.18
	28	2148.37 ± 18.98	131.09 ± 47.33	40.51 ± 2.36
C4	7	2160.00 ± 28.11	111.87 ± 204.10	34.50 ± 5.69
	14	2137.34 ± 15.83	129.66 ± 49.89	34.37 ± 2.01
	28	2117.50 ± 14.08	134.19 ± 19.85	35.02 ± 4.12

Table A.2 The Density tests between prepare method, depth and curing days.



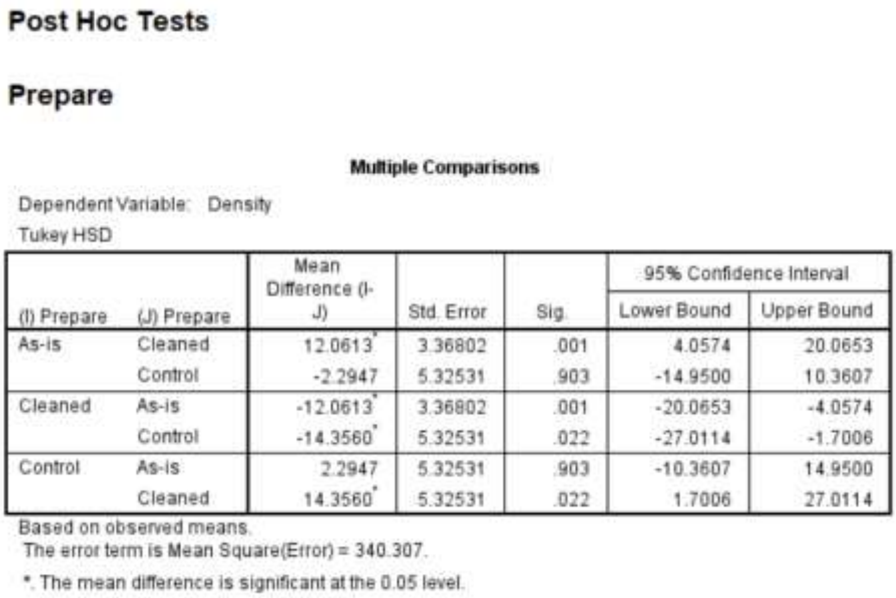
Tests of Between-Subjects Effects

Dependent Variable: Density

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	50397.647[a]	26	1938.371	5.696	.000
Intercept	549046564.0	1	549046564.0	1613387.230	.000
Prepare	4364.273	1	4364.273	12.825	.001
Day	5118.241	2	2559.120	7.520	.001
Depth	14238.694	3	4746.231	13.947	.000
Prepare * Day	1838.168	2	919.084	2.701	.072
Prepare * Depth	10996.246	3	3665.415	10.771	.000
Day * Depth	8399.165	6	1399.861	4.114	.001
Prepare * Day * Depth	4383.284	6	730.547	2.147	.054
Error	36753.129	108	340.307		
Total	621710390.4	135			
Corrected Total	87150.776	134			

a. R Squared = .578 (Adjusted R Squared = .477)

Table A.3 The multiple comparisons of *the* density of mortar blocks for effects of prepare methods.



Post Hoc Tests

Prepare

Multiple Comparisons

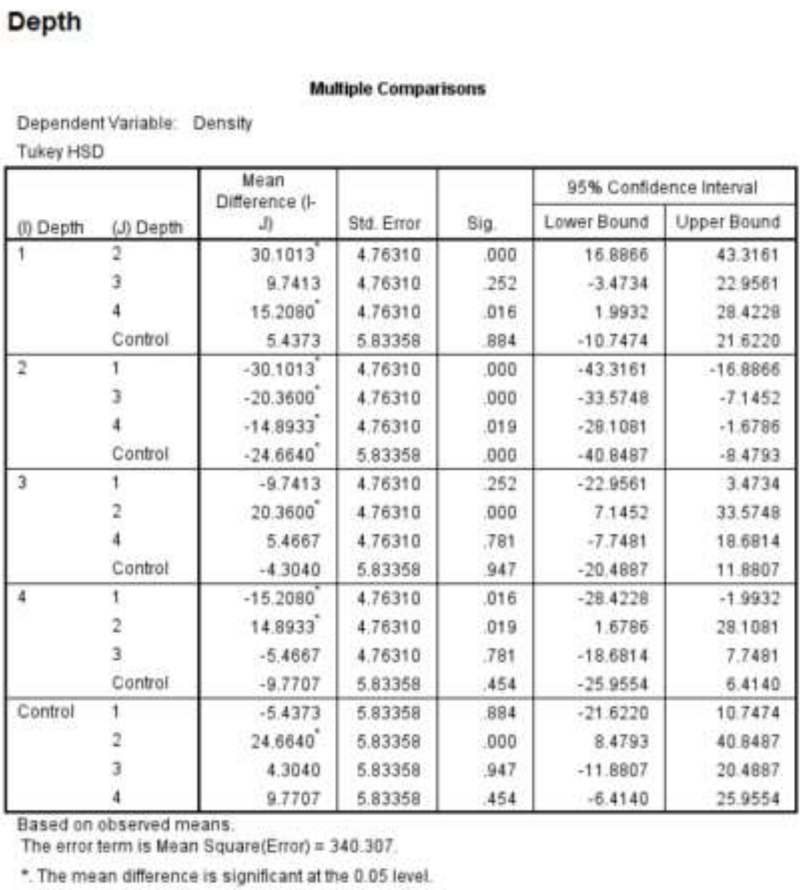
Dependent Variable: Density
Tukey HSD

(I) Prepare	(J) Prepare	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
As-is	Cleaned	12.0613*	3.36802	.001	4.0574	20.0653
	Control	-2.2947	5.32531	.903	-14.9500	10.3607
Cleaned	As-is	-12.0613*	3.36802	.001	-20.0653	-4.0574
	Control	-14.3560*	5.32531	.022	-27.0114	-1.7006
Control	As-is	2.2947	5.32531	.903	-10.3607	14.9500
	Cleaned	14.3560*	5.32531	.022	1.7006	27.0114

Based on observed means.
The error term is Mean Square(Error) = 340.307.

*. The mean difference is significant at the 0.05 level.

