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EVALUATION THE EFFECT OF REUSE SEWAGE SLUDGE AND SEWAGE SLUDGE ASH ON CONCRETE FOR CEMENT REPLACEMENT

SAMAA ALI HASSOONI[1], SALEEM ETHAIB[2,*]

[1]Ministry of Science and Technology, Baghdad, Iraq
[2]College of Engineering, University of Thi-Qar, Al-Nasiriya, Iraq
*Corresponding Author: dr.saleem@utq.edu.iq

Abstract

This study aims to evaluate the effect of reuse sewage sludge and sewage sludge ash on concrete for cement replacement. Two forms of sewage sludge were used, sun dried sewage sludge (DSS) and sewage sludge ash (SSA). SAA was produced by incineration of the DSS at 600°C for two hours. DSS and SAA were separately used as a partial replacement of cement in concrete mixes. The produced concrete mixes were experimentally tested via various mechanical and physical concrete testes such as compressive strength, workability, and water absorption. DSS and SSA were chemically characterized. Then, they were manually ground, sieved through sieve size of 150 μm, and added to the concrete mixes as a proportion of cement content using 5, 10, and 15% as cement replacement of cement content. 1% of a super plasticizer was added to the concrete mixes that prepared using two contents of cement 450 kg/m^{3}and 550 kg/m^3. The results showed that DSS chemically included 21.973% of SiO_2 while SSA contained of 38.71% SiO_2. The concrete mixes containing 5 and 10% of cement replacement by DSS showed slight increments in compressive strength compared to the concrete control at the final age of 28 days. The increments were 0.25, 1.58 % and 0.36, 2.02% for mixes of 450 kg/m^3, and 550 kg/m^3 of cement content, respectively. Meanwhile, the employment 10% of SSA appears higher increasing in compressive strength at the age of 28 days, by 8.05% and 8.90% for cement content of 450, and 550 kg/m^3, respectively. Water absorption of DSS or SSA concrete samples also showed a decrease in water absorption percentage compared to control concrete samples. Therefore, recycling DSS and SSA could provide another route for cheap cement materials, and a potential alternative to landfill process.

Keywords: Cement replacement, Compressive strength, Concrete, Sewage sludge ash.

1. Introduction

Safe disposal of solid waste is a vital element to continue the life and create smart cities and sustainable societies [1]. Different studies were mentioned that indiscriminate solid waste disposals on land and accumulation of solid wastes such as sewage sludge are causing serious environmental problems, and adversely impact socioeconomic factors [2, 3]. For instance, the annual sewage sludge production has been estimated at 10 million tons (dry matter), 20 million tons, China and the United States, respectively [4].The huge quantities of sewage sludge make the proper disposal of this material using the disposal techniques like landfills, composting or storage is fast becoming unsustainable from an environmental perspective due to face some practical and environmental concerns such as space limitations of existing landfills, rising environmental and health concerns odour emissions, pathogen vectors spreading, soil contamination, and groundwater pollution from landfill leachate. These concerns have prompted the investigation of alternative and viable final disposal methods [5, 6].

Various scenarios were applied for sludge treatment, including energy recovery technologies such as anaerobic digestion, gasification, combustion, and pyrolysis [7]. However, these technologies have several challenges that need to resolve and improve the operational, environmental and cost competitiveness. For instance, the differences in the chemical and physical properties of sludge present a unique technical challenge influences the energy recovery process and reactions [4]. Therefore, the recovery and reuse of sludge for practical purposes like concrete production supports the sustainability measures and reduces sludge disposal requirements [8]. Furthermore, the utilization of sewage sludge as a partial replacement of cement in the concrete industry can compensate a part of the high demand of cement [9, 10]. As well known, the inflation of global population led to increase in the concrete demand, which is the construction industry where the concrete is one of its main materials [11]. Besides mitigating sludge accumulation problems using sludge for cement replacement will assist to reduce the negative impacts of the cement industry. As well known that, the cement is the main component in the concrete production process and cement manufacturing process is costly due to the energy requirement. Moreover, cement manufacturing emits massive quantities of carbon dioxide (CO_2) which the primary greenhouse gas, particle pollution and consumed natural resources [12].

