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Evaluation of the reuse and recycling of drill cuttings in concrete applications

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HIGHLIGHTS

- Well-graded samples (SW and SC-SW) performed better than the poorly-graded samples (SP).
- At 300 psi or higher, fine aggregates can be replaced up to 20%.
- Results indicate that fine aggregates can be successfully replaced by drill cuttings.

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ABSTRACT

Drill cutting (DC) is a major waste produced during petroleum extraction, which could present a major source of contamination to soil and groundwater, if not disposed properly. The objective of this study aims to test the hypothesis that drill cuttings can be incorporated as an aggregate in the production of concrete, and is suitable for use in controlled, low-strength material (CLSM) for non-structural applications. To achieve this objective, the physical and consensus properties of drill cuttings were characterized. Concrete mixtures were designed for CLSM applications with and without drill cuttings sampled from two sources. Prepared concrete mixes were then evaluated in terms of strength for use in non-structural concrete applications. Results showed that well-graded drill cuttings performed better than poorly-graded samples. Furthermore, when compared to the control samples, no significant compressive strength reduction was observed for concrete mixes prepared with drilled cuttings at high strength targets (2800, 1200 and 300 psi). Yet, a significant reduction was observed at low strength targets (80 and 200 psi). This may be due that the higher content of cement in high strength concrete mixtures compensates for the lack of strength as a result of drill cuttings. At high strength targets, it is feasible to replace the fine aggregates up to 20% without reducing the target compressive strength significantly.

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1. Introduction

Material recycling in construction applications shows a global trend that is significantly increasing. This noticeable growth is essentially attributed to efforts to limit landfilling of waste and to decrease the consumption of virgin raw materials in new construction activities. Recycled materials are mostly being used as components in mixtures such as concrete – one of the most widely construction materials used in the world – production, which consumes a large amount of raw materials.

Concrete causes a significant burden on virgin resources and their extraction, which creates major environmental damages. In view of such environmental impacts, many researchers have studied the possibility of incorporating new aggregate into the concrete mix design, by replacing wholly or partially the natural aggregate component with waste materials such as coconut shells [1], blast furnace slag [2], recycled glass, or demolished concrete constituents [3,4]. Others have tested the hypothesis that all components of the mixture, including cement, could be substituted by levels of replacement. Perumal and Sundarajan [5] found that replacing 10% of silica fumes in cement rendered a more durable concrete. Dayahlan and Beulah [6] evaluated the simultaneous replacement of cement, sand, and coarse aggregate with silica fume, waste ceramic tiles, and crushed animal bones, respectively, which yielded more positive results than when replaced

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individually. Another material that has also been considered to be a potential replacement is drill cuttings; a waste that is generated during petroleum exploration and production.

Drill cutting (DC) is a major waste produced during petroleum extraction; drill cuttings can be a major source of contamination to soil and groundwater if not disposed properly [7]. Drill cuttings consist of excavated soil mixed with drilling fluid, which may include a fuel oil cut; drill cuttings can be separated from drilling fluid by using shale shakers, centrifuges, or other methods [7]. Drill cuttings have usually been considered a waste, which requires proper disposal in landfills or pits. Yet, leaching of DC becomes a major concern in order to avoid soil and groundwater contamination. Hence, potential reuse applications have been suggested in recent years for drill cuttings, which may offer the possibility of reclassifying it as a recyclable product instead of a waste. Potential markets for drill cuttings include land farming, land treatment, and road base applications [8]. With an inventory of over 400,000 yd^3 in South Texas, there is a strong potential to recycle DC as road construction materials; however, DC must be dried, treated, and screened to produce a material with consistent physical and mechanistic properties. Scant research, however, has explored the possibilities of incorporating drill cuttings as a replacement of the aggregate component in concrete mixtures.

2. Objectives

The objective of this study aimed to test the hypothesis that drill cuttings may be incorporated as a natural fine aggregate in the production of concrete, suitable for use in controlled low strength material (CLSM) and similar non-structural applications. To achieve this objective, three main tasks were conducted: (1) Characterize the physical, mechanical and mineralogical properties of drill cuttings; (2) Define the optimum mix proportion of CLSM to attain specific levels of compressive strength; and (3) Measure the effects of drill cuttings on fresh and hardened properties of the CLSM mixture.