Table A.4 The multiple comparisons of *the* density of mortar blocks for effects of depths.



Depth

Multiple Comparisons

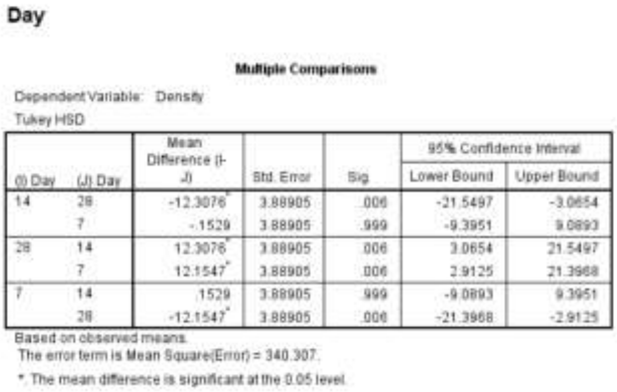
Dependent Variable: Density
Tukey HSD

(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	30.1013*	4.76310	.000	16.8866	43.3161
	3	9.7413	4.76310	.252	-3.4734	22.9561
	4	15.2080*	4.76310	.016	1.9932	28.4228
	Control	5.4373	5.83358	.884	-10.7474	21.6220
2	1	-30.1013*	4.76310	.000	-43.3161	-16.8866
	3	-20.3600*	4.76310	.000	-33.5748	-7.1452
	4	-14.8933*	4.76310	.019	-28.1081	-1.6786
	Control	-24.6640*	5.83358	.000	-40.8487	-8.4793
3	1	-9.7413	4.76310	.252	-22.9561	3.4734
	2	20.3600*	4.76310	.000	7.1452	33.5748
	4	5.4667	4.76310	.781	-7.7481	18.6814
	Control	-4.3040	5.83358	.947	-20.4887	11.8807
4	1	-15.2080*	4.76310	.016	-28.4228	-1.9932
	2	14.8933*	4.76310	.019	1.6786	28.1081
	3	-5.4667	4.76310	.781	-18.6814	7.7481
	Control	-9.7707	5.83358	.454	-25.9554	6.4140
Control	1	-5.4373	5.83358	.884	-21.6220	10.7474
	2	24.6640*	5.83358	.000	8.4793	40.8487
	3	4.3040	5.83358	.947	-11.8807	20.4887
	4	9.7707	5.83358	.454	-6.4140	25.9554

Based on observed means.
The error term is Mean Square(Error) = 340.307.

*. The mean difference is significant at the 0.05 level.

Table A.5 The multiple comparisons of *the* density of mortar blocks for effects of curing days.



Day

Multiple Comparisons

Dependent Variable: Density

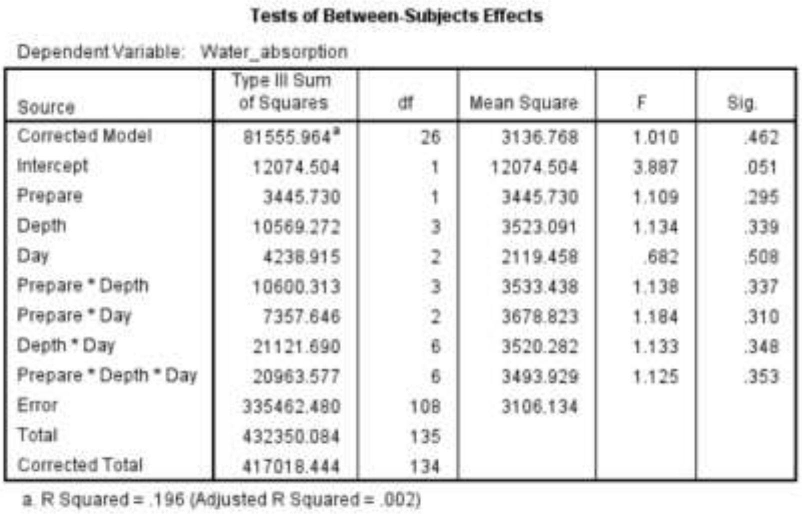
Tukey HSD

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
14	28	-12.3076*	3.88905	.006	-21.5497	-3.0654
	7	-.1529	3.88905	.999	-9.3951	9.0893
28	14	12.3076*	3.88905	.006	3.0654	21.5497
	7	12.1547*	3.88905	.006	2.9125	21.3968
7	14	.1529	3.88905	.999	-9.0893	9.3951
	28	-12.1547*	3.88905	.006	-21.3968	-2.9125

Based on observed means.
The error term is Mean Square(Error) = 340.307.

*. The mean difference is significant at the 0.05 level.

Table A.6 The water absorption tests between prepare method, depth and curing days.



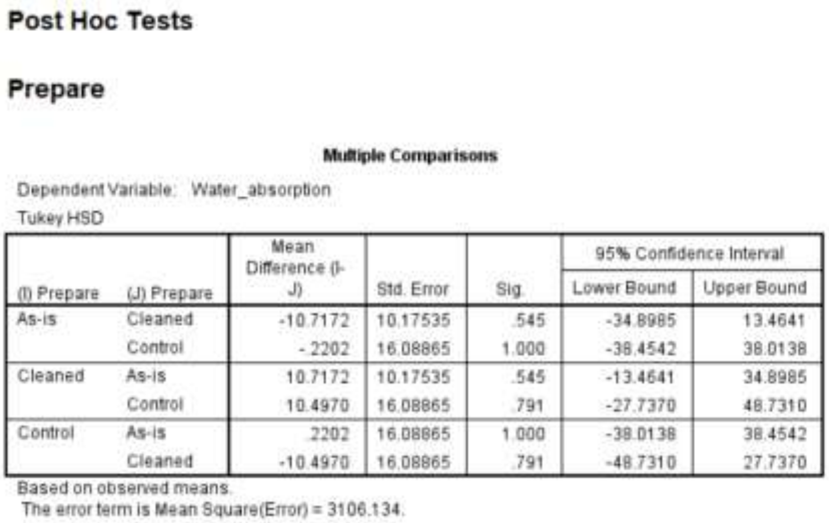
Tests of Between-Subjects Effects

Dependent Variable: Water_absorption

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	81555.964[a]	26	3136.768	1.010	.462
Intercept	12074.504	1	12074.504	3.887	.051
Prepare	3445.730	1	3445.730	1.109	.295
Depth	10569.272	3	3523.091	1.134	.339
Day	4238.915	2	2119.458	.682	.508
Prepare * Depth	10600.313	3	3533.438	1.138	.337
Prepare * Day	7357.646	2	3678.823	1.184	.310
Depth * Day	21121.690	6	3520.282	1.133	.348
Prepare * Depth * Day	20963.577	6	3493.929	1.125	.353
Error	335462.480	108	3106.134		
Total	432350.084	135			
Corrected Total	417018.444	134			

a. R Squared = .196 (Adjusted R Squared = .002)

Table A.7 The multiple comparisons of the water absorption of mortar blocks for effects of prepare methods.



