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Effect of Domestic Dry Sewage Sludge on Concrete Compressive Strength

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HIGHLIGHTS

- Dry sewage sludge is obtained from Al-Jissr WWTP in Baghdad, Iraq.
- Using sewage sludge as partial replacement of cement in concrete production.
- Identifying the effect of sludge on the compressive strength of concrete.
- The point of interest is finding new technology as sustained natural materials utilized in the construction sector.

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ABSTRACT

The possibility of saving and sustaining natural materials by reusing waste is one of the most important goals researchers seek to achieve and prove its effectiveness and positive impact on the environment. In this study, domestic wastewater sludge was utilized in concrete production as partial cement changing with different ratios (0, 5, 10, and 15) % with dry sludge. The study showed that the compressive strength test showed that the partial replacement of cement by dry sludge caused reduction increased directly with the increase of sludge ratio compared with concrete reference specimens. The study found that dry sludge can be used up to 15% as a replacement in concrete sidewalks and roads because these applications use horizontal construction, which does not require the same high strength resistance as vertical construction. In addition, it was also found that using up to 10% dry sludge content in concrete may positively impact reducing sludge levels in the environment and the cost of cement production without a significant effect on the compressive and flexural strength of concrete. The study aimed to encourage government agencies and the business sector to employ excess quantities of domestic sludge in the construction industry, as well as to investigate the influence of partial replacement of cement with dry sludge on the compressive strength of concrete.

1. Introduction

The rising resource consumption per capita, coinciding with the growth of the human population, is forcing the natural environment and reducing the ability of Earth to provide the materials essential for human life [1]. One of the most often stated goals for sustainable wastewater treatment is to find the most sustainable sludge disposal and/or reuse techniques[2]. Although liquid treatment facilities are a significant focus of treatment plant design and operation due to standards for treated effluent reuse and disposal, sludge processing facilities are receiving more attention due to the possibility of resource recovery. Because of operational challenges, increasingly severe reuse regulations, and limited disposal options, solids processing is frequently the most problematic area for many plants [3]. Sludge disposal accounts for up to half of a wastewater treatment plant's operational costs [4]. The domestic wastewater sludge consists of solids (screenings, sand, grit, and scum) and bio-solids produced from typically treatment activities and processes that are liquid or semisolid and have (0.25- 12) percent solid by weight. It is classified as primary, waste activated, and secondary sludge [5]. In a wastewater treatment plant, the amount of sludge produced is about 1% of the total amount of treated wastewater [5].

As the population grows and natural resources are depleted, civil engineers must use readily available recycled materials that contribute to long-term growth rather than focusing solely on short-term needs [6]. The use of sewage sludge in construction, on the other hand, is a relatively new and novel technology [7]. Sludge reuse in the construction industry as a partial replacement for cement can substantially contribute to sustainable development by adopting new technology for saving energy, cost, and resource conservation associated with concrete and cement production [8–10].

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Various studies proved the effectiveness of using sludge in producing construction units such as bricks, tiles, and blocks. They had similar specifications to those available in the market and conformed to the accepted parameters for that purpose. According to Al-Nasrawi's research [11], the pozzolanic activity of tested concrete was within ASTM criteria for 5 and 10% replacement compared to control samples (free of sludge). Still, it was somewhat lower for 15 and 20% replacement. When 10% sludge was added, Yagüe et al. [12] discovered that compressive strength was reduced. The strengths of the 2.5 and 5% sludge-containing mortars, on the other hand, are nearly identical. According to Matar's research [13], using dry sewage sludge in concrete resulted in no noticeable strength reduction when concrete samples were tested. However, when 10% of high organic sludge was added to the concrete mixture, the strength was reduced by up to 17%. Jamshidi et al. [14] and Mandlik and Karale [15] concluded that using dry sludge at 5, 10, and 20% lowered compressive strength as the sludge ratio grew, while Mourtada [16] and Rabie et al. [17] concluded that dry sludge could be used as a partial substitute in concrete compositions up to 15%.

Although the main reuse of sewage sludge in Iraq is for agricultural purposes as fertilizers, the agricultural use has been declining recently, in addition to not conducting tests on the sludge to ensure that it conforms to national instructions for its use for agricultural purposes. Therefore, its use as fertilizer has decreased, which calls for searching for new ways to reuse that sludge quantity.

This study aims to encourage governmental authorities and the private sector to use extra quantities of produced domestic sludge in the construction industry and investigate the effect of partial replacement of cement with domestic dry sludge on the compressive strength of concrete.

