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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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Keywords: Drill Cuttings, Concrete Materials, Additives, Compressive Strength, Reuse and Recycle;

1. Introduction

Increasing world energy demand, which is compensated by drilling more oil wells has led to unavoidable increase in drilling waste. One of the environmental concerns of increased rate of oil production is generation of contaminated drill cutting, which results in disturbing the marine and terrestrial life (1). Drill cutting is an environmentally hazardous by-product of drilling process. Statistics shows that only a minor portion of this waste is being disposed in pits and the majority remains on site which should be stabilized and managed wisely. Therefore, a best management strategy is needed to properly manage the volume of waste and worksite condition as well as economic constraints and sustainability (2).

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Recently, different methods have been used to manage petroleum contaminated soil including steam stripping and ultraviolet (UV) oxidation to decrease the potential contamination of drilling waste. However, since these methods are not economically feasible, landfilling and pit disposal are widely employed in this regard. In landfilling, the liquid fraction of the waste is evaporated prior to the disposal of the solid waste in the landfill (3). 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; however soil must be decontaminated to the level which can be classified as non-hazardous according to New Jersey Department of Environmental Protection (18).

In recent years, many researchers have studied different approaches of hazardous waste stabilization (4-6). In parallel, investigations focusing on various applications of drilling wastes such as manufacturing of Portland cement (7,8), brick and concrete blocks (8,9), highway construction materials (10,11), and as substrate in wetlands restoration (12-15) were performed. Tuncan et al. (11) used drilling waste to construct road sub-base. The petroleum contaminated soil which was stabilized by 5% cement, 10% fly ash, and 20% lime showed a significant increase in unconfined compressive strength and California bearing ratio of the sub-base material. However, a decrease was seen in conductivity and cation exchange capacity. The result of a study conducted by Massachusetts Department of Environmental Quality and Engineering suggested that replacement of 5% of the aggregates in hot mix asphalt with soil containing 3% oil, gasoline, or kerosene will not negatively affect the mechanical properties of the hot mix asphalt (16). In another study, Meegoda and Muller (17) examined the effects of incorporating drilling waste into the hot mix asphalt concrete. They concluded that the mixture can contain up to 35% of petroleum contaminated soil. Moreover, Meegoda et al. (18) investigated the tensile strength ratio of hot mixed asphalt using petroleum-contaminated soil and revealed that the tensile strength ratio of hot mix asphalt has the same order as the control mix. It was also indicated that the hydraulic conductivity of the samples which were made by petroleum-contaminated soil were less than 2×10^{-6} cm/s. Aydilek et al. (19) used a mixture of flyash and drilling waste as the road base and sub-base. Results also showed that flyash has a significant effect on leachate reduction. Taha et al. (20) studied the application of petroleum tanks bottom sludge in production of paving material. Hot mix asphalt specimens were made by blending 3% to 7% of heated sludge and clean aggregates without adding the fresh asphalt. Results showed that adding up to 5% of sludge significantly improved the stability.

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.

2. Chemical Analysis

To determine the mobility of inorganic phase of polluted soil, USEPA 1312 toxicity characteristic leaching procedure, was employed. The objective of chemical analysis of drill cuttings was to study the presence and concentration of Volatile Organic Compounds (VOC), Semi-Volatile Organic Compounds (SVOC), Total Petroleum Hydrocarbon (TPH), and metals. Metal concentration was measured based on Synthetic Precipitation Leaching Procedure (SPLP). VOC, SVOC, and TPH concentrations were determined by Gas Chromatography-Mass Spectrometry (GC/MS) method. Results of the chemical analysis were compared with the Toxicity Characteristic Leaching Procedure (TCLP) regulatory levels (21). The concentration of different compounds and allowable amounts are plotted in Figure 1. As it can be seen, the drill cutting can be classified as non-hazardous waste.

