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Feasibility Study of the Potential Use of Drill Cuttings in Concrete

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Abstract: Increasing the need of energy and its high price tempts companies to drill more oil wells every day and create more drilling waste. Most of these drilling wastes are managed to be disposed but they will always have many environmental impacts. Therefore, this study investigates the potential of using drill cuttings in concrete as a partial replacement of cement. The innovation of this study is not only to produce a new and cost-effective material from drill cuttings, but also to mitigate its negative environmental impacts. To achieve this objective, laboratory studies carried out to quantify the compressive strength of concrete samples and to determine the chemical composition of drill cuttings. Results showed that replacing 5% of cement with dried drill cuttings reduces the compressive strength of concrete by 10%. However, comprehensive strength of concrete samples decreases by 20% when replacing 10, 15, and 20% of cement with drill cuttings. Furthermore, the effect of some additives such as fly ash and silica fume on the compressive strength of the concrete samples containing drill cuttings was studied. It was concluded that adding these additives have a significant influence on the compressive strength of concrete samples containing 20% drill cuttings.

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***Key words**: Additives, Compressive strength, Concrete materials, Drill cuttings, Reuse and recycle.*

Introduction

With the ever-increasing worldwide energy demands, drilling more oil wells has become paramount to stakeholders and this leads to a greater amount of generated waste during drilling activities. Environmental agencies have expressed great concerns on the environmental implications of drilling activities since increased rate of oil production generates more greenhouse gases and the drilling process will disturb both the marine life and terrestrial life of the area [1]. Oil well drilling activities generate large amount of wastes in the form of drilling muds and cuttings. These wastes are disposed in open pits and large amount of un-stabilized wastes remain at a number of sites in U.S. To decrease the high risks of environmental damage, the most effective and economical alternative is to stabilize the wastes and manage them properly.

The most effective waste management approach largely depends on the volume of waste and worksite conditions and can involve waste treatment and disposal, waste minimization, recycling and re-use options [2]. Although treatment is the most sustainable method to control the effects of drilling wastes, but treatment methods are complicated and they impose high costs on companies. Managing operational parameters of treatment processes can increase the efficiency and decrease the costs significantly. For example, in a study performed by Khanpour et al. [3], supercritical extraction process was employed to mitigate the level of contamination of drilling muds. In this study, effect of different parameters including extraction temperature, pressure, CO_2 flow rate, and static time on the removal efficiency were investigated and the optimal condition of removal was determined. Commercial disposal companies use different methods to treat these wastes. Landfills and pits are the most common methods employed by these companies in disposing solid and oily drilling waste. In these methods, the liquid fraction of the waste is first evaporated before the solids are transported to landfills [4]. Other methods involve chemical stabilization of the waste, biological or chemical treatment and even thermal treatment or incineration of these wastes. All of these approaches vary with the geographical location where the drilling operations take place. In a study performed by Ghazi et al. [5] the life cycle environmental impacts of different drilling mud treatment systems were investigated. The life cycle assessment of this study contained different stabilization and treatment systems such as reserve pit without treatment and solidification and thermal desorption. Comparing different scenarios for the treatment, they showed that stabilization and solidification are the best approaches and have the lowest impacts.

In recent years, many researchers have studied the stabilization of hazardous waste [6-8]. In a parallel recent trend, researchers have begun to investigate the incorporation of recycling drill cuttings in various applications such as using them as a kiln feed in the manufacture of Portland cement [9, 10], in the manufacture of bricks and concrete blocks [10, 11], highway construction [12, 13], as substrate in wetlands restoration [14-17], and soil fertilizer [18]. One wide spread application of drill cuttings is to stabilize areas that are susceptible to getting eroded such as roads and drilling pads [13].

In a study conducted by Tuncan et al. [13], petroleum-contaminated soil was stabilized with 5% cement, 10% fly ash, and 20% lime, so it can be used as a sub-base material for road construction. These mixtures were found to be effective and safe for using as a sub-base material. Laboratory studies showed a significant increase in the unconfined compressive strength, California bearing ratio, and durability. However, a similar decrease