In recent, the sewage sludge has been used to produce for partial replacement of aggregates and/or cement in the concrete production in raw or dried form [13]. The incineration of wastewater sludge is one of the technologies that applied in some European countries to meet the current environmental regulations for sewage sludge disposal [14]. The thermal disposal of sewage sludge results in the might useful product of sewage sludge ash and decrease the final disposal space. This product generally contains siliceous and aluminous materials which can contribute in the pozzolanic activity, these materials in there self, possesses little or no cementitious value, but, in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

However, still there is a concern about the temperature of incineration because it has a direct effect on preserving pozzolanic properties of sludge [15]. The source of sludge has the major influence on temperature of incineration. One of the researches at the Nanyang Technological Institute shows that 550°C is a favourable condition for sludge incineration [15]. Meanwhile, Tantawy et al. [16] reported the optimum sludge incineration temperature is 800°C. However, the elevated temperature sewage sludge ash production process causes an increase in the energy consumption. On the other, reusing of sun dried sewage sludge can save the energy consumption and the environment and may provide another sustainable materials source for the building industry. Past studies on sewage sludge and their results emphasizes the dependence of the end product on the sludge properties. Limited research has been conducted and compared the reuse of sewage sludge in two forms: sun dried sludge (DSS) and incinerated sludge (sludge ash, SSA) from the same source as a partial replacement of cement. Therefore, this study aims to evaluate the effect of reuse sewage sludge and sewage sludge ash on and on the mechanical and physical properties of concrete as a partial replacement of cement by weight in concrete.

2.Materials and Methods

2.1. Material

The ordinary Portland cement (OPC) was used to prepare the concrete mixes of the experimental work. This material was produced by the Northern Cement Company, Iraq. The chemical and physical characterizations of OPC were curried out to ensure its consistence with Iraqi standard specifications (IQS No.5/1984) [17]. The OPC was sent for the chemical analyses using X-ray fluorescence (XRF) spectrometer (EDX-7000 Fluorescence Spectrometer; Shimadzu, Japan). The physical characterization was carried out based on Iraqi Standard Specifications (IQS No.5/1984) [15]. The chemical and physical characteristics of OPC are shown in Tables 1 and 2, respectively. The aggregate from local sources was used. The crushed gravel and the natural sand were used as a course and fine aggregate. The grading and physical properties of coarse and fine aggregate were tested to ensure the consistency of these materials to the Iraqi standard specifications (IQS No.45/1984) [18] as illustrated in Table 3. The sun dried sewage sludge (DSS) and sewage sludge ash (SSA) were used in this research. The sludge was collected at "Al-Rustamiyah Wastewater Treatment Plant ", located in the southern part of the Baghdad city. A DSS sample was incinerated at 600°C for 2 hours using a controlled temperature furnace to get SSA. In this work, DSS and SSA were ground and sieved to get fine particle powder < 150 μm as shown in Fig. 1. The chemical composition of DSS and SSA was conducted using the same XRF that was employed in the cement analyses. The super plasticizer of Conplast SP2000 as high range water reducing admixture was kindly supplied by Fosroc constructive solutions, Fosroc Jordan. All materials were subjected to test in the National Center for Construction Laboratories.

Fig. 1. Preparation of DSS and SSA.

Table 1. Chemical characteristics of OPC.

Parameter	Weight (%)	Iraqi specification No.5/1984 limits of [15]
CaO	64.14	−
SiO_2	19.887	−
Al_2O_3	4.792	−
Fe_2O_3	3.132	−
SO_3	2.537	≤ 2.8 %
MgO	2.20	≤ 5 %
Loss on Ignition (L.O.I.)	3.018	≤ 4 %
Lime saturation Factor (L.S.F.)	0.908	0.66-1.02
Insoluble residue (I.R.)	1.22	≤ 1.5%
Main compounds (Bogues eq.)	**By weight of cement (%)**	
Tricalcium silicate (C_3S)	65.99	
Dicalcium silicate (C_2S)	7.32	
Tricalcium aluminate (C_3A)	7.405	
Tetracalcium aluminoferrite (C_4AF)	9.521	

Table 2. Physical characteristics of OPC.