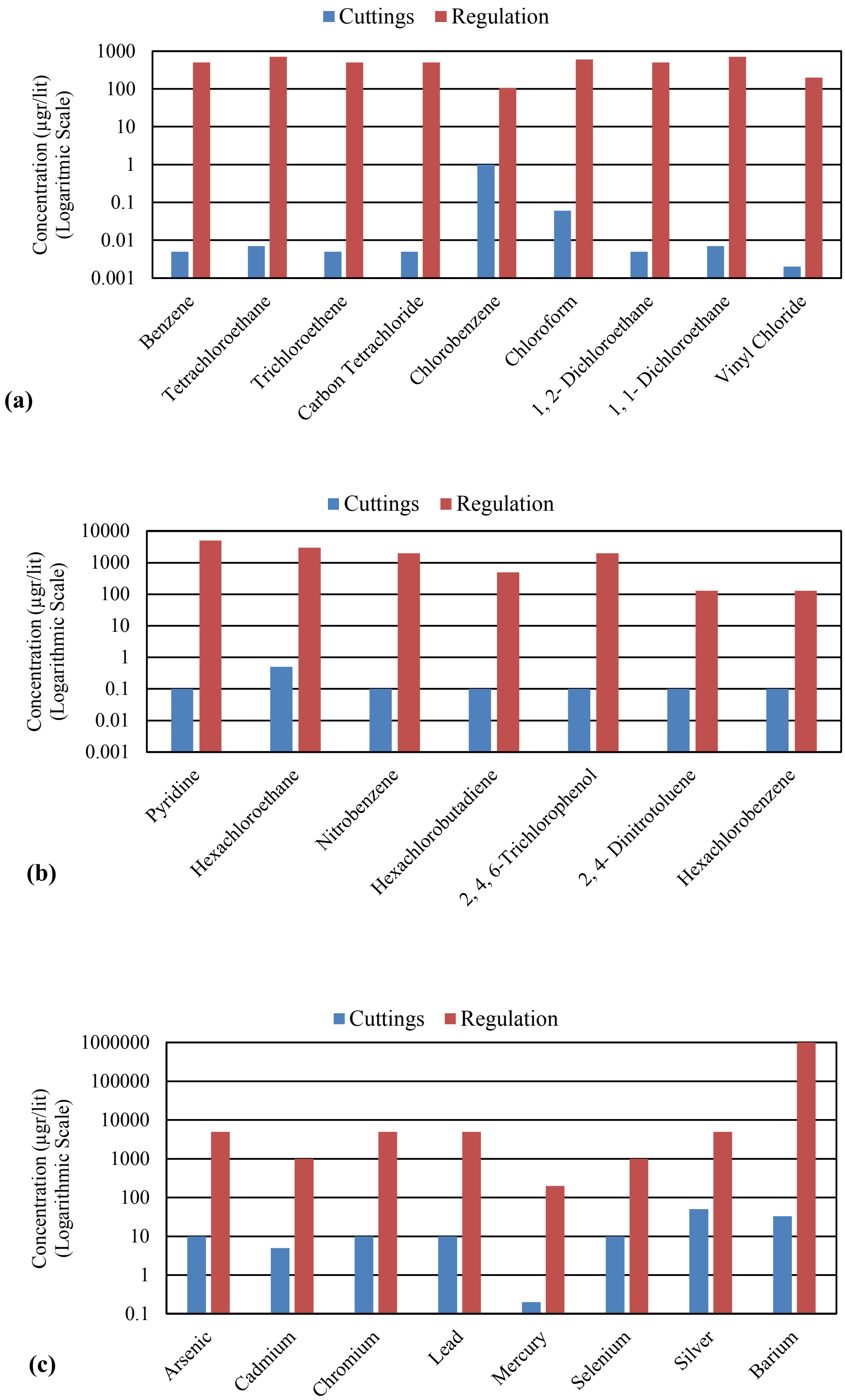
Cuttings
Regulation
Concentration (µgr/lit) (Logaritmic Scale)
1000
100
10
1
0.1
0.01
0.001
Benzene
Tetrachloroethane
Trichloroethene
Carbon Tetrachloride
Chlorobenzene
Chloroform
1, 2- Dichloroethane
1, 1- Dichloroethane
Vinyl Chloride
(a)
Cuttings
Regulation
Concentration (µgr/lit) (Logarithmic Scale)
10000
1000
100
10
1
0.1
0.01
0.001
Pyridine
Hexachloroethane
Nitrobenzene
Hexachlorobutadiene
2, 4, 6-Trichlorophenol
2, 4- Dinitrotoluene
Hexachlorobenzene
(b)
Cuttings
Regulation
Concentration (µgr/lit) (Logarithmic Scale)
1000000
100000
10000
1000
100
10
1
0.1
Arsenic
Cadmium
Chromium
Lead
Mercury
Selenium
Silver
Barium
(c)