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was obtained in electrical, conductivity and cation exchange capacity. In another study performed by Li et al. [19], the effect of diesel based drilling fluids on Portland cement was investigated. They examined the mechanism of contracting cement slurry and diesel based fluid materials which lead to the contamination mitigation. Results showed that the changes in the slurry properties were caused by osmotic pressure and demulsification. Having investigated the physical and chemical properties of drill cuttings, several studies have attempted to use petroleum-contaminated soil in hot mix asphalt concrete. In a study conducted in Massachusetts Department of Environmental Quality and Engineering, it was permitted to replace 5% of the aggregate in hot mix asphalt with soil containing 3% of oil, gasoline, or kerosene [20]. In another study, Meegoda and Muller [21] examined the integration of petroleum-contaminated soil into hot mix asphalt concrete in New Jersey. It was found that it is possible to include up to 35% petroleum-contaminated soil in the mix. Later, Meegoda et al. [22] revealed that the tensile strength ratio for hot mix asphalt containing petroleum-contaminated soil was not meaningfully different from the control mix. Their results indicated that saturated hydraulic conductivity values of all hot mix asphalt samples containing petroleum-contaminated soil were less than 2×10^{6} cm/s. In a similar study, Aydilek et al. [23] mixed fly ash with drilling waste to be used as base or sub-base material. Fly ash can be used as mineral filler in hot mix asphalt paving applications. Their results showed that fly ash is a good additive to reduce leaching.

Taha et al. [24] studied the possible application of bottom sludge from petroleum tanks as paving materials in roads. In their study, the total petroleum hydrocarbon contents were as high as 50 to 65%. Hot mix asphalt specimens containing petroleum waste were created by blending the heated sludge and aggregates without the addition of fresh asphalt. Different sludge percentages, ranging between 3% and 7% were added to the clean aggregate. Test results showed a noteworthy increase in stability with the addition up to 5% of sludge, followed by a stability decrease upon further increase in sludge content.

The present study investigates the potential of using drill cuttings in concrete as a partial replacement of cement. The innovation of this study is not only to produce a new and cost-effective material from drill cuttings, but also to mitigate its negative environmental impacts. To achieve this objective, laboratory studies were conducted to quantify the compressive strength of concrete samples and to determine the chemical composition of drill cuttings. Results revealed that replacing 5% of cement with dried drill cuttings reduces the compressive strength of concrete by 10%. However, comprehensive strength of concrete samples decreases by 20% when replacing 10, 15, and 20% of cement with drill cuttings. Furthermore, the effect of some additives such as fly ash and silica fume on the compressive strength of the concrete samples containing drill cuttings was studied.

Chemical Analysis

Drill cuttings were subjected to the USEPA 1312 toxicity characteristic leaching procedure. Chemical analysis of the extract was executed to determine concentrations of volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and metals. Gas chromatography–mass spectrometry (GC/MS) was used to determine the concentration of VOC, SVOC, and total petroleum hydrocarbon (TPH). The Synthetic Precipitation Leaching Procedure (SPLP) was utilized to analyze the metal concentration in the extract. The results of the chemical analysis in addition to the Toxicity Characteristic Leaching Procedure (TCLP) regulatory levels [25] are shown in Table 1. Results showed that the analyzed drill cuttings can be considered as a non-hazardous waste.

Table 1. Chemical Analysis of the Drill Cuttings

Material	Concentration Level	
	Extract (μg/l)	Regulatory(μg/l)
Volatile Organic Compound (VOC)		
Benzene	0.005	500
Tetrachloroethane	0.007	700
Trichloroethene	0.005	500
Carbon Tetrachloride	0.005	500
Chlorobenzene	1	10^5
Chloroform	0.06	600
1, 4- Dichlorobenzene	0.075	7500
1, 2- Dichloroethane	0.005	500
1, 1- Dichloroethane	0.007	700
Methyl Ethyl Ketone	2	20×10^5
Vinyl Chloride	0.002	200
Semi Volatile Organic Compounds		
Pyridine	< 0.100	5000
2-Methylphenol	< 0.100	N/A
Hexachloroethane	< 0.500	3000
3/4-Methylphenol	< 0.500	N/A
Nitrobenzene	< 0.100	2000
Hexachlorobutadiene	< 0.100	500
2, 4, 6-Trichlorophenol	< 0.100	2000
2, 4, 5- Trichlorophenol	< 0.100	40×10^5
2, 4- Dinitrotoluene	< 0.100	130
Hexachlorobenzene	< 0.100	130
Pentachlorophenol	< 0.100	10×10^5
Metals		
Arsenic	<10	5000
Barium	33	10×10^5
Cadmium	<5	1000
Chromium	<10	5000
Lead	<10	5000
Mercury	<0.2	200
Selenium	<10	1000
Silver	<50	5000

Materials

Drill Cuttings

The drill cuttings were tested for grain size distribution. Grain size distributions and some properties of drill cuttings are given in Fig. 1. This figure shows that 95% of the soil sample falls in the range between 4.75 and 0.075 mm, which is mainly the range for sands.