Parameter	Test results	Iraqi specification No.5/1984 limits [15]
The specific surface area, Blaine Method (m^2 per kg)	375	> 230
A- The Initial setting (min)	70	≥ 45 min
B- The Final setting (hr)	3.5	≤ 10 hr
The compressive strength of OPC mortar (MPa)		
3 days	32	≥ 15
7 days	38	≥ 23
Soundness percentage (Autoclave)	0.01	≤ 0.8

Table 3. Fine and course aggregate grading.

Fine aggregate grading			Coarse aggregate grading		
Sieve size (mm)	**Passing (%)**	**Limits of Iraqi specification No.45/1984/Zone 2 [16]**	**Sieve size (mm)**	**Passing (%)**	**Limits of Iraqi specification No.45/1984 [16]**
10	100	100	**37.5**	100	100
4.75	100	90-100	**20**	100	95-100
2.36	85	75-100	**10**	48	30-60
1.18	65	55-90	**4.75**	3	0-10
0.6	50	35-59	**-**	-	-
0.3	15	8-30	**-**	-	-
0.15	4	0-10	**-**	-	-

2.2. Methods

2.2.1. Preparation of concrete samples, mixing, casting and curing

The American Concrete Institute Standard ACI 211.1R [19] was used to design and prepare all concrete mixes. Two cement contents were employed to prepare concrete mixes including 450 kg/m^3 and 550 kg/m^3. The tap water was used for preparing all mixes and the water-cement ratio was 0.41. The super plasticizer admixture was used to increase workability. The components of concrete were manually mixed depending on the ASTM C192-02 [20] for concrete production. Firstly, the fine aggregate was well mixed with the cement to attain a uniform mix. The DSS and SSA were used as an additive in concrete mix by partial replacement of cement DSS and SSA were added to concrete mixes as a ratio of cement content using 5, 10, and 15% as cement replacement for each one of them. The required quantity of DSS or SSA powder, then added to the mixture. Then, the course aggregate was added to dry the mixture and the whole materials are well mixed with water. The super plasticizer was added gradually in 1%. Finally, the whole constituents are mixed to get homogenous mixture. A slump test was conducted to assess the workability for all concrete mixes; the test was carried out based on ASTM C143-00 [21]. Then, the concrete mixes were transferred into the steel molds (10*10*10 cm). The specimens of fresh concrete molds were well compacted using a metal rod vibrating table. Then the surface of concrete molds was well smoothed by means of trowel and covered by nylon sheets for 24 hrs. Finally, the concrete molds are opened and cured by emerging in a tap water container until testing dates as illustrated in Fig 2.

Fig. 2. Preparation of concrete cubes.

2.2.2 Concrete tests

The concrete cubes were subject to test to identify the compressive strength of concrete was detected at the ages of 7, and 28 days, according to the British Standard (B.S.1881-part 116-1989) [22] as can be seen in Fig 3. The density of concrete cubes was determined according to ASTM C642-97 [23]. The ultrasonic pulse velocity test (U.P.V.) was carried out according to the later aforementioned specification. This non-destructive test was accomplished by commercially a device that is known as (PUNDIT). The direct method was applied, in which the transducers are placed on opposite faces of the concrete cube to be tested. The ultrasonic pulse velocity is calculated from the following Eq. 1.

$$v = \frac{l}{t} \tag{1}$$

where v: ultrasonic pulse velocity (km/sec); l: the average length of specimen (mm); and t: the transit time (microsecond).

Water absorption was measured to identify the percentage of concrete absorption of concrete at the age of 28 days according to ASTM C642-97 [23].

Fig. 3. Tests of concrete for compressive strength.