Figure 1. Concentration of different materials in cuttings and regulation (a). VOC, (b). SVOC, and (c). metals

3. Materials

3.1. Drill Cuttings

Figure 2 shows the drill cuttings aggregate size distribution. The maximum grain size is less than 6 mm, and coefficient of uniformity (Cu) and curvature (Cc) are 8.63 and 1.22, respectively. As can be seen in Figure 2, the drill cutting sample is classified as fine aggregates in accordance with ASTM-C330.

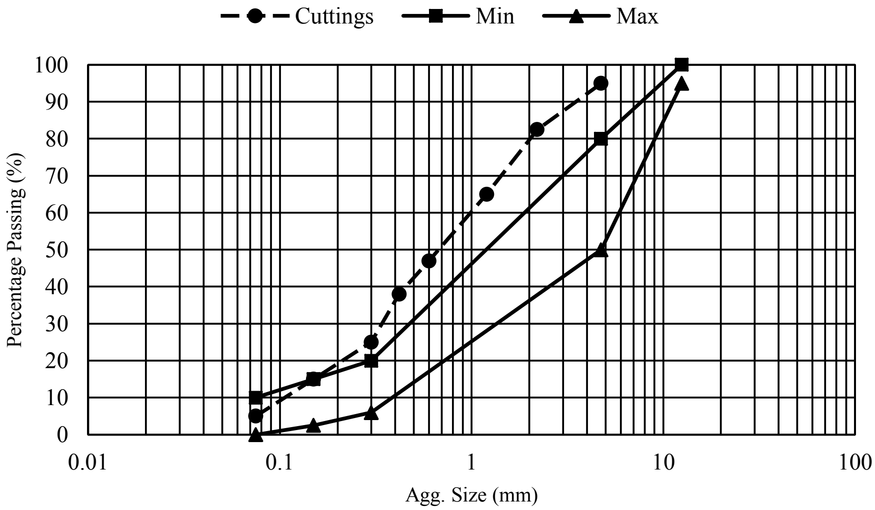

Figure 2. Drill cuttings aggregate size distribution

3.2. Supplementary Cementitious Materials

Flyash and silica fume are two supplementary cementitous materials which are widely used in concrete production. To investigate the effect of flyash and silica fume on the compressive strength of concrete containing drill cuttings, samples including specified percentages of aforementioned materials were made.

Flyash is a byproduct of coal combustion which is directly emitted to air and cause air pollution. Currently, because of the air pollution concerns, different strategies are applied to collect flyash from gas streams and use it for other applications. During past decades, flyash is extensively used as an additive in concrete. Using flyash in concrete lowers the hydration temperature and increases the compressive strength because of pozzolanic effects (22, 23). Similarly, silica fume with small particle size which has pozzolanic behavior can fill the space between aggregates and cement, consequently increase the strength and durability of concrete (24, 25).

4. 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 (Figure 3a), dried in oven at 100~105ºC 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 colour. 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 specimen 20 cm (8 in) × 10 cm (4 in) were cast as shown in Figure 3b, and were tested in triplicate. The reported strength values represented the average strength of three specimens. After being stripped from molds, the specimens were submerged in water for 7 days at room temperature. The mixture proportions associated are shown in Table 1. To compensate the loss in compressive strength, different percentages of silica fume and fly ash was added to the mixture as an additive.

Figure3. (a) Drill Cuttings (b) Concrete Samples

Table 1. 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% flyash	215	155	745	1305	53.5	0	10.75
10% flyash	215	155	745	1305	53.5	0	21.5
15% flyash	215	155	745	1305	53.5	0	32.25
20% flyash	215	155	745	1305	53.5	0	43
25% flyash	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

5. 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. Figure 4 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.