Post Hoc Tests

Prepare

Multiple Comparisons

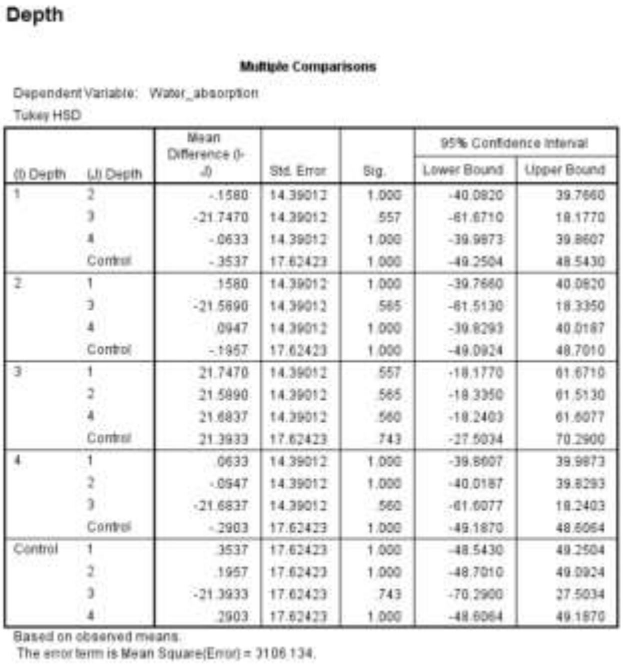
Dependent Variable: Water_absorption

Tukey HSD

(I) Prepare	(J) Prepare	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
As-is	Cleaned	-10.7172	10.17535	.545	-34.8985	13.4641
	Control	-.2202	16.08865	1.000	-38.4542	38.0138
Cleaned	As-is	10.7172	10.17535	.545	-13.4641	34.8985
	Control	10.4970	16.08865	.791	-27.7370	48.7310
Control	As-is	.2202	16.08865	1.000	-38.0138	38.4542
	Cleaned	-10.4970	16.08865	.791	-48.7310	27.7370

Based on observed means.
The error term is Mean Square(Error) = 3106.134.

Table A.8 The multiple comparisons of the water absorption of mortar blocks for effects of depths.



Depth

Multiple Comparisons

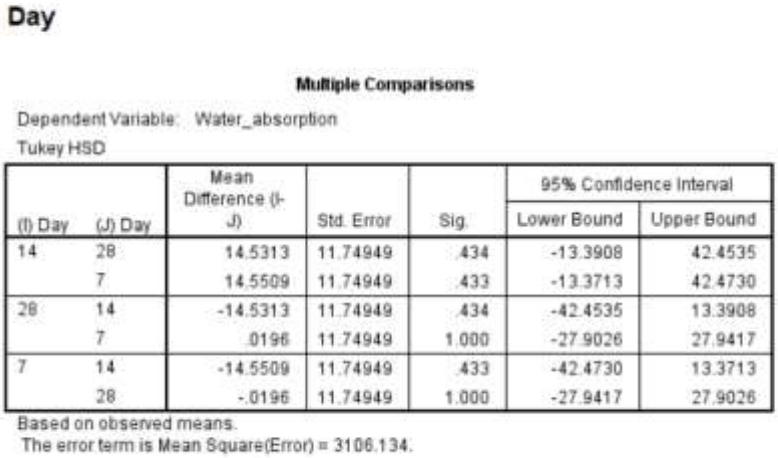
Dependent Variable: Water_absorption

Tukey HSD

(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.1580	14.39012	1.000	-40.0820	39.7660
	3	-21.7470	14.39012	.557	-61.6710	18.1770
	4	-.0633	14.39012	1.000	-39.9873	39.8607
	Control	-.3537	17.62423	1.000	-49.2504	48.5430
2	1	.1580	14.39012	1.000	-39.7660	40.0820
	3	-21.5890	14.39012	.565	-61.5130	18.3350
	4	.0947	14.39012	1.000	-39.8293	40.0187
	Control	-.1957	17.62423	1.000	-49.0924	48.7010
3	1	21.7470	14.39012	.557	-18.1770	61.6710
	2	21.5890	14.39012	.565	-18.3350	61.5130
	4	21.6837	14.39012	.560	-18.2403	61.6077
	Control	21.3933	17.62423	.743	-27.5034	70.2900
4	1	.0633	14.39012	1.000	-39.8607	39.9873
	2	-.0947	14.39012	1.000	-40.0187	39.8293
	3	-21.6837	14.39012	.560	-61.6077	18.2403
	Control	-.2903	17.62423	1.000	-49.1870	48.6064
Control	1	.3537	17.62423	1.000	-48.5430	49.2504
	2	.1957	17.62423	1.000	-48.7010	49.0924
	3	-21.3933	17.62423	.743	-70.2900	27.5034
	4	.2903	17.62423	1.000	-48.6064	49.1870

Based on observed means.
The error term is Mean Square(Error) = 3106.134.

Table A.9 The multiple comparisons of the water absorption of mortar blocks for effects of curing days.



