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EFFECT OF SYNTHETIC DRILL CUTTINGS ON MORTAR PROPERTIES

Magdi H. Almabrok[1,2]*, Robert G. McLaughlan[2] & Kirk Vessalas[2]

[1] *Department of Civil Engineering, Faculty of Engineering and Petroleum, University of Benghazi, Libya*
[2] *School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology, Sydney, Australia*

*Corresponding Author: *magdi.almabrok@uob.edu.ly*

Abstract: Drill cuttings from oil exploration are recognised as a major environmental concern. Current cost-effective treatment technologies often involve sending treated products to landfill without any potential end-use thereby rendering these solutions unsustainable. There is potential for using drill cuttings comprising of oily, saline and clayey waste materials as fine aggregate replacements in structural concretes requiring characteristic compressive strength from 20-32 MPa. Research into the hydration process as well as evaluating the fresh and hardened properties of mortars incorporating synthetic drill cuttings were undertaken. Replacement of sand by synthetic drill cuttings (up to 25% by weight) produced mortar with accelerated hydration as well as reduced flow and density. In addition, the 28-day compressive strength of mortar incorporating synthetic drill cuttings decreased by up to 50%. Satisfactory strength for all sand replacement levels evaluated in mortars was still attainable for reuse of these synthetic of drill cuttings as fine aggregate replacements in structural concretes.

Keywords: *Mortars, drill cuttings, hydration, stabilisation, solidification*

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1.0 Introduction

Various types of wastes are generated from the drilling process of oil exploration and production activities. Drill cuttings are inert solids that have resulted from the drilling of subsurface formations. A significant amount of drilling fluid and water-soluble salts is also attached with the discharge of the drill cuttings. These materials are considered an environmental hazard, and are usually disposed of in landfill. Many countries around the world are experiencing economic growth with governments investing monies into expanding infrastructure to accommodate the needs of population growth. With the creation and expansion of infrastructure comes the need to conserve natural resources to harness a sustainable future for humankind. Natural resources are commonly used as the principal source of raw materials to produce construction materials required to build infrastructure. Indeed, vast amounts of construction materials are often required to address the increasing demands of modern day construction needs (Al-Ansary *et al*.,2012).

The potential to re-use waste materials where a shortage of raw materials exists is an effective solution in mitigating the dependence on natural resource commodities, which have a finite life cycle (Taha *et al*., 2014). Cement-based stabilisation/solidification (S/S) has emerged as a viable technology to immobilise petroleum wastes into monolithic form. The immobilisation of the petroleum waste is achieved by binding the oily, salty and clayey materials into a solid structure from the hydration of cementing materials to produce a chemically, physically and mechanically stable product that is handleable (Tuncan and Koyuncan, 1997). If the monolithic material incorporating the waste material exhibits satisfactory compressive strength, and leaching properties, then it can be utilised to manufacture traditional construction materials such as concrete masonry blocks (Hago *et al*., 2007). Potential applications of monolithic materials, which incorporate waste, not only include concrete masonry units but also include structural concretes requiring characteristic compressive strengths ranging from 20-32 MPa at 28 days (AS 1379, 2007; OPSS 315, 2010). Structural concretes having compressive strength grades of 20-32 MPa are often employed in road construction to produce cast in-situ rigid concrete pavement slabs where steel reinforcement is not required (Fwa and Wei, 2006).

S/S of drill cuttings has received relatively little research (Al-Ansary and Al-Tabbaa, 2007). Recognised limitations of using S/S treated drill cuttings include the impact of oily, salty and clayey materials upon cement hydration and strength development (Leonard and Stegemann, 2010; Opete *et al*., 2010; Smith *et al*., 1999). Trends from the literature for these additives (salt, oil, clay) indicate an individual effect that either increases or decreases, or imparts no change to the compressive strength at 1, 7 or 28 days. Kaolinite clay present in the base soil has been reported to increase the compressive strength of concrete at 28 days (Fan *et al*., 2014). In the case of oily materials present in the synthetic base mud, the addition of crude oil products such as kerosene and diesel have been reported to decrease the compressive strength of concrete at 7 and 28 days (Attom *et al*., 2013). In contrast, the introduction of saline water as mixing water in concrete has been reported to increase the compressive strength of concrete at 7 days but not at 28 days (Akinkurolere *et al*., 2007). The collective impact of these additives upon strength development needs to be better understood.