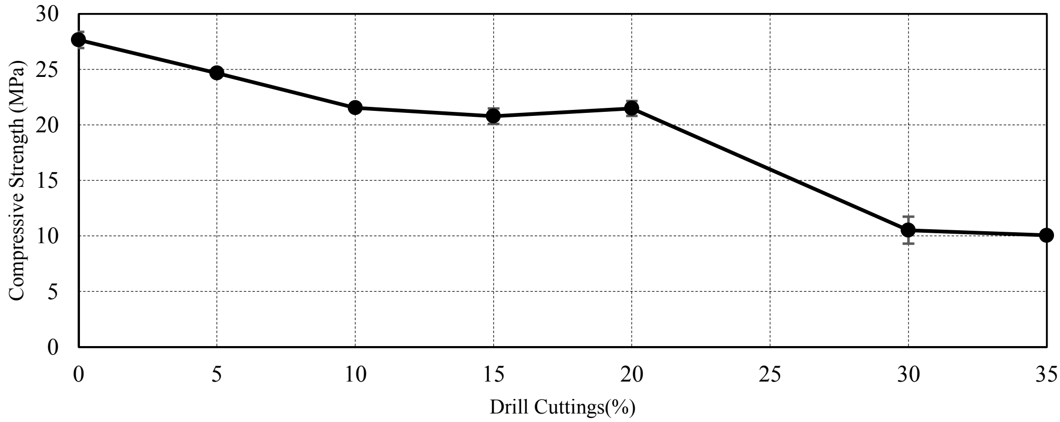

Figure 4. Compressive Strength of Samples Containing Different Amount of Drill Cutting

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 Figure 5 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.

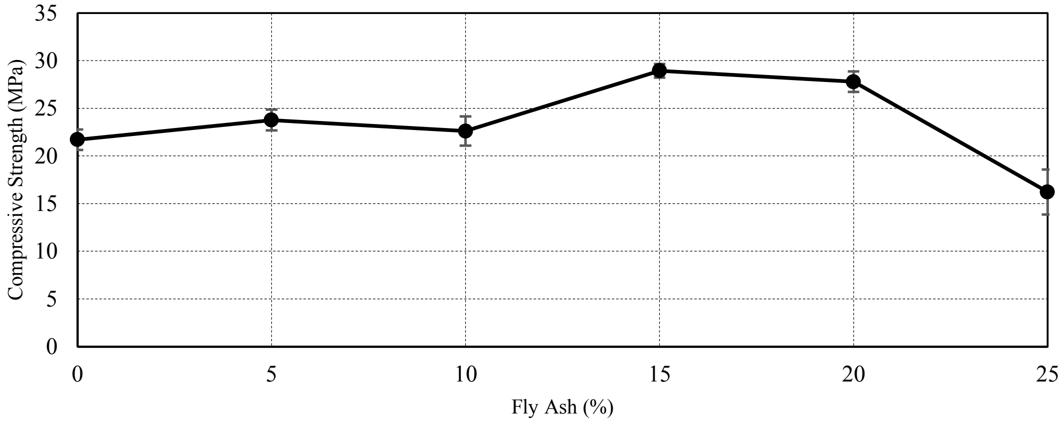

Figure 5.Compressive Strength of Samples Containing Flyash

Figure 6 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 Figure 6, 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.

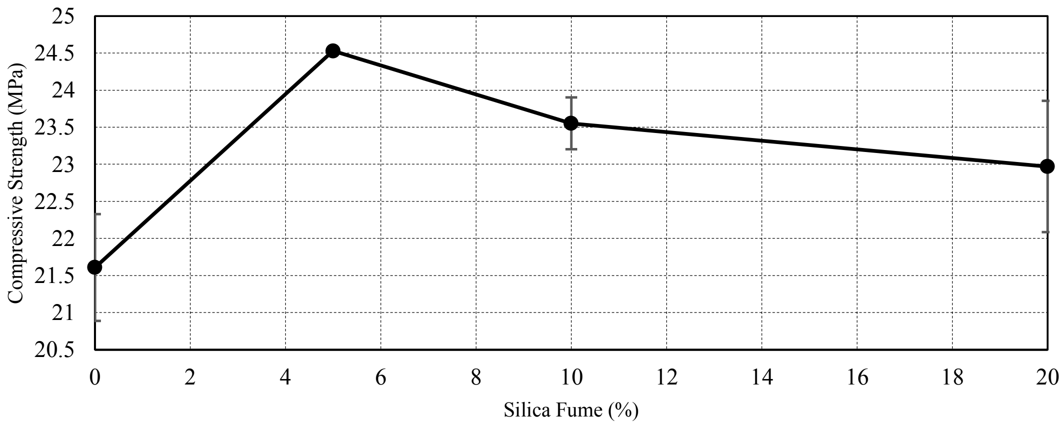

Figure 6. Compressive Strength of Samples Containing Silica Fume

Based on the obtained results, it was found that adding 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. Figure 7 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 figure 7 demonstrates, adding 15% of fly ash and silica fume will steadily increase the compressive strength up to 40%.