Day

Multiple Comparisons

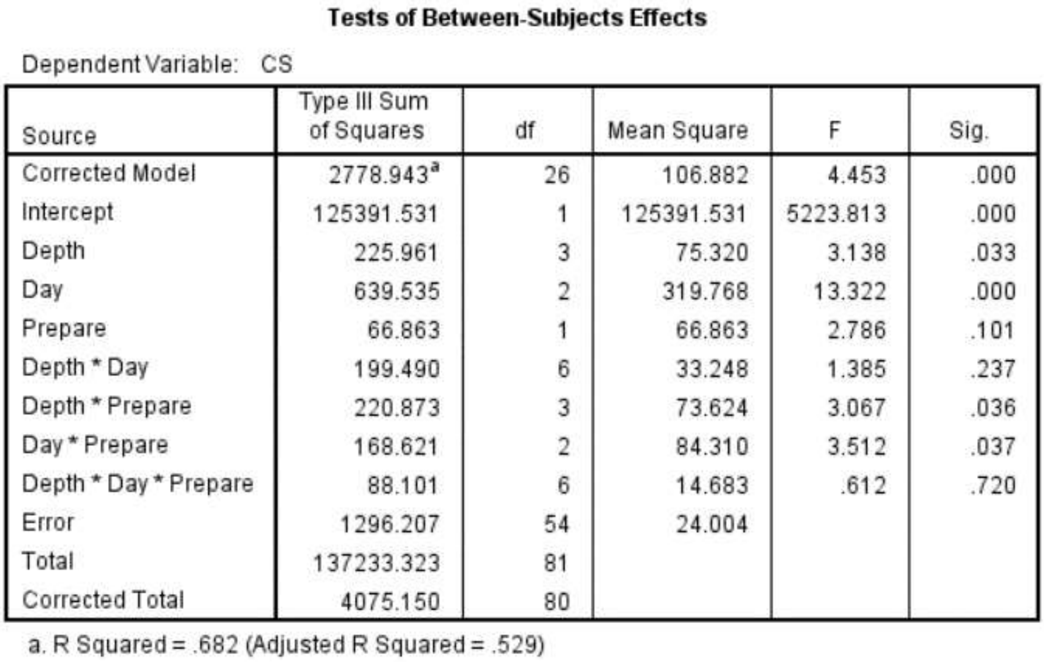
Dependent Variable: Water_absorption

Tukey HSD

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
14	28	14.5313	11.74949	.434	-13.3908	42.4535
	7	14.5509	11.74949	.433	-13.3713	42.4730
28	14	-14.5313	11.74949	.434	-42.4535	13.3908
	7	.0196	11.74949	1.000	-27.9026	27.9417
7	14	-14.5509	11.74949	.433	-42.4730	13.3713
	28	-.0196	11.74949	1.000	-27.9417	27.9026

Based on observed means.
The error term is Mean Square(Error) = 3106.134.

Table A.10 Compressive strength tests between effects of prepare method, depth and curing days.



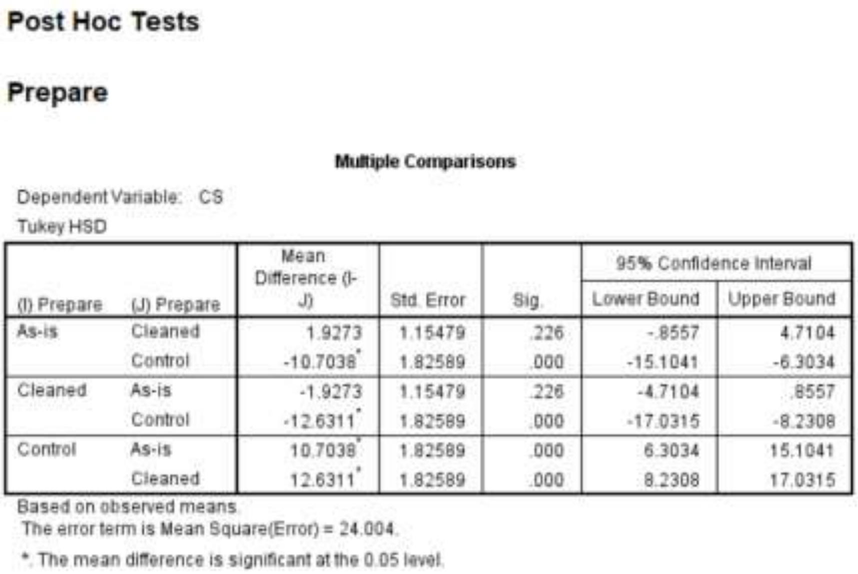
Tests of Between-Subjects Effects

Dependent Variable: CS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2778.943[a]	26	106.882	4.453	.000
Intercept	125391.531	1	125391.531	5223.813	.000
Depth	225.961	3	75.320	3.138	.033
Day	639.535	2	319.768	13.322	.000
Prepare	66.863	1	66.863	2.786	.101
Depth * Day	199.490	6	33.248	1.385	.237
Depth * Prepare	220.873	3	73.624	3.067	.036
Day * Prepare	168.621	2	84.310	3.512	.037
Depth * Day * Prepare	88.101	6	14.683	.612	.720
Error	1296.207	54	24.004		
Total	137233.323	81			
Corrected Total	4075.150	80			

a. R Squared = .682 (Adjusted R Squared = .529)

Table A.11 The multiple comparisons of compressive strength of mortar blocks for the effect of prepare method.