2. Experimental works

2.1 Materials

Domestic sewage sludge is obtained from (Al Jisr) wastewater treatment plant WWTP, shown in Figure 1, which serves the residential area of Jisr Diyala district of an area of 235 ha with a capacity of 21000 m^3/d. The city is located in the southern part of Baghdad governorate, about (15.5) km from the town center near Diyala river, which bounds it from the north [18]. Dry sludge from Al-Jisr WWTP was collected from drying beds to be used in concrete mixtures to partially replace Portland cement with various percentages (5, 10, and 15) % by cement weight. In addition, a sample of dry sludge was chemically analyzed before starting concrete works, as shown in Table 1

The Ordinary Portland Cement (OPC) type (I) of (Tasluja), which was manufactured in Sulaimanya, Iraq, is used in this study. The cement is packed in paper bags conforming to the requirements of the Iraqi standard Specifications. Tables 2 and 3 provide the chemical and physical characteristics of the cement employed in this research. The testing is carried out according to the Iraqi Standard Specification (No. 5:1984).

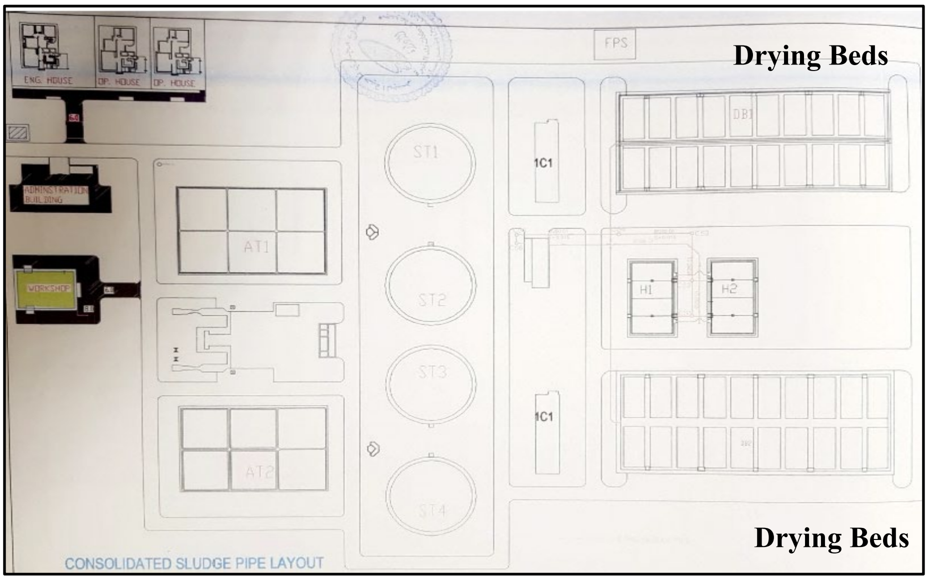


Figure 1: The layout of Al Jisr WWTP

Table 1: Chemical composition of dry domestic wastewater sludge

Item	Unit	Results
pH	-	6.9
Water content	Vol %	0.4
SiO_2	%	29.94
TDS		5.02
Fe		9.32
PO_4		34.35
Na		0.96
K		1.07
Mg		6.97
Pb		0.49
Cu		0.08
Cr		0.32
Zn		0.31
Al		3.28
Mn		0.13
SO_4		3.89
Cl^-		3.88

Table 2: Cement's Chemical Composition

Compound Composition	By weight %	Limits of Iraqi Specification
CaO	61.35	-
SiO_2	19.50	-
Fe_2O_3	3.90	-
Al_2O_3	4.90	-
MgO	2.20	<5.0
SO_3	1.28	<2.8
LOI	1.38	<4.0
Lime saturation factor	0.88	0.66 – 1.02
Insoluble residue	0.99	<1.5
Main Compounds (Bogue´s equation)	**% by weight of cement**	
Tricalcium silicate (C_3S)	48.50	
Dicalcium silicate (C_2S)	32.35	
Tricalcium aluminate (C_3A)	4.80	
Tetracalcium aluminoferrite (C_4AF)	4.80	

Table 3: Cement's physical properties

Physical properties	Value	Limits of Iraqi specification
Specific surface area, Fineness Blaine method (m^2/kg)	263	>230
Setting time by Vicat´s method		
Initial setting (min)	169	>45
Final setting (min)	246	<10 hrs
Soundness using Autoclave (%)	0.30	<0.8

Table 4: Fine aggregate Sieve analysis of (Zone II)

Sieve size(mm)	% passing by weight	Limits of Iraqi specification
9.5	100	100
4.75	96	90-100
2-36	90.5	75-100
1.18	78.5	55-90
0.6	55.4	35-59
0.3	21.6	8-30
0.15	6.5	0-10
Pan	0	-

Normal sand from the AL-Ukhaider district of Karbala, Iraq, was used in the study, and it met Iraqi Standard Specification (No.45: 1984- Zone II) as stated in Table 4 and Table 5.