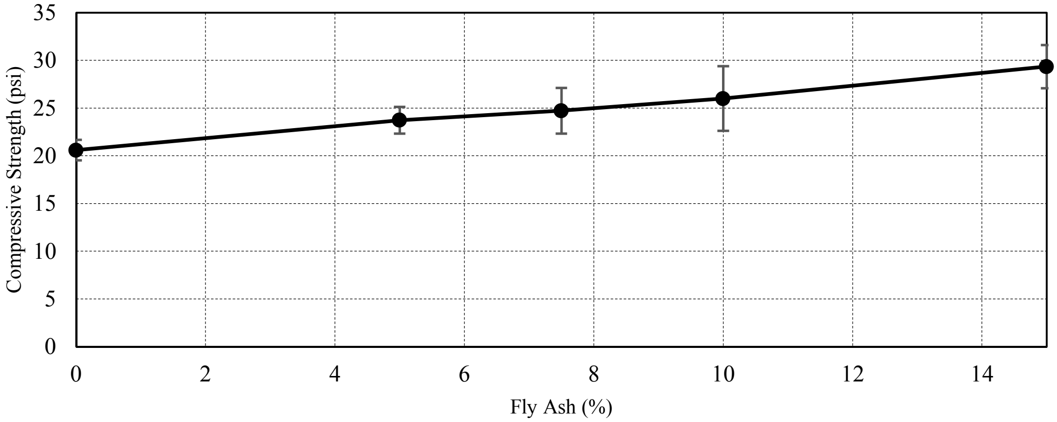

Figure 7. Compressive Strength of Samples Containing Silica Fume/Flyash

6. 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:

- Using drill cuttings as a partial replacement of cement in concrete leads to the reduction in compressive strength of samples. Compared to the control samples, replacing 10, 15, and 20% of cement with drill cuttings reduces the compressive strength by 15%, however, replacing more amount of cement with drill cuttings causes a steep fall in compressive strength. Therefore, replacing 20% of cement with drilling waste was considered as the optimum value.

- To compensate the strength reduction caused by replacing cement with drilling waste, 5, 10, 15, 20, and 25% of flyash were added to concrete samples containing 20% drill cuttings. Results showed a steady increase in the compressive strength and a maximum of 33% increase as the result of adding 20% flyash. However, adding more flyash reduced the compressive strength significantly.

- Results showed that 13% increase in compressive strength of concrete samples containing 20% drilling waste can be gained by using 5% silica fume. Nevertheless, increasing the amount of silica fume would not result in higher strengths.

- The maximum compressive strength of samples containing 20% drill cuttings was obtained by utilizing a mixture of flyash and silica fume. Results indicated that adding 7.5% of flyash and 7.5% of silica fume will increase the compressive strength by 40%.