3. Results and Discussion

3.1. Sludge characterization

Sludge has different physicochemical properties, thus it is essential to identify these properties for select the proper methods of its management [24]. The chemical characterization of DSS and SSA showed that the presence of the major oxides such Fe2O_3, SiO_2, CaO, and Al2O_3 in different concentrations as summarized in Table 4. These oxides represent around 95% of cement clinker which is responsible of the process for hardening the cement slurry [25]. In addition, performing the incineration process of the DSS at the temperatures of 600°C to get SSA showed that changing the of some oxide content. For instance, the DSS included 21.973% of SiO_2 and this content of SiO_2 was increased to 38.71% in SSA which is nearly double the silicon content. The amount of SiO_2 was increased in the sludge ash due its relative content increasing in the residual matter of the burning process as a result of the thermal destructive of the organic component of sludge during the incineration process [16]. This shows that the burning of sewage sludge up to 600°C triggers the increase of silicon (S) content in the SSA, which can be considered as an active mineral addition on Portland cement based composites.

However, there is some limitations should be considered about temperature degree of incineration. Tantanaty and his co-workers [16] burnt the sewage sludge temperature range 650–950°C. They found that that the incineration of sewage sludge at higher temperature, especially more than 800°C leads to a decrease in the pozzolanic activity of sewage sludge ash due to crystallization of amorphous silica. The process of incineration is able to produce more silicon, which is the main component that is responsible for pozzolanic activity in cementitious material. This could enhance the thermochemical reactions among components of cement-based materials, the basic phases are obtained: dicalcium silicate and tricalcium silicate, which enhance the hardening process of cement [25]. Identical results reported by Baeza-Brotons et al. [26] that reported sludge ash included a considerable amount of SiO_2 and Al_2O_3.

Furthermore, DSS shows higher content of heavy metal oxides such as magnesium and sodium as compared to the SSA. The content of heavy metal was decreased via the burning temperature that reached 600°C. This can be attributed to the release mechanism and volatility of heavy metals during the thermal decomposition that allow escaping most of the organic heavy metals; the remaining elements were mainly from the residual state.

The residual state was the elements, mainly present in the clay minerals, which was difficult to be volatilized before 800°C [27]. This can offer another process solution to overwhelm of the difficulties with the management of solid residues that related to the content of heavy metal. The presence of toxic chemicals (heavy metals) in soil, in high enough concentrations may pose a risk to human health and/or the ecosystem. The burning process is a very effective method of reducing the volume and weight of solid waste. The high temperature led to reduce the risk potential of these environmental hazardous elements [28]. This indicates that the thermal decomposition of sludge and transform sludge in ash form could be a suggested solution to curb the pollution rate that result in the sludge disposal problem.

Table 4 DSS and SSA characterization.

Compound	Content in DSS (%)	Content in SSA (%)
SiO_2	21.973	38.71
CaO	16.636	21.731
Al_2O_3	14.042	18.618
Fe_2O_3	9.289	12.927
K_2O	4.522	5.833
SO_3	0.776	0.827
MgO	2.99	2.6
Na_2O	0.062	0.056
L.O.I	27.71	6.698

3.2. Workability

The workability of the concrete mixes containing various proportions of DSS or SSA was tested using the slump test for every different batch of concrete. The results of slump test are depicted in Fig. 4. The results showed that the type of slump for the various amounts of replacement of the DSS and SSA with W/C = 0.41 can be categorized as a true slump. This revealed that the fresh concrete batches were well mixed and the concrete components were well distributed because the concrete did not tend to segregate and shear. For mixes containing super plasticizer and without sludge (Control 2) showed the highest slump of 180 mm, and 210 mm for two cement contents, respectively.