Table 5: Fine aggregate physical properties

Physical properties	Value	Limit of Iraqi specification
Specific gravity	2.55	-
Sulfate content (%)	0.09	≤ 0.50 %
Absorption (%)	2.89	-
Particles finer than (75) µm sieve (%)	2.56	< 5%
Modulus of Fineness	2.60	-

Table 6: Coarse aggregate Sieve analysis

Sieve size (mm)	% passing by weight	Limits of Iraqi specification
19	100	100
12.5	97	95-100
9.5	45	30-60
4.75	4.5	0-10

Table 7: Coarse aggregates chemical and physical characteristics

Properties	Value	Limit of Iraqi specification
Specific gravity	2.63	-
Absorption	2.60	-
Sulfate content (%)	0.06	≤ 0.1% max

Gravel from the AL-Nibaee area/AL-Anbar, Iraq, with a maximum size of 12.5 mm, was used. Natural coarse aggregate sieve analysis according to Iraqi Standard Specification (No. 45:1984) is shown in Table 6, and physical parameters of this aggregate are shown in Table 7

All mixes and concrete specimens were prepared with ordinary tap water, with a constant Water to Binder (W/b) ratio of 0.45, and Superplasticizer named "ViscoCrete 5930L" of (0.5-1) % by weight of binder as the optimal ratio that gives the preferable slump for mixes.

2.2 Method of Work

Two mixing groups were cast to test and evaluate sludge's effect on concrete properties. The details of the mixes are as follows:

2.2.1 **Group one**:

This group is considered as the control group with a mix of (1:1.75:2.7) (cement: sand: gravel) with 400 kg/m^3 of cement, no sludge is added to the mixture of concrete, and it is adopted as a measure to compare the test results for the rest of the groups.

2.2.2 **Group two**:

Dry domestic wastewater sludge (dewatered naturally by the sun in drying beds) is added to the mixture to partially replace cement with percentages of (5, 10, and 15) % by cement weight.

Standard concrete specimens were cast with cube steel molds of 100 mm. The steel molds were cleaned to prevent adhesion with concrete after hardening, and the inside surfaces were lubricated. The mixes were poured into the tight steel molds until they were filled with compaction. Dry sludge was milled and sieved to a particle size less than 75 µm as shown in Plate (1) to use in concrete mixtures of group two.

The mixing procedure was illustrated in the items according to ACI 211 [19,20]. The strategy was chosen based on other researchers' observations about mixing restrictions. [21,22]. Plate (2) illustrates the casting operation.

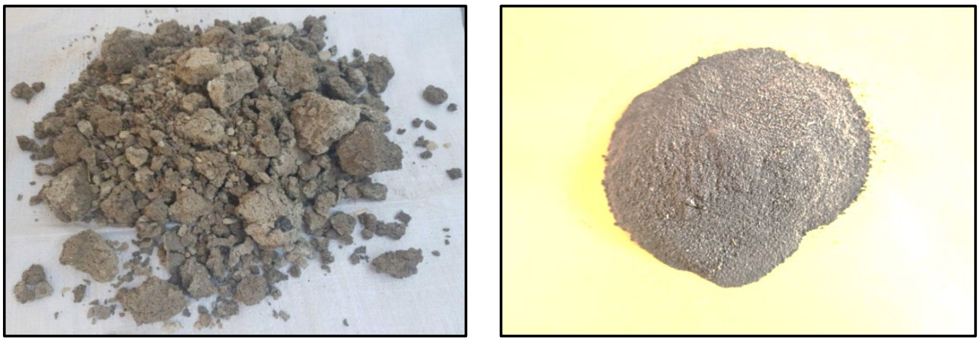
Following the casting procedure, the specimens were held for 24 hours before being taken from the molds and placed in a water tank, and the specimens were totally submerged in it for 7, 28, and 90 days. Table 8 shows the concrete mixes made and the quantities of components used in this study.