In this research, the S/S of Portland cement-based mortars incorporating synthetic drill cuttings (SDC) containing salts, oil and microfine contaminants have been evaluated. The effect of partial substitution of sand (by weight) with SDC at 5, 15 and 25% on the hydration process as well as the fresh and hardened properties of the resultant mortar have also been evaluated. This will create a better understanding of the cumulative impact of the oil, salt and clay components within the synthetic drill cuttings upon the resultant mortar strength. This knowledge can then be used to create guidance on allowable levels of sand substitution with drill cutting to create mortars of specified strength. This type of information is expected to help create opportunities for the re-use of drill cuttings within cement-based construction materials rather than their disposal to landfill.

2.0 Materials and Methods

2.1 Synthetic Drill Cuttings (SDC) Mortar Properties

Due to the limited information on properties of drill cuttings and the difficulty in getting raw cuttings from drilling sites due to confidentiality, the physical characteristics of the SDC was based on drill cuttings from the North Sea (Al-Ansary and Al-Tabbaa, 2007). The base soil of the SDC was produced using Calga sand (Rocla Quarry Products Pty Ltd), silica flour, kaolin and bentonite clay supplied by SIBELCO Australia Ltd. Synthetic base mud (SBM) obtained from AMC Drilling Fluids, Australia and Table salt (Reeva, Aldi Incorporated) was used as the source of petroleum-based product. The SBM had a viscosity of 28.88 cSt@40ºC, a density of 1078 mg/mL and a chloride value of 4926 mg/L. A SBM content of 10% by weight of the base soil with total dissolved salts of 32,220 mg/L were used to represent the average level of contaminants found in the North Sea. Sodium and chloride ions were at 13114 and 18996 mg/L, respectively. A water content of 30% by the weight of the base soil was used to achieve the typical Atterberg limit values of the North Sea drill cuttings. The properties of synthetic SBM and SDC used in the experimental work are given in Table 1.

Table 1: Properties of synthetic base mud and drill cuttings

Property	*Percentage by total mass (%)*
Base soil contents	
Sand	7.14
Silt (silica flour)	35.71
Kaolinite	14.29
Bentonite	14.29
Synthetic Base mud content	7.14
Saline water content	21.43
Property	*Value*
Density	1860 kg/m^3
Liquid limit	44%
Plastic limit	25%
Plasticity limit	19%

An ASTM type 1 cement (Cement Australia) was used to produce the mortars (ASTM C150, 2012). The fine aggregate used was that of Calga double washed sand (Rocla Quarry Products Pty Ltd) with an absorption capacity of 0.65%, specific gravity of 2.57 and median particle size of 0.5mm. Glenium, a polycarboxylate ether polymer-based high-range water reducing admixture (HWR) (BASF Construction Chemicals Pty Ltd) was also used.

The composition of the mortar was in accordance with the mix proportions specified in AS 2350.12 (2006) . Attaining the required flow (60 ± 10%) in mortars incorporating SDC for sand replacement required the addition of HWR (0.2 – 2.5 mL) to give reproducible flow and proper consolidation of the mortar. The mortar mixes were prepared in accordance with AS 2350.12 (2006) except for the addition of SDC. The fine aggregate (sand) was partially replaced (by weight) with different levels of SDC (5%, 15% and 25%), and both the sand and SDC were premixed thoroughly with a spatula before being added to the other ingredients. All laboratory work was carried out at 22 ± 2 °C. The protocol for moulding the mortar taken from ASTM C109/C109M (2013) was adopted and modified. Specimens were initially cured (24 h) in zip lock plastic bags and, after demoulding, placed into a curing tank filled with water for up to 28 days at a temperature of 22.0 ± 0.5 °C.