The concrete control (Control 1, 0% sludge + 0% super plasticizer) was recorded the highest decrease for slump test, followed by mixes containing different percentages of DSS and SSA. The slumps of DSS and SSA mixes decreased with the increase replacement percentage of cement by 5%, 10%, and 15% which mean decrease the concrete workability. It is observed that the mixes containing 5, and 10% of DSS and SSA has slightly decreased in slump compared to mix of 15%, which can be exhibited equal slump or little higher than the control 1 mixes, which in accordance with [29]. Increasing DSS and SSA to be 15% caused a reduction in concrete workability. It might be related to due to the irregular morphology and rough texture of SSA particles [26, 29]. This might lead to higher water demand that caused by high cement replacement ratios which results in higher water demand observed at high SSA replacement ratios can lead to a decrease in higher water demand a decrease in the mechanical performance the concrete mixes [30]. Similar observations were reported by Vouk et al. [31]. They found that workability was decreased about 20% when 20% of cement was replaced by SSA.

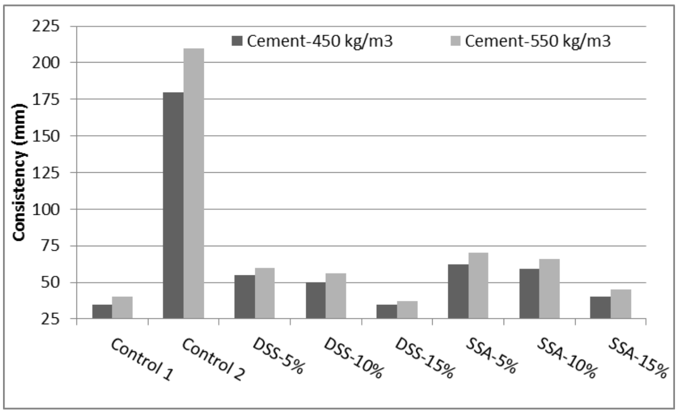

Fig. 4. Concrete workability.

3.3. Concrete compressive strength

The concrete compressive strength results showed that presence of many factors that might influence the concrete strength evolving of various different mixes. These factors included the type of sludge either DSS or SSA, the effect of percentages cement replacement for each DSS and SSA, and cement content. Figs. 5 (A and B) and 6 (A and B) show the results of concrete specimens that included DSS compared to control (concrete without addition), respectively.

By the same token, the results revealed that the compressive strength decreased at the age of 7 days for all mixes that included DSS in the replacement percentages of compared to control as shown in Fig. 5. The results showed that slight reduction compressive strength at the age of 7 days for DSS relative to control concrete. On the other hand, SSA mixes showed a slight increase in compressive strength at the same age, except the mixes that included 15% of SSA which behaved like DSS mixes as shown in Fig. 6.

Meanwhile, the continuous hydration process of concrete led to evolve its compressive strength with time. The compressive strength for concrete mixes containing 5 and 10% replacement of cement by DSS have a slight increase relative to concrete control at the final age of 28 days. The increments were 0.25, 1.58% and 0.36, 2.02% for mixes of for both 450 kg/m^3, and 550 kg/m^3 cement content, respectively. However, the mixes of 15% replacement for cement contents 450, and 550 kg/m^3 showed a decrease in compressive strength of 8, and 7.32%. The results showed that the addition of 10% of DSS or SSA for both cement content slightly higher than concrete control. The employment 10% of SSA appears higher increasing in compressive strength at the age of 28 days, by 8.05, and 8.90%, with cement content 450, and 550 kg/m^3, respectively. The slight increase in compressive strength might be related to the slight increase in

DSS or SSA sample density and lower porosity compare to control as illustrated in the followed subsections.

Generally, compressive strength of concrete is affected by its porosity. As it well known, the decrease of concrete porosity and increase concrete density reflects positively on its compressive strength. The slight increase in compressive strength probably related to the slight increase in DSS or SSA density and lower porosity samples compared to concrete control samples as illustrated in the followed subsections of concrete density and water absorption. These improvements might be as a result of the pozzolanic activity and attributed to formation spherical particle hydration products which act to fill the voids and pores in concrete [32]. However, increasing the DSS and SAA content to be 15% led to increase the porosity as shown in the followed section of water absorption in the way that exceeds the pozolanic activity that result in DSS or SSA addition. The increment in of DSS or SSA content led to increase rough and irregular particles in the concrete mix which are the basic reason for increasing the inner porosity of concrete that caused an increase in water absorption [33]. Therefore, the mixes of 10% of DSS or SSA have the higher strength for both cement contents (450 kg/m^3, and 550 kg/m^3).

