Sewage sludge reuse in concrete industry: a review

Alaa R. Al-Obaidi¹, Riyad H. Al-Anbari² and Maan S. Hassan²

¹ Ministry of Municipalities and Public Works, General Directorate of Sewerage, Baghdad, Iraq.
² Civil Engineering Department, University of Technology, 10066, Baghdad, Iraq.
E-mail: bce.19.33@grad.uotechnology.edu.iq

Abstract. In any industrial or municipal population areas, the excess sewage sludge produced by wastewater treatment plant WWTP creates significant problems due to its growing quantity and possibly containing toxic materials or heavy metals. The concrete industry is one of the fields where wastewater sludge, as well as other wastes, could be utilized inefficient way. The inclusion of wastewater sludge in materials incorporated with cement reduces some of the costly and high energy stages of usage, and the obtained product is often safe and stable. Several studies promoted that the reuse of sludge in concrete can be an ideal solution to get rid of its negative effects, especially the hazardous ones, as it is an effective alternative to reuse the sludge for land applications. The main aim of this study is to present the recent methods of utilizing wastewater dried, dehydrated, and/or raw sludge in concrete industries. The present review revealed the difficulty of choosing the most general technique of utilizing sludge in the concrete industry, due to its various physical and chemical properties.

Keywords: Wastewater sludge, sludge reuse, concrete, sustainability.

1. Introduction

The obsolescence of treatment plants in Iraq and the inefficiency of sludge treatment in them due to exceeding their operating capacity the design limits in addition to shutting off the digestion units in large plants such as the Rustumiya wastewater treatment plant in Baghdad and other old plants in Iraq, as well as the suspension of most industrial treatment units or their lack, all of this has expanded the problem of increasing quantities of untreated and/or treated sludge, which constituted great pressure to find alternative ways to reuse it and reduce its negative effects. Although the main reuse of sewage sludge in Iraq is mainly for agricultural purpose as fertilizers, agriculture 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 as shown in Table 1 [1]. Therefore, its use as fertilizer has decreased and this calls for searching for a new way to reuse that sludge.

Table 1. Iraqi Specification for using sludge for agricultural purposes

| Components  | Symbol | Maximum safe concentrations mg/kg |
|-------------|--------|----------------------------------|
| Zinc        | Zn     | 2800                             |
| Copper      | Cu     | 1500                             |
| Nickel      | Ni     | 420                              |
| Cadmium     | Cd     | 39                               |
| Lead        | Pb     | 300                              |
| Mercury     | Hg     | 17                               |
| Chromium    | Cr     | 1200                             |
| Selenium    | Se     | 36                               |
| Arsenic     | As     | 41                               |

Table 1. Iraqi Specification for using sludge for agricultural purposes

Constructing infrastructure is essential for the development and progress of commerce and industry in modern society [2]. The producing concrete precedes two and a half tons for every human being in
the world each year. Unfortunately, large quantities of non-renewable raw materials are consumed for concrete production [3]. As the population increases and more of the natural resources are consumed, the responsibility of civil engineers is to utilize available recycled materials that participate in sustainable development instead of accepting only the short-term requirements [4]. However, the use of sewage sludge in construction applications is a relatively recent and innovative technique yet [5].

The possibility of containing heavy metals or other toxic substances in sewage sludge prohibits the disposal of it to a landfill or use it as fertilizer in many countries [6]. Several studies have proved that the utilizing of wastewater sludge in the produced eco-construction materials like cement is feasible [7] and reducing the negative effects resulting from the increase in the quantities of sludge from treatment plants as a result of the population expansion, as well as reducing the costs resulting from the handling and disposal of sludge [8] [9] [10].

Nowadays, the increase in demand for construction materials as a result of development has called for an alternative way to develop construction materials from different sources, including sewage sludge ash [11]. Although there are no regulations for using sludge in the construction industry, there are many studies and researches focused on testing different types of sludge reuse, including sludge enriched with heavy metals in concrete and/or brick manufacturing, and investigated the effect on their properties [12] [13] [14] [15]. Many kinds of sludge, including sewage sludge have been combined in the production of fired clay brick and its utilization usually has beneficial impacts on its properties such as porosity, shrinkage, and strength [16].