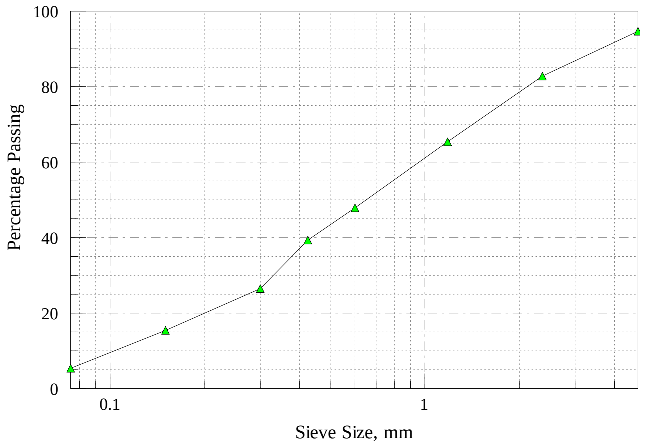

Fig. 1. Sieve Analysis.

The coefficients of uniformity (C_u) and curvature (C_c) were 8.63 and 1.22, respectively which represents for well graded sand.

Supplementary Cementitious Materials

The effect of some supplementary cementitious materials such as fly ash and silica fume was investigated to understand their ability to enhance the properties of concrete samples containing drill cuttings. Each of these supplementary materials possesses different properties and reacts differently in the presence of water. Fly ash is widely used in blended cements and is a by-product of coal-fired electric power plants. Fly ash lowers the heat of hydration and improves the durability when used in concrete as a cement replacement. It also contributes to concrete strength by pozzolanic and filler effects [26], [27]. Similarly, silica fume is a pozzolanic material which is a by-product of the silicon smelting process. Silica fume serves a dual role as a filler and pozzolan. Due to its small particle size, it can enter the spaces that exist between the particles of cement to improve packing [28, 29].

Sample Preparation

The test specimens were cast from 5 separate batches of concrete: one control, 4 mixes containing different percentages of drill cuttings, fly ash, silica fume, and a mixture of silica fume and fly ash. Drill cuttings obtained from drilling site (Fig. 2(a)), dried in oven at 100~105℃ for 24 hours first, then passed through Sieve No. 100. Concrete mixture was designed according to ACI recommendations. Portland cement type I was used in this study as cementitious material. Cement and drill cuttings were thoroughly mixed to obtain a uniform color. The coarse aggregate was a crushed limestone with 100% passing the sieve No.3/8-in. (9.5-mm) and 20% passing the sieve No. 4 (4.75-mm) and with none passing the sieve No. 8 (2.36-mm). The coarse aggregate had absorption of 1.8% and relative density of 2.63, whereas the fine aggregate absorption was 0.5% with relative density of 2.61. The cylindrical specimens 8 in. (20 cm) × 4 in. (10 cm) were cast as shown in Fig. 2(b), and were tested in triplicate. The reported strength values represented the average strength of three specimens. After being stripped from the molds, the specimens were submerged in water for 7 days at room temperature. The mixture proportions associated are shown in

Fig. 2. (a) Drill Cuttings (b) Concrete Samples.

Table 2. To compensate the loss in compressive strength, different percentages of silica fume and fly ash was added to the mixture as an additive.

Results and Analysis

To assess the effect of drill cuttings on the compressive strength of concrete samples, various amounts of drill cuttings were replaced with cement. Fig. 3 shows the compressive strength of concrete samples containing different amount of drill cutting after 7 days of curing. Error bars in the figure show ±1 standard deviation. Compared to control sample, the specimens containing 5%, 20%, and 35% of drill cuttings showed 10, 22, and 63% reduction in their compressive strength. It was found that replacing 10, 15, and 20% of cement with drill cuttings do not have a significant effect on the compressive strength of prepared samples.

Further studies were conducted to investigate how much improvement in compressive strength could be accomplished by adding different amount of fly ash to concrete samples containing 20% drill cuttings. When properly proportioned and placed, fly ash concrete generally shows improved workability, cohesiveness, finish, ultimate strength, and durability. It has been found that fly ash is of particular value in high-strength concrete. Therefore, different percentages of fly ash including 5, 10, 15, 20, and 25% were added to concrete samples in which 20% of the cement weight was replaced with drill cuttings. It can be observed from Fig. 4 that the compressive strength of the concrete samples with 15-20% fly ash was increased by 33%. However, adding 25% of fly ash to concrete samples containing 20% drill cuttings significantly reduced their compressive strength.