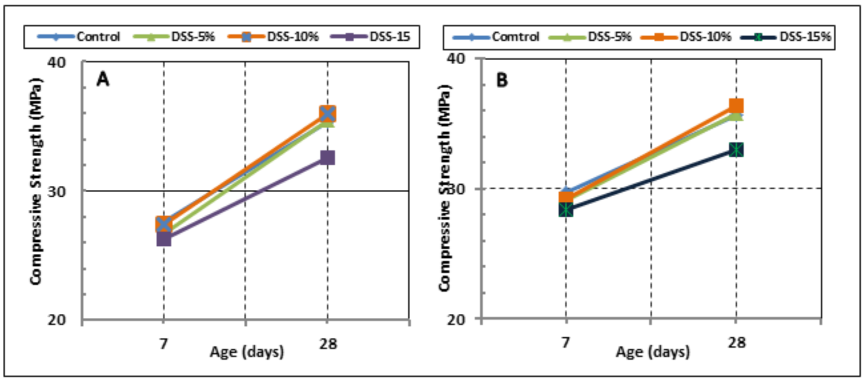

Fig. 5. Compressive strength of DSS based on cement contents A) 450 kg/m^3 and B) 550 kg/m^3.

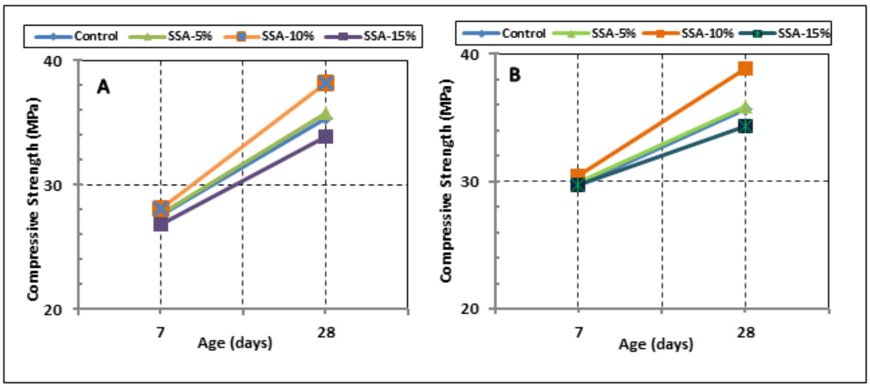

Fig. 6. Compressive strength of SSA based on cement contents A) 450 kg/m^3 and B) 550 kg/m^3.

The ultrasonic pulse velocity results for concrete mix containing DSS, and SSA are shown in Figs. 7 and 8. The results showed a continuous increase velocity test value for DSS and SSA with age of concrete. This behavior due to the effect of continues curing process that improves of hydration process which lead decreases the void space the concrete mixes [34]. All the ultrasonic pulse velocity test values were between 4.65 km/s and 4.86 km/s for all specimens. Compared to the classification of concrete quality on ultrasonic pulse velocity based on ASTM C597-02 [35] are illustrated in Table 5. The results indicated that all mixes of DSS, and SSA concrete were excellent or good mixes according to ASTM C597-02 [35]. The results of ultrasonic pulse velocity were close for all mixes of DSS and SSA with two cement contents. For mix of 10% replacement showed the best results for DSS and SSA. This behavior can be attributed to fine particles of DSS and SSA which act to fill the gap between aggregate particles. Finally, for compressive strength, the concrete with 10% of SSA is the optimum mixture. Meanwhile, the concrete mixes of 15% replacement showed the lower ultrasonic pulse velocity test values. This might be related to the same reasons that were discussed in the previous paragraphs of compressive strength tests. There is no significant difference for two cement contents (450 kg/m^3, and 550 kg/m^3) for all mixes. Therefore, it is recommended to use cement content (450 kg/m^3) because it is considered more economical in building construction.

Table 5. The ultrasonic pulse velocity classification for concrete quality based on ASTM C597-02 [35].