Many researchers studied the benefit of utilizing sewage sludge ash (SSA) as a cementitious material. Talking about sewage sludge as supplementary cementing material is essential, Figure 1 explains perfectly where is situated the sludge about its components compared with the other famous cement replacement materials.

![Figure 1: SCM pozzolanic components](image)

Although SSA characteristics changes according to the type of sludge, production method, and incineration conditions [17] [18] [19] [20] while other researchers found that the use of hazardous sludge as an alternative aggregate for concrete could preserve the environment and decrease the cost of concrete production [21]. The main aim of this study is to present the recent methods of utilizing wastewater dried, dehydrated, and/or raw sludge in concrete industries. The present review revealed the difficulty of choosing the most general technique of utilizing sludge in the concrete industry, due to its various physical and chemical properties.
2. Using Sludge in concrete construction

The following sections give a general overview of relevant previous research and information concerning wastewater sludge used in concrete mixture and how it affected physical and mechanical properties.

2.1 Using Sewage Sludge as an additive

Yagüe, Valls, and Vázquez studied the impact of utilizing dry sewage sludge on physical and mechanical properties of Portland cement mortar as an additive with different percentages (2.5, 5, 10) % by weight of cement. The result showed a decrease in mechanical strength when adding 10% sludge, as well as the longest initial and final setting times. The strengths of the 2.5 and 5% mortars are relatively similar, and there is a considerable decrease in strength at 10% sludge content. They concluded that there was a reduction in the mechanical strength and density of the mortar due to the addition of sludge to the increase in its porosity, also there was a retard in the hydration process of the cement. Sewage sludge stabilized and the quantity of leachable heavy ions was reduced in comparison with that of control sample [22].

Al-Nasrawi investigated the use of different samples of dewatered sludge are collected from Rustumiya WWTP and additionally treated and the sludge ash as partial replacement of cement with percent of (5, 10, 15, and 20) by weight to investigate the properties of produced concrete (workability, compressive strength, splitting tensile strength, absorption, and drying shrinkage). The results showed that pozzolanic activity of testing concrete was within ASTM requirements for 5 and 10 percent replacement by ash in comparison with control samples (free of sludge), for 15 and 20 percent replacement the activity was slightly less than ASTM values [23].

According to the study of Matar, the use of dry sewage sludge in concrete showed no significant strength loss when testing concrete samples. However, the reduction in strength was increased up to 17% when adding 10% of the high organic sludge to the concrete mixture. The usage of sludge in specimens elevated its absorption and reduced its density coefficient. More than 73% of the total organic material could be fixed by a concrete matrix according to (NEN 7345) leaching test in the worst case. The conclusions revealed that utilization of dry sludge (with high organic content and finer particles) as an additive in concrete mixtures could adversely influence the strength development. However, its usage was considered as one of the available disposal strategies for Gaza Strip sludge [12].

Jamshidi et al. applied industrial and domestic sewage dry sludge in concrete mixture with different (w/c) ratios (0.55 and 0.45) and different percentages (0, 5, 10, 20, and 30) % of cement weight. Crystalline phases (XRD analysis), Chemical composition (XRF analysis), and pozzolanic activity were characterized for dry sludge. The study investigated the influence of using dry sludge on compressive strength, flexural strength, water absorption, and porosity of concretes at different curing intervals (3, 7, 28, and 90) days. It was concluded that utilization of dry sludge at 5, 10, and 20% reduced the compressive strength about 9, 14.5, and 29% respectively in 28 days of curing, and about 3.5, 8, and 20% respectively in 90 days of curing compared with reference samples [6].