2.2 Testing Procedures

Both a semi-adiabatic calorimeter (F-Cal 4000) and an isothermal calorimeter (I-Cal 4000) from Calmetrix Incorporation (USA) were used for monitoring the temperature and heat evolution of the mortar mixes. All sets of calorimetric data were repeated in triplicate forms and the average was taken. The fresh mortars were tested in accordance to ASTM C1437 (2007) for flow, ASTM C138 (2010) for wet density and ASTM C807 (2013) for setting times (H-3085 Humboldt Vicat Tester). Compressive strength was tested using ASTM C109/C109M (2013) test method requirements and a compliant compression testing machine. A vertical load rate of 1.5 kN.s^{-1} was applied to each specimen until failure. The maximum loads recorded for three individual test specimens were taken to represent the average compressive strength of each set of mortars tested.

3.0 Experimental Results and Discussion

3.1 Effect of SDC on Hydration Process

The hydration data obtained from semi-adiabatic calorimetry (Table 2) showed a shorter induction period and higher peak temperature for increasing SDC additions in mortars. Progressive acceleration in the induction period (0.5–4% compared to the control mortar) and higher temperature (5–10% compared to the control mortar) were noted with increasing SDC additions in mortar.

The acceleratory effect of SDC on the early hydration process is also supported by the isothermal hydration profile shown in Figure 1. More heat evolution was found to occur in the dormant period as the content of SDC increased in mortars. This indicates a deviation away from the slow and well-controlled hydration behaviour exhibited by the control mortar (ASTM C1679, 2013). Hydration reactions constituting both setting behaviour and strength development, sulphate depletion and C_3A reactivity are represented by the main hydration peak. This peak was found to commence at earlier hydration times with increasing SDC additions in mortar. A significant change in the intensity of the main hydration peak was also noted for increasing SDC additions.

The height of the peak was found to increase with more SDC addition indicating earlier setting behaviour and strength development. In addition, the sulphate depletion point was found to commence earlier with more SDC addition in mortars. It is interesting to note that the peak representing C_3A reactivity commenced the earliest for the 25% SDC mortar, and the intensity of this peak was also found to be the lowest of all the SDC mortars examined. The enhancement in hydration behaviour exhibited by increasing SDC content in mortars is believed to have occurred from the presence of chloride ions and clayey materials in the ingredients of the SDC.

Jensen (1987) reported that hydration peaks produced during hydration of cement mixed with sea water accelerated and enhanced hydration behaviour. Clay particles can also act as nucleation agents for the formation of the C-S-H products (Kroyer *et al*., 2003). The presence of hydrocarbons in the SDC is also known to inhibit hydration and compressive strength development (Ajagbe *et al*., 2012; Ezeldin *et al*., 1992). Some correlation exists between the semi-adiabatic and isothermal calorimetric hydration data for increasing SDC additions in mortars. The higher temperature peaks noted in semi-adiabatic calorimetric data correlates well with the increase noted in thermal power data in the main hydration peak for isothermal calorimetry. Although not as significant, a further correlation exists with the shortening of hydration times between the two calorimetric techniques.

Table 2: Summary of hydration characteristics for mortar containing synthetic drill cuttings using semi-adiabatic calorimetry

SDC		*Peak temperature*	*Time at peak temperature*
(%)	*(g)*	*(°C)*	*(minutes)*
0	0	16.11	571
5	33.8	16.69	569
15	101.3	17.31	561
25	168.8	17.64	549