2.3 Compressive Strength Test

Plate (3) depicts the equipment used to measure compressive strength for each specimen (ELE – ADR Touch). The average of three cubes tested according to (BS 1881: part 116) was used to calculate this strength.

Table 8: Quantities of materials

Mix Type		Symbol	Binder		Sand kg/m³	Gravel kg/m³	w/b	Sp %
			Cement Kg/m³	*Sludge Kg/m³*				
Control specimens		C	400	0	700	1080	0.45	0.5
% Dry sludge	5%	Ds-5	380	20	700	1080	0.45	0.6
	10%	Ds-10	360	40	700	1080	0.45	0.8
	15%	Ds-15	340	60	700	1080	0.45	1.0



(a) (b)

Plate 1: Dry sludge; (a) before milling and (b) after milling

Plate 2: Casting operation of concrete samples

Plate 3: Compressive strength test

3. Results and Discussion

All mixtures' workability was instantly evaluated after the mixing process following the test method ASTM C143-05a [24]. Figure 2 illustrates the variation in slump value according to the percentage of sludge replaced in the concrete mix. The results revealed that the increase of sewage sludge percentage, partially replaced by the cement, reduced the slump of fresh concrete compared with the control specimens (without sludge addition). The reduction ranged between (4.5-18.2) % for concrete incorporated with dry sludge. These results are compatible with those obtained by other researchers [16,24]. This result is reasonable due to the porous nature of dry sludge, which makes them hygroscopic and high-water absorption due to the high surface area of the solids. Therefore, increasing the content of sludge naturally leads to a decrease in workability.

Figure 3 illustrates the results of compressive strength for 7-day, 28-day, and 90-day age of curing. According to the results obtained from the test of compressive strength of hardened concrete for 7 days of curing, the results of concrete incorporated with dry sludge (5, 10, and 15) % showed a reduction of (36.7, 55.8, and 71.7) %, respectively, compared with the control specimens. Similarly, compressive strength results for 28-day age of curing, as the concrete incorporated with dry sludge (5, 10, and 15) % showed a reduction of (32.8, 52.7, and 68.9) %, respectively, compared with control specimens. Finally, the results of compressive strength for the 90-day age of curing. The results of concrete incorporated with dry sludge (5, 10, and 15) % showed a reduction of (26.5, 50.7, and 71.1) %, respectively, compared with control specimens.