Concrete quality category	Velocity (km/sec)
Excellent	≥ 4.58
Good	3.66 − 4.57
Doubtful	3.05 − 3.66
Poor	2.14 − 3.00
Very poor	≤ 2.14

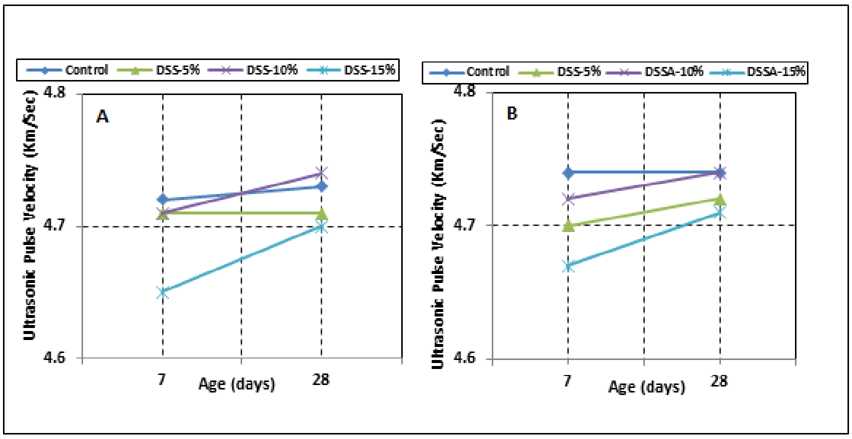

Fig. 7. Ultrasonic pulse velocity results of DSS based on cement content A) 450 kg/m^3 and B) 550 kg/m^3.

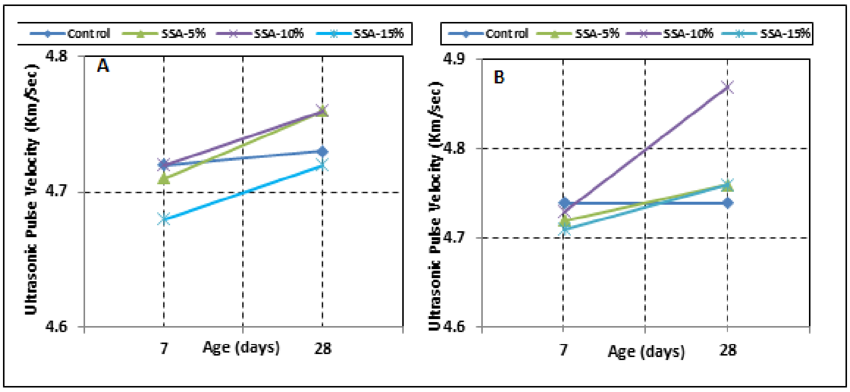

Fig. 8. Ultrasonic pulse velocity results of SSA based on cement content A) 450 kg/m^3 and B) 550 kg/m^3.

3.4. Density

The density results for concrete mix containing DSS, and SSA are shown in Table 6. In general, the mixes of DSS and SSA exhibited an increase in density with the increase of cement content and age of concrete due to the increase of specific gravity for mixes. As well as, the mixes containing 5, and 10% replacement of cement for both DSS showed a slight increase in density compared to a mix containing 15% of replacement. A similar observation was found in SSA samples.

By the same token, the density of SSA samples was higher than DSS samples. This might be attributed to formation spherical particles with act to fill the voids and pores as a result to the pozzolanic activity that triggered by the SSA components [33]. Moreover, increasing DSS and SSA percentage over 10% led to reduction in concrete density relative to control concrete samples at the age of 28 days for with two cement contents. An identical behavior was reported by Baeza-Brotons et al. [26]; they concluded that the use of the high quantities of SSA (over 10%) could reduce the concrete density. It was reported that the presence of sludge in hardened mortars or concretes in considerable quantities might lead to deteriorating of the concrete properties [36]. By the same token, Vouk et al. [31] recommended that the amount of sewage sludge and ash should be less than 20% when they consider for mortars or concretes.

Table 6. Concrete density.