A study done by Mohammed et al. tested the effect of Alum Sludge (AS) powder as a partial replacement of Portland cement (Type I) on the mechanical properties of high-performance concrete (HPC). The study investigated a concrete mix with a constant (w/b) ratio of 0.33 and a binder content of 483 kg/m³. The alum sludge was used with (0%, 6%, 9%, 12%, and 15%) by weight of cement. The mechanical properties such as workability, dry densities, compressive strengths, flexural strength, and splitting tensile strengths were tested for the concrete specimens were tested at (3, 7, and 28) days and compared with control samples. The study concluded that the workability of concrete increased as the percentage of AS increased and that the replacement 6% of AS increased the compressive strength and splitting tensile strength at all curing aging in comparison with the control specimens [24].

Al-tersawy and Sergany experienced the feasibility of utilizing the sludge produced from the Water Treatment Plant (WTP) and Rice Husk Ash (RHA) generated from agricultural waste in concrete
production. Different mixing percentages of fired RHA and SA (between 0% and 30%) as a cement replacement were used in concrete casting. Compressive and tensile strength had values close to reference specimens in 28 days with 10% RHA. However, it was found that when the SA percentage was more than 10% it may be suitable to utilize other kinds of concrete. The study concluded that increasing the ratio of cement replacement made a slight reduction in water absorption of RHA specimens while for SA specimens, water absorption values showed a steady increase as the replacement ratio increased [25].

**Mourtada Rabie** evaluated the reuse of wet and dry sewage sludge as partial replacement of cement in concrete with different ratios of (5, 10, 15, and 20) % by weight of cement to produce new feasible construction materials. The results revealed that adding wet sludge showed retardation in the strength development in comparison with dry sludge for the same percentage. The average strength loss was about 13.76% for wet sludge and 7.73% for dry sludge at 28 days of curing. The study concluded that the dry and wet sludge can be utilized in concrete mixtures to 15% as partial replacement of the cement weight as one of the available sludge disposal techniques in Egypt [26].

**Chen and Poon** investigated the comparison study when using Fine Sewage Sludge Ash (FSSA) obtained from dewatered sewage sludge by mechanical incineration and Pulverized Fly Ash (PFA) as a partial replacement of cement. The conclusion showed that the presence of SSA causing an acceleration in the heat development rate from cement hydration while PFA did not produce the same influence. No significant changes were made to the pore structure of the pastes when replacing cement with SSA or FSSA till 10%. FSSA had weak pozzolanic activities compared with PFA. However, the compressive and flexural strength of mortars incorporated with PFA or FSSA is similar at the same replacement ratio till 20%. Replacing cement with PFA showed a reduction in the drying shrinkage of mortar, while the incorporation of FSSA developed the drying shrinkage [27].

Research done by **Mandlik and Karale** investigated the application of sewage sludge as a cement replacement in the concrete mix with different percentages of (5, 10, 15, and 20) % by weight of ordinary Portland cement (OPC) Grade (20) and (30) with water to cement ratio of (0.50 and 0.45) respectively. Compressive strength, split tensile strength test, flexural strength test was investigated and compared with control samples. The results illustrated that all values of sludge-incorporated concrete compressive strength were less than that of reference specimens with only OPC, and as the percentage of sludge increased the strength decreased. However, the increase of the sludge replacement ratio showed an increase in absorption and permeability of water. The study concluded that using this sludge as a cement replacement material could be feasible [28].

A study done by **Chen, Li, and Poon** investigated the feasibility of using sewage sludge ash (SSA) as a cement replacement and glass cullet (GC) as a partial replacement of natural aggregates to produce a dry mix concrete blocks by compression (zero slumps) method. The results revealed that using (SSA) had a moderate pozzolanic activity with an increase in the long-term compressive strength of the concrete blocks. However, using (SSA) with (GC) was found to be better than using only (SSA) for block manufacturing because of a significant reduction in drying shrinkage. The results indicated that utilizing SSA together with GC could produce acceptable mechanical, durability, and leaching properties for paving blocks, in addition to the benefits obtained from the recycling of these types of waste [29].