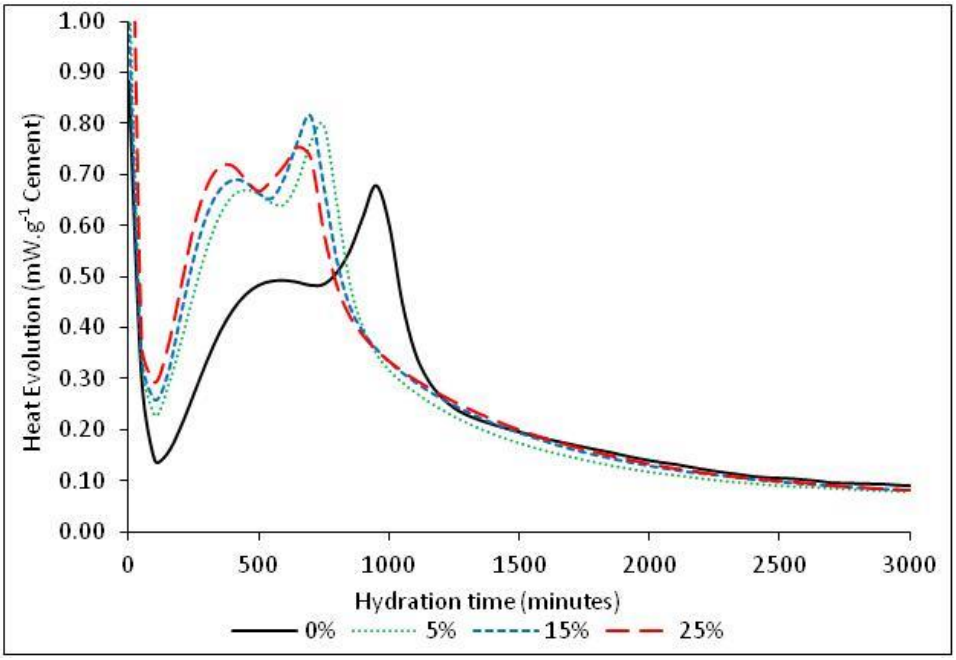

Figure 1: Isothermal profile for the hydration of mortar containing synthetic drill cuttings

3.2 *Effect of SDC on flow and wet density*

The mortar flow significantly reduced with the addition of SDC for sand replacement (Figure 2). A reduction in workability of between 6-39% was noted compared to the control mortar. This reduction in flow led to compaction difficulties during the consolidation process of mortar into moulds that in turn would be used for the determination of compressive strength. HWR was added to enhance the flow of SDC mortars to be within an acceptable flow range of 50 ± 10%. The amount of HWR required to achieve the desired flow increased proportionally with increased SDC additions in mortars.

A decrease in wet density of SDC mortars was noted with greater SDC addition as sand replacement. This density decrease may be attributed to particle density differences existing between SDC (1860 kg/m^3) and sand (2570 kg/m^3). Furthermore, it is quite possible that the clayey materials present in the ingredients of SDC have an affinity to water. Fan *et al*., (2014) showed the water demand for achieving normal consistency of cement pastes increased with more clay addition. The authors of this study also found the flow of the same cement pastes to decrease with increasing clay additions.