Post Hoc Tests

Prepare

Multiple Comparisons

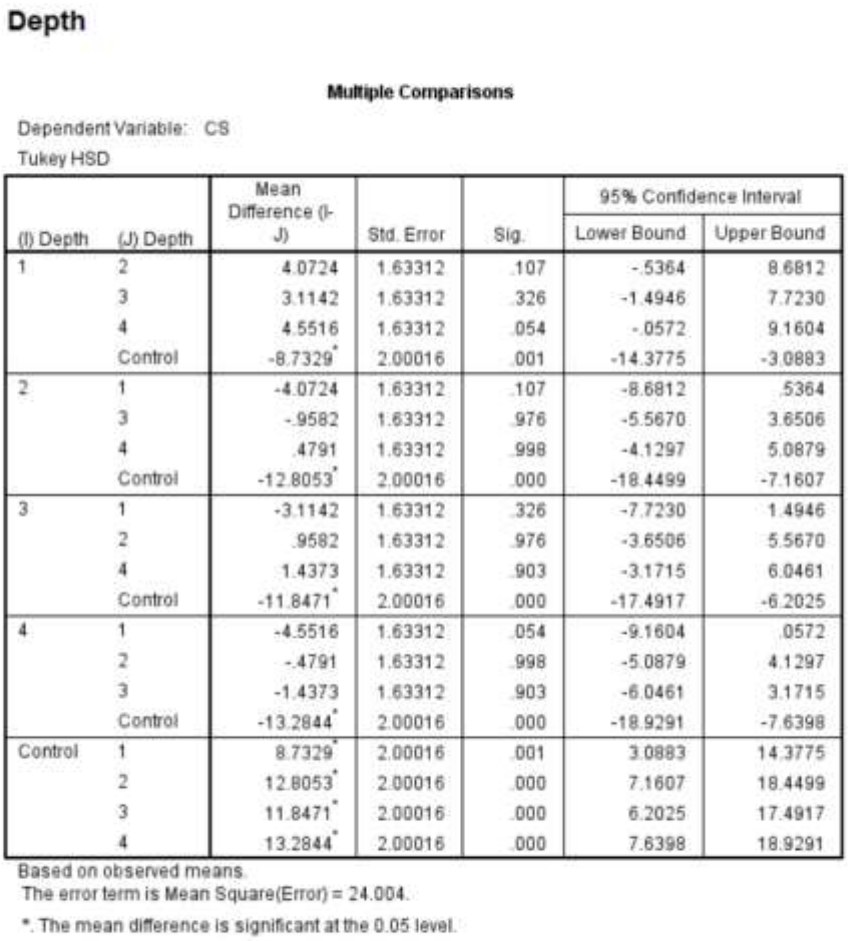
Dependent Variable: CS
Tukey HSD

(I) Prepare	(J) Prepare	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
As-is	Cleaned	1.9273	1.15479	.226	-.8557	4.7104
	Control	-10.7038*	1.82589	.000	-15.1041	-6.3034
Cleaned	As-is	-1.9273	1.15479	.226	-4.7104	.8557
	Control	-12.6311*	1.82589	.000	-17.0315	-8.2308
Control	As-is	10.7038*	1.82589	.000	6.3034	15.1041
	Cleaned	12.6311*	1.82589	.000	8.2308	17.0315

Based on observed means.
The error term is Mean Square(Error) = 24.004.

*. The mean difference is significant at the 0.05 level.

Table A.12 The multiple comparisons of compressive strength of mortar blocks for the effect of depth.



Depth

Multiple Comparisons

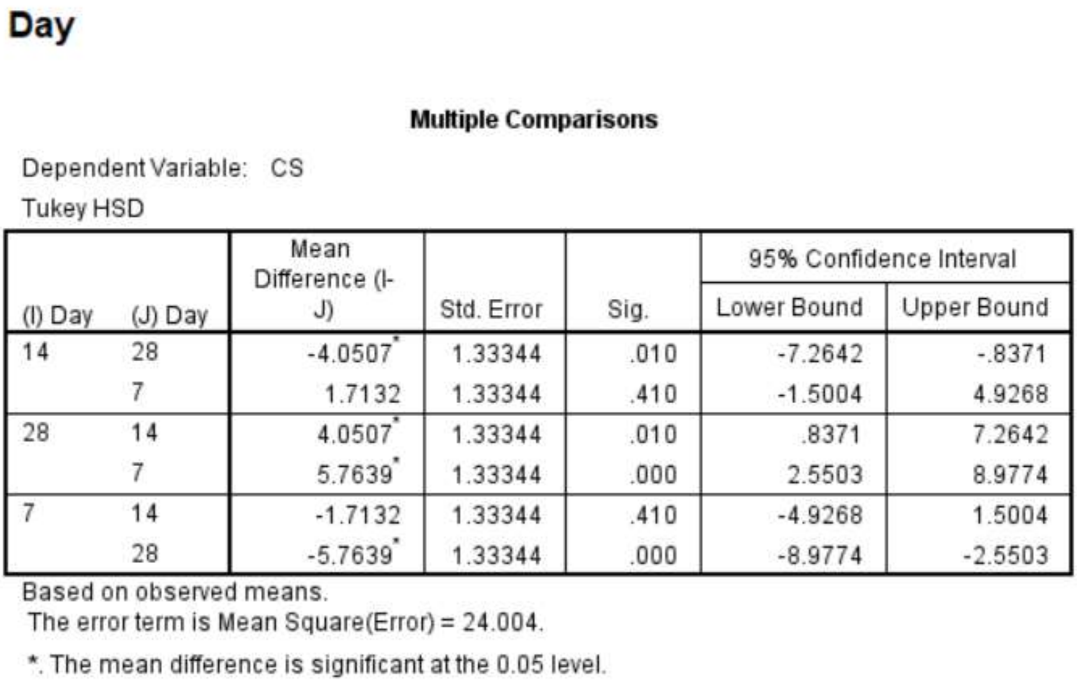
Dependent Variable: CS
Tukey HSD

(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	4.0724	1.63312	.107	-.5364	8.6812
	3	3.1142	1.63312	.326	-1.4946	7.7230
	4	4.5516	1.63312	.054	-.0572	9.1604
	Control	-8.7329*	2.00016	.001	-14.3775	-3.0883
2	1	-4.0724	1.63312	.107	-8.6812	.5364
	3	-.9582	1.63312	.976	-5.5670	3.6506
	4	.4791	1.63312	.998	-4.1297	5.0879
	Control	-12.8053*	2.00016	.000	-18.4499	-7.1607
3	1	-3.1142	1.63312	.326	-7.7230	1.4946
	2	.9582	1.63312	.976	-3.6506	5.5670
	4	1.4373	1.63312	.903	-3.1715	6.0461
	Control	-11.8471*	2.00016	.000	-17.4917	-6.2025
4	1	-4.5516	1.63312	.054	-9.1604	.0572
	2	-.4791	1.63312	.998	-5.0879	4.1297
	3	-1.4373	1.63312	.903	-6.0461	3.1715
	Control	-13.2844*	2.00016	.000	-18.9291	-7.6398
Control	1	8.7329*	2.00016	.001	3.0883	14.3775
	2	12.8053*	2.00016	.000	7.1607	18.4499
	3	11.8471*	2.00016	.000	6.2025	17.4917
	4	13.2844*	2.00016	.000	7.6398	18.9291

Based on observed means.
The error term is Mean Square(Error) = 24.004.