Fig. 5 shows the effect of silica fume on the compressive strength of concrete samples containing 20% drill cuttings. Different percentage of silica fume including 5, 10, and 20% were added to concrete samples containing 20% drill cuttings. It can be seen from Fig. 5, adding 5% silica fume as an additive increases the compressive strength by 13%, however, no significant difference is observed in compressive strength of samples containing 10 and 20% silica fume. It can also be noted that the enhancement effect of 20% silica fume on the compressive strength was not as significant as samples containing 20% fly ash. The higher compressive strength of the fly ash can be attributed to the improved interfacial bond between the paste and the aggregate.

Based on obtained results, it was found that adding silica fume

Table 2. Mix Proportions of Cement

Mix	Portland Cement I (kg/m³)	Water (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Drill Cuttings (kg/m³)	Silica Fume (kg/m³)	Fly Ash (kg/m³)
Control	268.5	155	745	1305	0	0	0
5% Drill Cuttings	255	155	745	1305	13.5	0	0
10% Drill Cuttings	241.5	155	745	1305	27	0	0
15% Drill Cuttings	228.3	155	745	1305	40.2	0	0
20% Drill Cuttings	215	155	745	1305	53.5	0	0
25% Drill Cuttings	201.4	155	745	1305	67.1	0	0
5% Fly Ash	215	155	745	1305	53.5	0	10.75
10% Fly Ash	215	155	745	1305	53.5	0	21.5
15% Fly Ash	215	155	745	1305	53.5	0	32.25
20% Fly Ash	215	155	745	1305	53.5	0	43
25% Fly Ash	215	155	745	1305	53.5	0	53.75
5% Silica Fume	215	155	745	1305	53.5	10.75	0
10% Silica Fume	215	155	745	1305	53.5	21.5	0
15% Silica Fume	215	155	745	1305	53.5	32.25	0
20% Silica Fume	215	155	745	1305	53.5	43	0
5% Silica Fume/Flyash	215	155	745	1305	53.5	5.4	5.4
7.5% Silica Fume/Flyash	215	155	745	1305	53.5	8	8
10% Silica Fume/Flyash	215	155	745	1305	53.5	10.7	10.7
15% Silica Fume/Flyash	215	155	745	1305	53.5	16.1	16.1

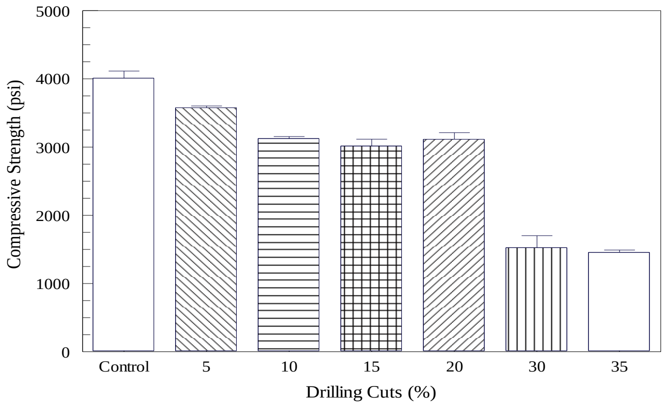

Fig. 3. Compressive Strength of Samples Containing Different Amount of Drill Cutting.

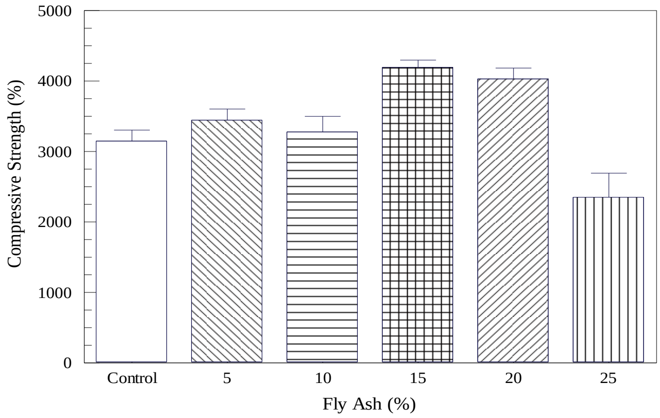

Fig. 4. Compressive Strength of Samples Containing Flyash.