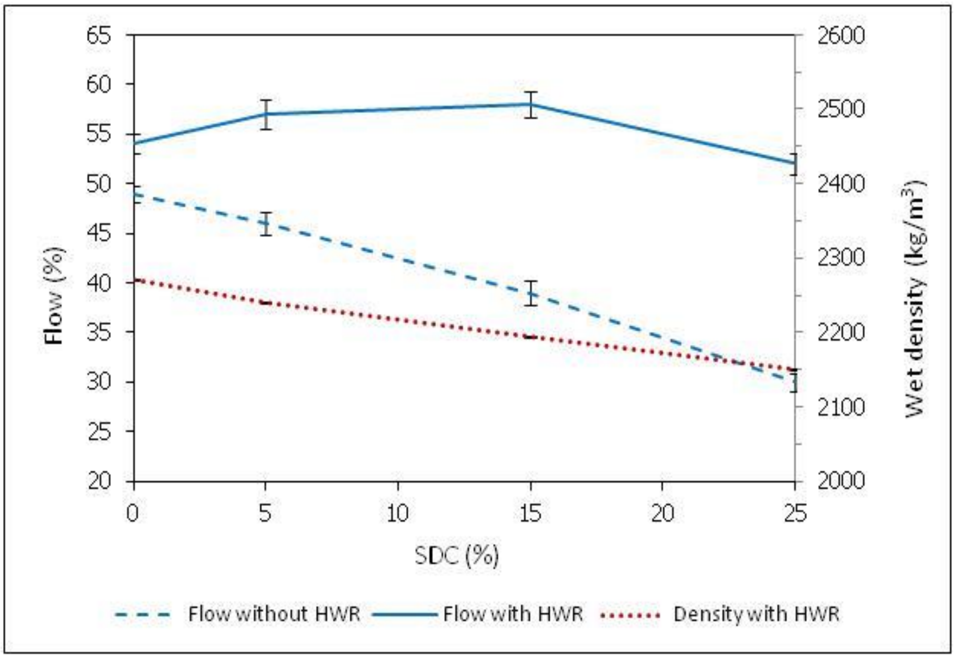

Figure 2: Effect of synthetic drill cuttings on flow and wet density of mortar mixes (Error bars equal average ± standard deviation)

3.3 *Effect of SDC on Setting Time and Compressive Strength*

Setting times were found to occur earlier with increasing SDC addition in mortars (Table 3). Relative to the control mortar, a decrease of 12% was noted for the 25% SDC mortar. This decrease indicates the utilisation of SDC in mortars accelerates setting times. This phenomenon is also confirmed in the semi-adiabatic and isothermal hydration profiles where shorter hydration times were noted for the hydration reactions contributing to setting and early strength development for increasing SDC additions in the mortars. This behaviour is believed to have occurred from the acceleratory effect of hydration initiating from the presence of chloride ions and clayey materials in the ingredients of the SDC (Ahmed and Mohammed, 2011; Kroyer *et al*., 2003).

The addition of SDC to mortars contributed to lower compressive strength compared to the control mortars at 1, 7 and 28 days (Table 3). Compressive strength continued to increase with increasing age in all mortars up to 28 days. This increase in strength indicates cement hydration occurs in all mixes but the efficacy of the hydration process varies with increasing SDC content in the mortars. The strength reduction resulting in SDC mortars at 1 day was much less compared to the strength reduction resulting in the same mortars at 7 and 28 days. For the 25% SDC mortar, a reduction of 32% was noted at 1 day compared to 51% at 7 days and 50% at 28 days. This indicates that the SDC has less influence on strength reduction at an early age than it does at 7 and 28 days. The large reduction in strength noted at 7 and 28 days was found to be constant across both ages evaluated with the same extent of strength loss resulting. The strength gain for the curing period 1-7 days was found to be highest for the control mortar (169%) followed by the 5% SDC mortar (115%). Some inhibition in the hydration process was found for the 15% and 25% SDC mortars with less strength gain resulting for the period 1-7 days (77% and 94%, respectively). For the period 7-28 days, the strength gain was found to be highest for the 15% SDC (28%) mortar followed by the 25% SDC mortar (11%). It is interesting to note that these higher SDC contents used in mortars have contributed the most to strength development for the period 7-28 days.

Table 3: Effect of synthetic drill cuttings on setting time and compressive strength

SDC		*Setting time*	*Compressive strength (MPa)*		
(%)	*(g)*	*(minutes)*	*1 day*	*7 day*	*28 day*
0	0	176±1.0	16	43	46.1
5	33.8	173±0.5	15.1	32.4	35.6
15	101.3	160±0.9	13.3	23.5	30.1
25	168.8	154±0.5	10.8	20.9	23.2

4.0 Conclusions

The compressive strengths attained at 28 days for all SDC mortars qualifies these mortars to be used in non-reinforced applications to satisfy the requirements of structural concretes requiring characteristic compressive strengths ranging from 20-32 MPa at 28 days. This demonstrates the potential reuse of drill cuttings as fine aggregate replacement in concrete rather than disposal in landfill. Calorimetry has been shown to be a useful tool to gain insight into the effect of SDC on cement hydration behaviour; however, the relative influences of the individual components of the SDC were not evaluated. While progress has been made into the impact of SDC on hydration behaviour and mortar properties, further work is still needed into the relationships that exist between the oily, salty and clayey materials in SDC. In particular, the relationship that exists between strength reduction due to either inhibited hydration and/or microstructural aspects requires additional investigation. The linkage between mortar strength and leaching potential also warrants further investigation.

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