References

[1] Agency, U. S. E. P. *An Assessment of the Environmental Implication of Oil and Gas production: A Regional Case Study*. www.epa.gov/sectors/pdf/oil-gas-report.pdf. Accessed 20 June 2014.
[2] Veil, J. A. Costs for Offsite Disposal of Nonhazardous Oil Field Wastes: Salt Caverns versus Other Disposal Methods.In, DOE's Office of Fossil Energy, 1997.
[3] Factsheet, D. w. M. *Offsite Disposal at Commercial sites*. http://web.ead.anl.gov/dwm/techdesc/commercial/. Accessed 21 June 2014.
[4] Cullinane M. J. Jr, Jones, L. W. & Malone, P. G. Handbook for Stabilization/Solidification of Hazardous Waste.In, Hazardous Waste Engineering Research Laboratory, Washington, DC, 1986. p. 102.
[5] Sell, N. Solidifiers for hazardous waste disposal. *Pollution Engineering*, 1988, pp. 44-49.
[6] Sharma, H. D. L., S. P. *Waste Containment Systems, WasteStabilization and Landfills: Design and Evalution* J. Wiley & Sons, New York, 1994.
[7] Bernardo, g., Marroccoli, M., Nobili, M., Telesca, A., and Valenti, G. L. The use of oil well-derived drilling waste and electric arc furnace slag as alternative raw materials in clinker production. *Resources, Conservation and Recycling,* Vol. 52, 2007, pp. 95-102.
[8] Smith, M., Manning, A., Lang, M. Research on the re-use of drill cuttings onshore.In, Aberdeen, Scotland, 1999.
[9] Chen, T., Lin, S., Lin, Z. An innovative utilization of drilling waste as building materials.In *Paper SPE 106913 presented at the 2007 SPE E&P Environmental and Safety Conference*, Galveston, TX, USA, 2007.
[10] Hossam F. Hassan, R. T., Amer Al Rawas, Badr Al Shandoudi, Khalfan Al Gheithi, Ahmed M. Al Barami. Potential uses of petroleum-contaminated soil in highway construction. *Construction and Building Materials,* Vol. 19, 2005, pp. 646-652.
[11] Tuncan, A., Tuncan, M., Koyuncu, H. Use of petroleum contaminated drilling wastes as sub-base material for road construction. *Waste Management & Research,* Vol. 18, 2000, pp. 489-505.
[12] Willis, J., Hester, MW., Shaffer, GP. A mesocosm evalution of processed drill cuttings for wetland restoration. *Ecological Engineering,* Vol. 25, No. 1, 2005, pp. 41-50.
[13] Ji GD, Y. Y., Zhou Q, Sun T, Ni JR. Phytodegradation of extra heavy oil-based drill cuttings using mature reed wetland: an in situ pilot study. *Environment International,* Vol. 30, No. 4, 2004, pp. 509-517.
[14] Weis, J. S. a. P. W. Metal uptake, transport, and release by wetland plants: Implications for phytoremediation and restoration. *Environment International,* Vol. 30, 2004, pp. 685-400.
[15] Veil, J. A. An Overview of Applications of Downhole Oil/Water Separators. Presented at Produced Water Workshop, Aberdeen, Scotland, 2003.
[16] Czarnecki, R. Making use of contaminated soil. *Civil Engineering,* Vol. 58, No. 12, 1988, pp. 72-74.
[17] RT, M. J. a. M. Petroleum contaminated soils in highway construction.In *Symposium proceedings: recovery and effective reuse of discarded materials and by-products for construction of highway facilities*, Denver, CO, 1993. pp. 4-83-84-95.
[18] Meegoda NJ, C. B., Gunasekera, SD, Pederson P. Compaction characteristics of contaminated soils-reuse as a road base material.In *Proceedings of the geocongress: geotechnical special publication*, Boston, MA, 1998. pp. 195-209.
[19] Aydilek, A. H., Demirkan, M. M., Seagren, E. A., and Rustagi, N. Leaching Behavior of Petroleum Contaminated Soils Stabilized with High Carbon Content Fly Ash.In *American Society of Civil Engineers*, Denver, CO, 2007.
[20] Taha, R., Hassan, H., Al-Rawas, A., Yaghi, B., Al-Futaisi, A., Jamrah, A., and Al-Suleimani, Y. Use of Tank Bottom Sludge to Construct and Upgrade Unpaved Roads. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1989, No. 1, 2007, pp. 208-214.
[21] EPA. Synthetic Precipitation Leaching Procedure In, Environmental Protection Agency 1994.
[22] Poon, C., Kou, SC., Lam, L., Lin, ZS. Activation of fly ash/cement systems using calcium sulfate anhydrite (CaSO4). *Cement and Concrete Research,* Vol. 31, 2001, pp. 873-881.
[23] VG., P. Effect of fly ash on Portland cement systems. Part 1: Low calcium fly ash *Cement and Concrete Research,* Vol. 29, 1999, pp. 1727-1736.
[24] Neville, A. *Properties of concrete*. Longman, UK, 1995.
[25] Thanongsak Nochaiya, W. W., Arnon Chaipanich. Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete. *Fuel,* Vol. 89, 2010, pp. 768-774.