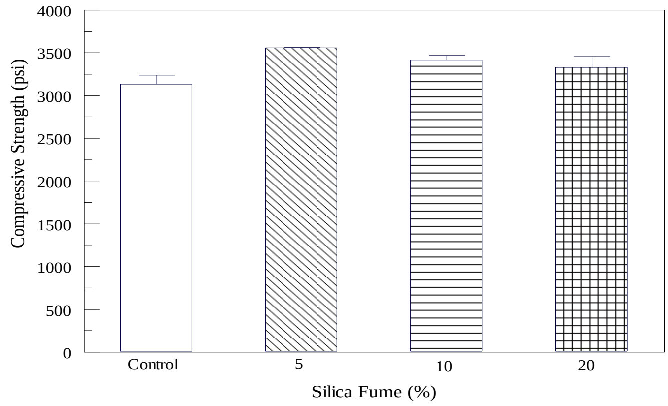

Fig. 5. Compressive Strength of Samples Containing Silica Fume.

and flyash separately to the prepared concrete samples improve their compressive strength. Therefore, to investigate the effect of utilization of fly ash and silica together on the compressive strength of concrete samples, different percentages of fly ash and silica mixture (i.e., 2.5% silica fume and 2.5% flyash; 3.75% silica fume and 3.75% flyash; 5% silica fume and 5% flyash; 7.5% silica fume and 7.5% flyash) were added to the prepared samples as an additive. Fig. 6 shows the effect of adding the silica fume/flyash mixture to concrete samples containing 20% drill cuttings. An increasing trend is seen in this figure by increasing the percentage of silica fume/flyash. As Fig. 6 demonstrates, adding 15% of fly ash and silica fume will steadily increase the compressive strength up to 40%.

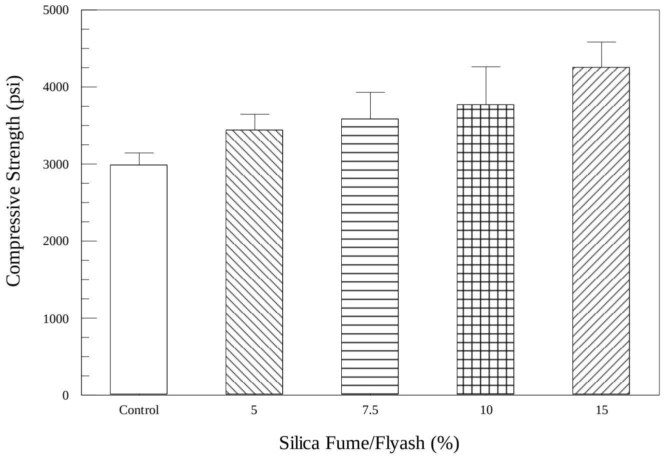

Fig. 6. Compressive Strength of Samples Containing Silica Fume/Flyash.

Conclusions

This study assesses the feasibility of using drill cuttings in concrete as a partial replacement of cement. The following conclusions have been drawn from this study:

- Drill cuttings can be used as a partial replacement with cement in concrete. Results indicated that compare to control sample, the specimens containing 5%, 20%, and 35% of drill cutting showed 10%, 22%, and 63% reduction in their compressive strength. It was also found that replacing 10, 15, and 20% of cement with drill cutting do not have a significant effect on the compressive strength of prepared samples. Therefore, replacing 20% of cement with drilling waste was considered as the optimum value.
- It has been found that flyash is of particular value in high-strength concrete. Therefore, various percentage of flyash including 5, 10, 15, 20, and 25% were added to concrete samples containing 20% drill cuttings. Results showed that the compressive strength of the concrete samples with 15-20% flyash was increased by 33%. However, adding 25% of flyash significantly reduces their compressive strength.
- Results indicated that adding 5% silica fume as an additive increased the compressive strength by 13%; however, no significant difference is observed in compressive strength of samples containing 10 and 20% silica fume. It can also be noted that the enhancement effect of 20% silica fume on the compressive strength was not as significant as samples containing 20% fly ash. The higher compressive strength of the fly ash can be attributed to the improved interfacial bond between the paste and the aggregate.
- In addition, different percentages of fly ash and silica mixture were added to the prepared samples as an additive. Results indicated that adding 15% of fly ash and silica fume will steadily increase the compressive strength up to 40%.

It remains for the future research to investigate how different mix design proportions can improve the compressive strength of concrete samples containing drill cuttings. In addition, we will investigate the effect of replacing sand by drill cuttings since the grain size distribution is similar.

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