*. The mean difference is significant at the 0.05 level.

Table A.13 The multiple comparisons of compressive strength of mortar blocks for the effect of curing days.



Day

Multiple Comparisons

Dependent Variable: CS

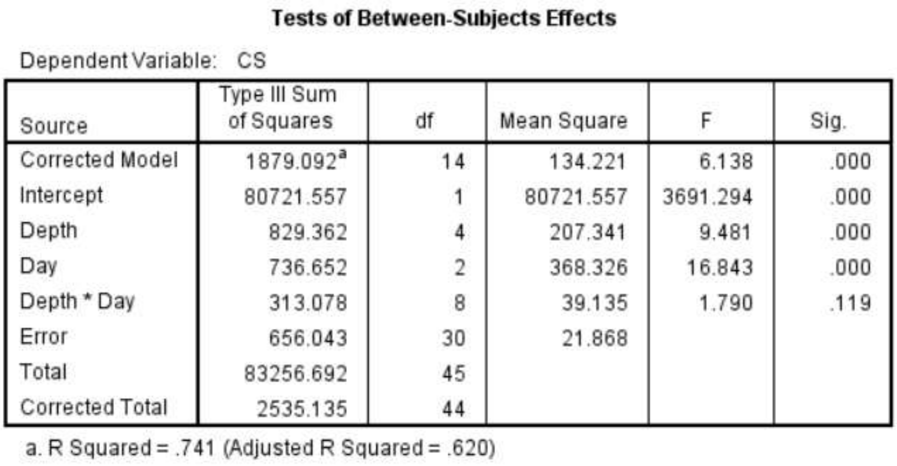
Tukey HSD

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
14	28	-4.0507*	1.33344	.010	-7.2642	-.8371
	7	1.7132	1.33344	.410	-1.5004	4.9268
28	14	4.0507*	1.33344	.010	.8371	7.2642
	7	5.7639*	1.33344	.000	2.5503	8.9774
7	14	-1.7132	1.33344	.410	-4.9268	1.5004
	28	-5.7639*	1.33344	.000	-8.9774	-2.5503

Based on observed means.
The error term is Mean Square(Error) = 24.004.

*. The mean difference is significant at the 0.05 level.

Table A.14 Compressive strength tests between effects of depth and curing days for as-is sample mortar blocks.



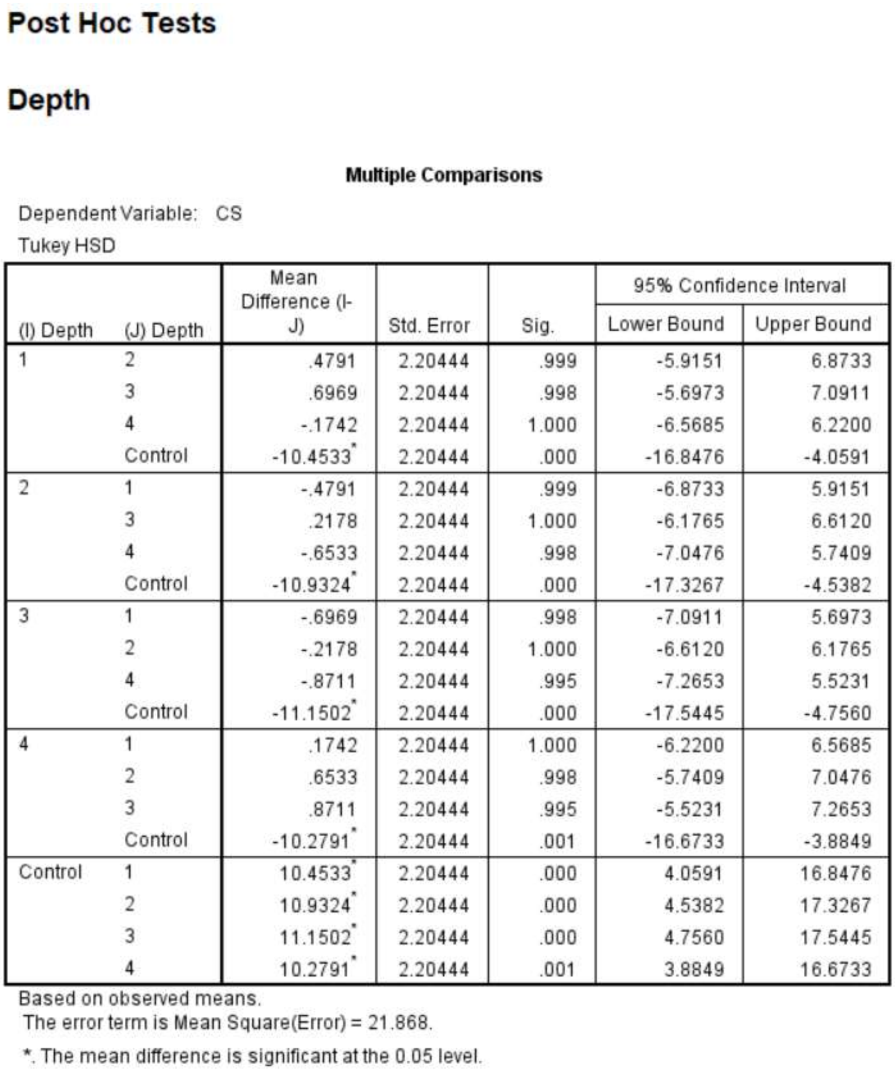
Tests of Between-Subjects Effects

Dependent Variable: CS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1879.092[a]	14	134.221	6.138	.000
Intercept	80721.557	1	80721.557	3691.294	.000
Depth	829.362	4	207.341	9.481	.000
Day	736.652	2	368.326	16.843	.000
Depth * Day	313.078	8	39.135	1.790	.119
Error	656.043	30	21.868		
Total	83256.692	45			
Corrected Total	2535.135	44			

a. R Squared = .741 (Adjusted R Squared = .620)

Table A.15 The multiple comparisons of compressive strength of as-is sample mortar blocks for the effect of depths.