3. Background

3.1. Drill cuttings

Well drilling activities generate large quantities of wastes composed generally of drilling muds and cuttings. Drill cuttings are produced beneath a drill bit by a combination of impacts, which crush and fracture a rock, thereby generating ground rock particles. Drill cuttings vary in size and texture, ranging from fine sand to gravel, depending on the type of rock being drilled, the drilling process employed, the type of drill being used, and the drilling fluid being applied. Drilling mud – also called drilling fluid – is used to lubricate the drill bit and transport the drill cuttings to the surface, where the mud and the cuttings are then separated.

Drilling muds are typically divided into three types: water-based, oil-based, and synthetic-based. The synthetic-based muds are more often used, since their effects on the environment are less impacting and their biodegradation occurs faster than the water- and oil-based muds [9,10]. Drilling fluids are usually made up of mineral oil or synthetic oil-based compounds, weighting agents, such as barite, clay, as well as stabilizing organic material, such as lignite. The main component of drilling mud is bentonite clay. The clay is mixed with a water, oil, or synthetic base, and several compounds are added to the mixture, such as cellulose polymers and barium sulfate to increase viscosity. It is these additives that increase the hazardous potential of the mud, which influences the type of drill cuttings being extracted from the ground.

3.2. Reuse practices of cuttings

Drilling wastes are often disposed of in landfills to allow the soil's naturally occurring microbial population to metabolize, transform, and assimilate waste constituents in place. This waste management approach is considered to be both treatment and disposal [11]. Although most drill cuttings are managed through disposal, some are treated and beneficially reused. Various treatment steps are employed to render the cuttings suitable for re-use. Some cuttings are thermally treated to remove the hydrocarbon fractions, moisture content salinity, and clay content, leaving behind a relatively clean solid material [12]. Other cuttings are screened or filtered to remove most of the attached liquid mud. From a construction perspective, treated cuttings have been used as fill material, cover materials at landfills, or as an aggregate or filler in concrete, brick, or block manufacturing [13]. Untreated cuttings are relatively hard to reuse for construction purposes.

Potential reuse applications of the cuttings have been suggested in recent years, with the inclusion of road construction applications, with research undertaken on the inclusion of drill cuttings in concrete mixtures as well, by level of substitution of cement [14]. Mostavi et al. [15] concluded that the compressive strength of concrete decreased significantly when cement was partially replaced with waste material. Similarly, Okoh [16] evaluated the use of drill cuttings as a subbase material stabilized with 10%, 20%, and 33% cement by weight of the total mixture. Results showed that the specimen met the limits for a subbase course in road construction, and a controlled utilization with only 10% cement content.

Other construction applications include usage in cement manufacturing, bitumen, and asphalt pavements [17]. Drill cuttings are also recycled for use as a bulk particulate with solid construction materials such as road base for site roads and pads [18] or as a major constituent of mixes making substantially monolithic, specialized, civil engineered, concrete structures of large size [18].

In most situations, reusing or recycling wastes or byproducts is a desirable practice. In light of the increased focus on duty of care, and commercial considerations, viable alternatives are being sought for the recycling and reuse of large volumes of material from current and future drilling programs.

3.3. Controlled low strength and recycled materials (CLSM)

From a sustainability standpoint, and based on the above review, it is important to develop further construction materials that incorporate drill cuttings. Finding more uses for drill cuttings can help reduce a consequential disposal in landfills and thereby conserve the consumption of natural aggregates. One of the possible construction applications where drill cuttings may be utilized is in CLSM mixtures.

The components of the CLSM are the cementitious-binder material, aggregates, water, and additives. Cement is used in a limited quantity in providing the cohesion and strength for CLSM. Portland cement types I and II are commonly used, according to ASTM C 150. CLSMs may be used in a variety of applications including backfills, structural fills, pavement bases, conduit beddings, and void fillings [17]. Materials used in the production of CLSM are usually the same as those used in traditional concrete; however, the mix proportion is different as the strength of CLSM is much less than that of traditional concrete. CLSMs can also incorporate supplementary cementing materials, such as high-calcium fly ash, together with co-generated products such as cement kiln dust [18].

The strength of CLSMs varies depending on the application. For back-fills with possible future excavation, such as some utility fills, the 28-day strength does not exceed 300 psi. For road bases and structural fills, such as a foundation support above weak or uneven