Mix Symbol	Cement (kg/m^3)	Sludge (kg/m^3)	Density (kg/m^3)	
			7 days	28 days
Control A	450	0	2346	2363
DSS-A-5%	427.5	22.5	2340	2362
DSS-A-10%	405	45	2345	2370
DSS-A-15%	382.5	67.5	2338	2356
Control B	550	0	2378	2390
DSS-B-5%	522.5	27.5	2371	2387
DSS-B-10%	495	55	2377	2391
DSS-B-15%	467.5	82.5	2368	2382

Control A	450	0	2346	2363
SSA-A-5%	427.5	22.5	2346	2364
SSA-A-10%	405	45	2352	2377
SSA-A-15%	382.5	67.5	2344	2360
Control 4	550	0	2378	2390
SSA-B-5%	522.5	27.5	2374	2392
SSA-B-10%	495	55	2380	2403
SSA-B-15%	467.5	82.5	2372	2386

3.5. Concrete water absorption

The concrete water absorption results for concrete mixes that contains DSS or SSA are depicted in Fig. 9. The concrete cube samples were tested as ASTM C642-97 [23] at the age of 28 days. The result showed that using of DSS and SSA with different percentages of partial replacement of cement led to reduce in concrete water absorption. The higher decrease compared to control concrete samples are 22.96% and 24.75%, which was found in DSS of 10% for 450 kg/m^3, and 550 kg/m^3 of cement content respectively. By the same token, SSA-10% concrete samples showed similar behavior, it 29%, 34.17%, water absorption for 450 kg/m^3, and 550 kg/m^3 of cement content, respectively. These related to the high concrete density of these samples which caused this reduction in water absorption, which offer a higher concrete durability that support the sustainability concept. Meanwhile SSA showed more tendencies to decrease in water absorption compared to DSS. This behavior was probably as a result of the decrease of concrete porosity due to the pozolinic activity that led to produce fine particles which occupying the gaps between coarse aggregates [26].

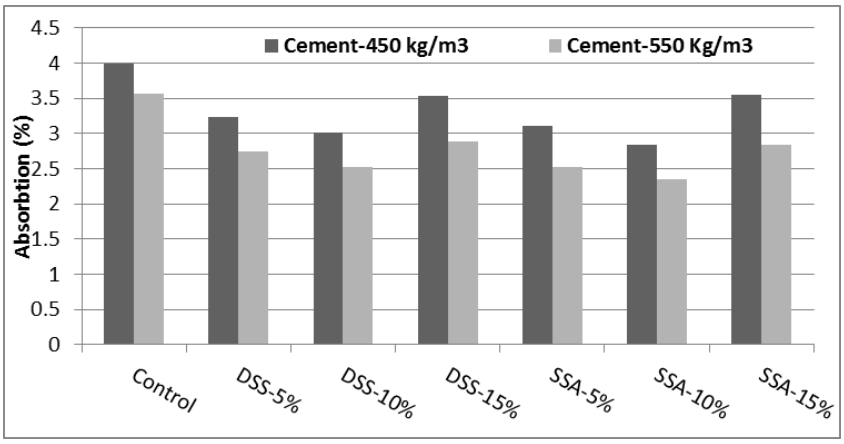

Fig. 9. Water absorption.

4. Conclusions

In light of the experimental investigation reported in this study, the following inferences are drawn:

- The volume of DSS was reduced by incineration at 600°C for 2 hours to produce SSA, which provides another feasible solution to the land disposal problems.

Besides that, the incineration process led increase the composition of oxide elements SiO_2, CaO, $Al2O_3$, and Fe_2O_3 which have pozzolanic activity.

- SSA shows higher performance properties of concrete than DSS at the different ages of the test for two cement contents.
- The mixes of 10% of DSS or SSA have the higher strength and higher durability for both cement contents (450 kg/m^3, and 550 kg/m^3).
- It is recommended not to use higher than 10% by SSA as a partial replacement of cement.
- It is recommended to use cement content (450 kg/m^3) because it is considered more economical in building construction.

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