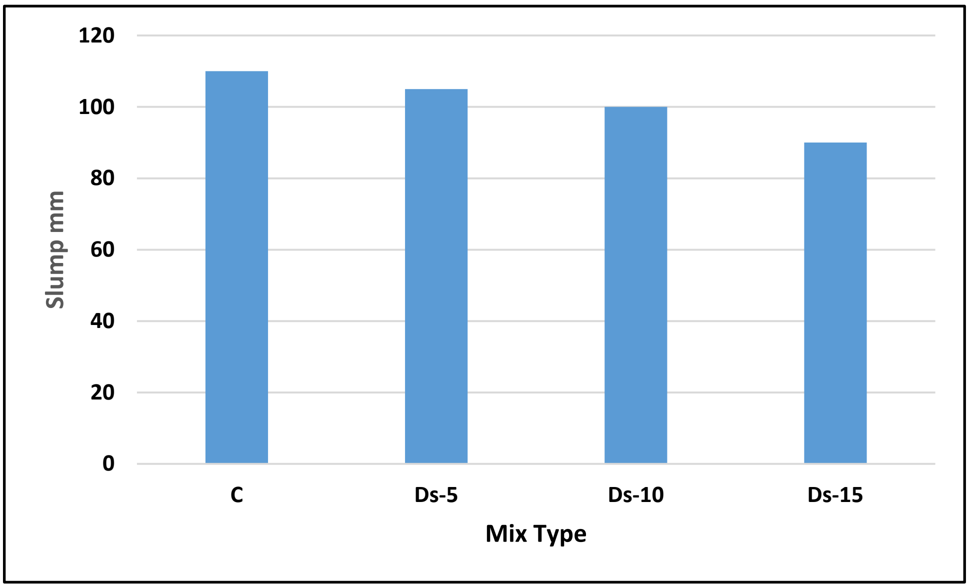


Figure 2: Slump test results

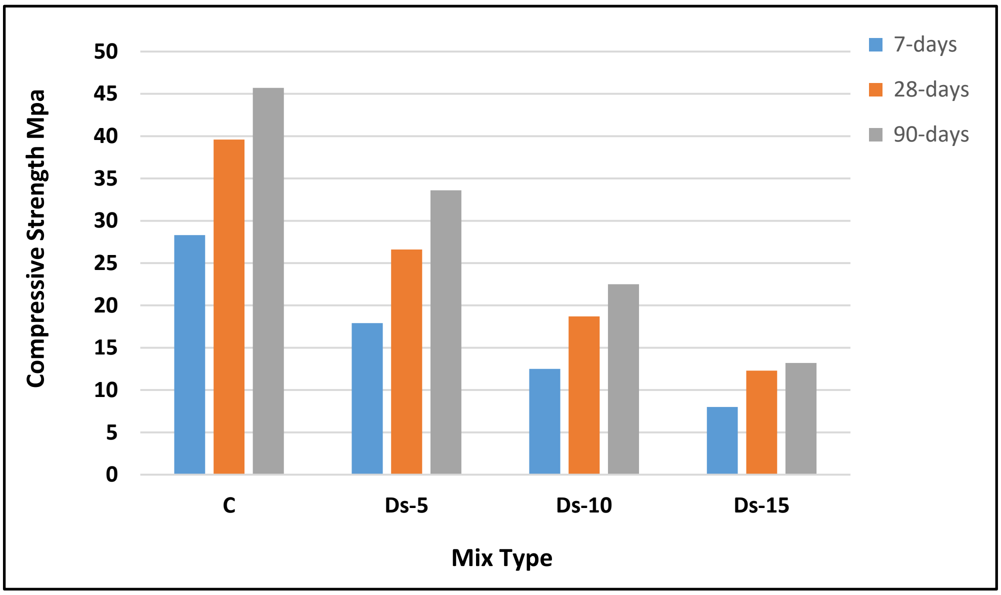


Figure 3: Compressive strength results

Table 9: Applications of concrete [26]

Concrete Grade	Applications	Type
M10	Non-structural works and pathways	Domestic and Commercial
M15	Pavement kerbs and floor blinding	Domestic and Commercial
M20	Foundations and domestic floors, driveways, internal slabs, and workshop bases.	Domestic
M25	Multi-purpose concrete mix, all-purpose use.	Domestic and Commercial
M30	Pathways and roadways are more durable and weather-resistant.	Commercial
M35	Commercial structures, external walls, and slab construction.	Commercial
M40	Commercial construction sites, foundations, and beams for structural support and roads. Most durable compared to the above ratios and can withstand chemical corrosion.	commercial

Noticeably, it is clear that the increase in the percentage of dry sludge replacement caused gradual lowness in compressive strength compared with zero sludge concrete. This result is compatible with what was obtained by [15-17] and others. Furthermore, the analysis results show that dry sludge less than 10% can be used as an additive to concrete mix with less reduction in compressive strength since the sludge acts as a filler material that improves the compressive strength of the mix with time, as the reduction decreased from 36.7% at 7-day to 26.5% at 90-day. However, Jamshidi et al. [14] concluded that the negative effect of the dry sludge on the mechanical properties of concrete is due to the presence of organic matter content and that water absorption by sludge resulted in low binding content.

One of the main processes of sludge treatment is cement production. Cementitious materials such as Ca, Si, Al, and Fe are found in the sludge [27]. The silica percentage (SiO2) increase in dry sludge may undergo a pozzolanic reaction with the portlandite and fill the pores with CSH [28]. The results obtained from experimental tests of Ds mixtures were all within ASTM requirements. However, they cannot be used for the same purpose according to the effect of increasing the replacement ratio of dry sludge to 15% by weight of cement which showed a noticeable reduction in concrete strength compared with the control specimens. Table 9 illustrates some applications of different types of concrete according to their grades.

4. Conclusion

1. Sludge significantly impacts the environment, which will exacerbate in the coming years as its volume grows. Dry sludge concentration of up to 10% in concrete may positively impact reducing sludge levels in the environment and cement production costs while having no significant effect on concrete compressive and flexural strength.
2. Dry sludge can be utilized to replace up to 15% of cement in concrete in sidewalks and roadways because these applications use horizontal construction rather than vertical construction, which requires higher strength resistance.
3. Recycling dry sludge as cementitious materials is a practicable option and a good alternative to landfilling. However, their use depends on finding regulations on the reuse of waste materials and on the readiness of the community to accept innovative strategies in concrete production.

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

Authors declare that their present work has no conflict of interest with other published works.

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