Post Hoc Tests

Depth

Multiple Comparisons

Dependent Variable: CS

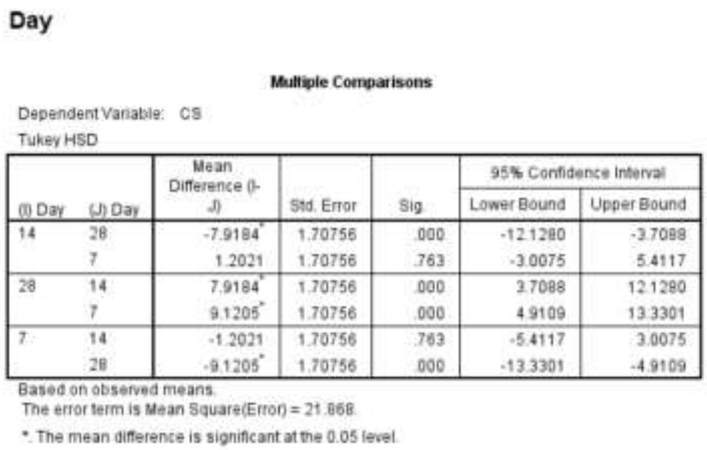
Tukey HSD

(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.4791	2.20444	.999	-5.9151	6.8733
	3	.6969	2.20444	.998	-5.6973	7.0911
	4	-.1742	2.20444	1.000	-6.5685	6.2200
	Control	-10.4533*	2.20444	.000	-16.8476	-4.0591
2	1	-.4791	2.20444	.999	-6.8733	5.9151
	3	.2178	2.20444	1.000	-6.1765	6.6120
	4	-.6533	2.20444	.998	-7.0476	5.7409
	Control	-10.9324*	2.20444	.000	-17.3267	-4.5382
3	1	-.6969	2.20444	.998	-7.0911	5.6973
	2	-.2178	2.20444	1.000	-6.6120	6.1765
	4	-.8711	2.20444	.995	-7.2653	5.5231
	Control	-11.1502*	2.20444	.000	-17.5445	-4.7560
4	1	.1742	2.20444	1.000	-6.2200	6.5685
	2	.6533	2.20444	.998	-5.7409	7.0476
	3	.8711	2.20444	.995	-5.5231	7.2653
	Control	-10.2791*	2.20444	.001	-16.6733	-3.8849
Control	1	10.4533*	2.20444	.000	4.0591	16.8476
	2	10.9324*	2.20444	.000	4.5382	17.3267
	3	11.1502*	2.20444	.000	4.7560	17.5445
	4	10.2791*	2.20444	.001	3.8849	16.6733

Based on observed means.
The error term is Mean Square(Error) = 21.868.

*. The mean difference is significant at the 0.05 level.

Table A.16 The multiple comparisons of compressive strength of as-is sample mortar blocks for the effect of curing days.



Day

Multiple Comparisons

Dependent Variable: CS

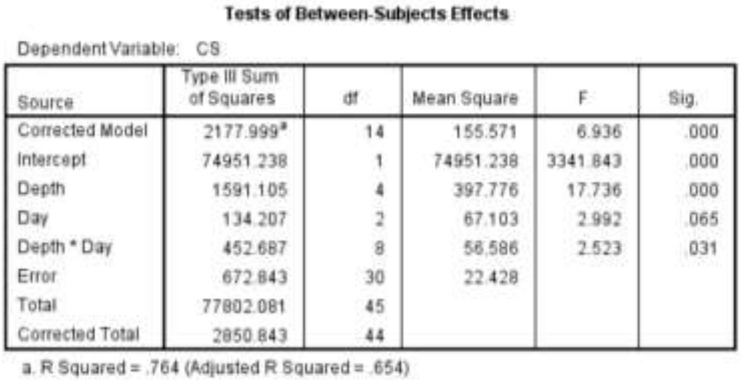
Tukey HSD

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
14	28	-7.9184*	1.70756	.000	-12.1280	-3.7088
	7	1.2021	1.70756	.763	-3.0075	5.4117
28	14	7.9184*	1.70756	.000	3.7088	12.1280
	7	9.1205*	1.70756	.000	4.9109	13.3301
7	14	-1.2021	1.70756	.763	-5.4117	3.0075
	28	-9.1205*	1.70756	.000	-13.3301	-4.9109

Based on observed means.
The error term is Mean Square(Error) = 21.868.

*. The mean difference is significant at the 0.05 level.

Table A.17 Compressive strength tests between effects of depth and curing days for cleaned sample mortar blocks.



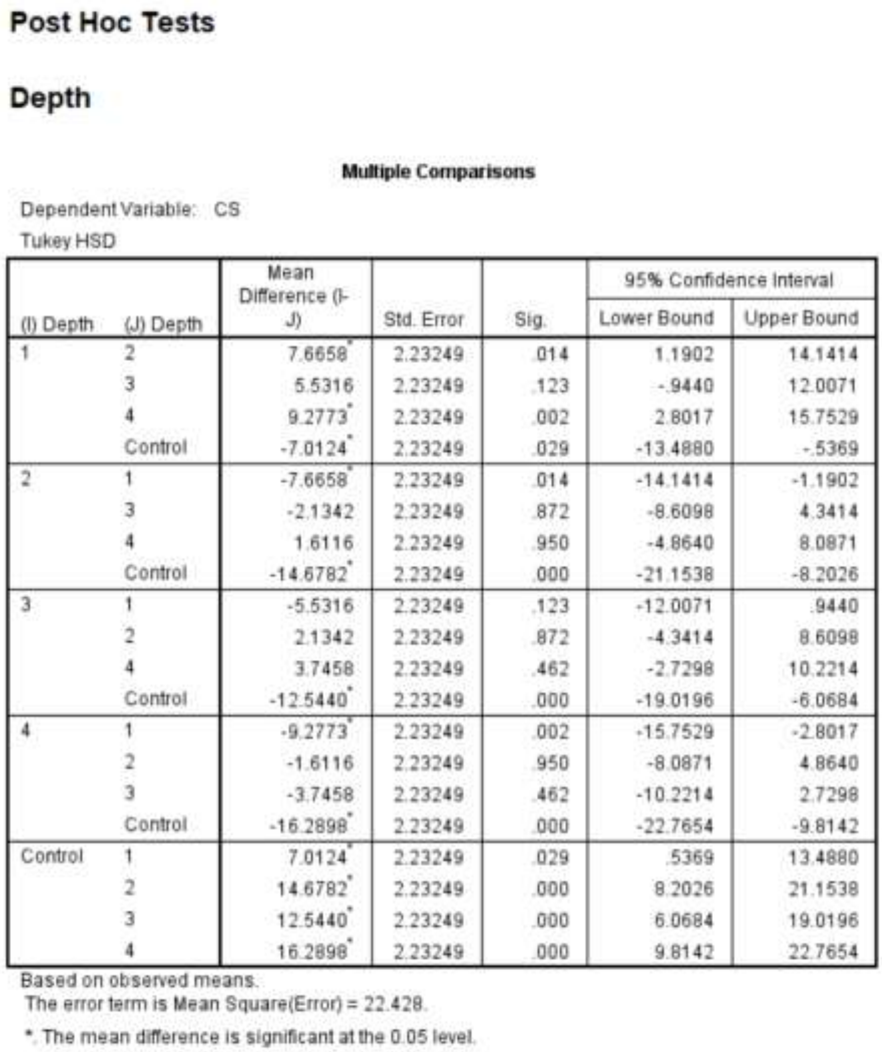
Tests of Between-Subjects Effects

Dependent Variable: CS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2177.999ᵃ	14	155.571	6.936	.000
Intercept	74951.238	1	74951.238	3341.843	.000
Depth	1591.105	4	397.776	17.736	.000
Day	134.207	2	67.103	2.992	.065
Depth * Day	452.687	8	56.586	2.523	.031
Error	672.843	30	22.428		
Total	77802.081	45			
Corrected Total	2850.843	44			

a. R Squared = .764 (Adjusted R Squared = .654)

Table A.18 The multiple comparisons of compressive strength of cleaned sample mortar blocks for the effect of depths.



Post Hoc Tests

Depth

Multiple Comparisons

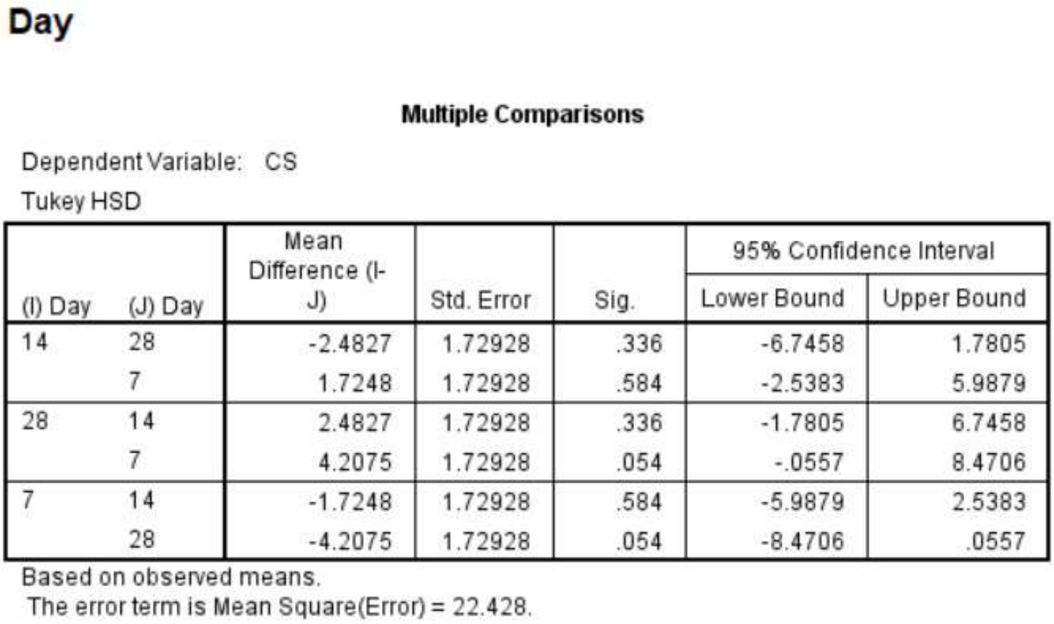
Dependent Variable: CS
Tukey HSD

(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	7.6658*	2.23249	.014	1.1902	14.1414
	3	5.5316	2.23249	.123	-.9440	12.0071
	4	9.2773*	2.23249	.002	2.8017	15.7529
	Control	-7.0124*	2.23249	.029	-13.4880	-.5369
2	1	-7.6658*	2.23249	.014	-14.1414	-1.1902
	3	-2.1342	2.23249	.872	-8.6098	4.3414
	4	1.6116	2.23249	.950	-4.8640	8.0871
	Control	-14.6782*	2.23249	.000	-21.1538	-8.2026
3	1	-5.5316	2.23249	.123	-12.0071	.9440
	2	2.1342	2.23249	.872	-4.3414	8.6098
	4	3.7458	2.23249	.462	-2.7298	10.2214
	Control	-12.5440*	2.23249	.000	-19.0196	-6.0684
4	1	-9.2773*	2.23249	.002	-15.7529	-2.8017
	2	-1.6116	2.23249	.950	-8.0871	4.8640
	3	-3.7458	2.23249	.462	-10.2214	2.7298
	Control	-16.2898*	2.23249	.000	-22.7654	-9.8142
Control	1	7.0124*	2.23249	.029	.5369	13.4880
	2	14.6782*	2.23249	.000	8.2026	21.1538
	3	12.5440*	2.23249	.000	6.0684	19.0196
	4	16.2898*	2.23249	.000	9.8142	22.7654

Based on observed means.
The error term is Mean Square(Error) = 22.428.

*. The mean difference is significant at the 0.05 level.

Table A.19 The multiple comparisons of compressive strength of cleaned sample mortar blocks for the effect of curing days.



Day

Multiple Comparisons

Dependent Variable: CS

Tukey HSD

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
14	28	-2.4827	1.72928	.336	-6.7458	1.7805
	7	1.7248	1.72928	.584	-2.5383	5.9879
28	14	2.4827	1.72928	.336	-1.7805	6.7458
	7	4.2075	1.72928	.054	-.0557	8.4706
7	14	-1.7248	1.72928	.584	-5.9879	2.5383
	28	-4.2075	1.72928	.054	-8.4706	.0557

Based on observed means.
The error term is Mean Square(Error) = 22.428.

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