**Rabie et al.** tested the effect of utilizing dry and wet sewage sludge on the physical and mechanical properties of concrete mix. Using these types of sludge with (5, 10, and 15) % by weight of cement had a slight effect on the strength of concrete mix, while the retardation was about 61.6% for dry sludge and 68.5% for wet sludge at 20% sludge ratio. The results showed that using wet sludge reduced the strength development more than using dry sludge, and its adverse effect on compressive strength was greater than that of dry sludge for the same percentage. The study concluded that the utilization of dry and wet sludge till 15% of the cement weight as an additive in concrete production can be one of the available and feasible options for sludge disposal [30].

**Krasinikova et al.** tested the feasibility of using chemical water treatment sludge generated from heat and power facilities as an active mineral additive in cement production systems. The study
concluded that using sludge after being dried was effective when separately introduced with superplasticizer, and showed an increase in water demand with the reduction in consumption of binding agent by 7.5% without retardation in strength properties, also there was a reduction in porosity of cement stone by 7% and a slowdown in the time of setting-up to 9 hours which accordingly will aid to avoid temperature deformations [31].

2.2 Using Sewage Sludge as aggregate

The objective of the study done by Mun is to effectively treat sludge generated from wastewater treatment plants (WWTP) and to assess the acceptability of lightweight aggregate manufacturing from a large amount of wastewater sludge. Various mass ratios of clay to sewage sludge were used to produce (sintered lightweight aggregate) from sewage sludge by a rotary kiln. Density, crushing value, abrasion loss, water absorption, heavy metal leaching, and impact value were investigated in the study to compare the physical properties of producing lightweight aggregate with commercial type for non-structural concrete. The results revealed that the physical properties of the produced aggregate incorporated with wastewater sludge are similar or better than that of the commercial type, especially for water absorption which is about half or less than that of commercial aggregate. The study concluded that the sludge-incorporated lightweight aggregate could be environment-conscious due to nonexistence of toxic heavy metals in the artificial aggregate [32].

A study done by Jamshidi et al. evaluated the influence of utilizing sewage sludge ash (SSA) as a partial replacement of sand on the properties of concrete. Chemical composition (XRF analysis), crystalline phases (XRD analysis), and pozzolanic activity were tested to characterize the produced concrete. Also, the influence of incineration of dry sludge crystals phases was tested. The mechanical properties of concrete incorporated with SSA were performed in the study by using (5, 10, and 20) percent of the sludge as cement replacement with 0.55 and 0.45 (W/b) ratios at different curing ages (3, 7, 28, and 90) days. Results showed a reduction in the density and mechanical strength of producing concrete. However, concrete incorporated with 20% of SSA and (W/b) of 0.45 had a compressive strength of almost 30 MPa at 28 days of curing [33].

Tay et al. presented the feasibility of producing artificial aggregate using low organic dry industrial sludge and clay after crushing them individually to fine size and then mixing with water to make a paste. The producing paste was created aggregate shape prior to sintering at high temperature. A comparison was performed between the compressive strength of concrete specimens incorporated with the granite aggregate and those incorporated with artificial aggregate to assess the performance of the last one. The results revealed that the compressive strength of concrete specimens incorporated with artificial aggregate was between 31-38.5 MPa, while the reference specimens incorporated with granite aggregate valued 38 MPa at 28-day. However, the artificial aggregate showed lower density and higher porosity than that of the granite aggregates [34].

A study done by Nagar and Bhargava tested the effect of adding the sewage sludge in various proportions on the property of the concrete mixture. Sludge material was replaced with fine and coarse aggregate in various percentages ranging between (3-50) percent with a reference concrete mix for comparative reasons. The study concluded that the workability of concrete decreased with the addition of waste dry sludge, the optimum percentage of sludge coarse and fine aggregate was 15 percent. The replacement level of 15 percent of sludge coarse and fine aggregate improved the compressive strength, Flexure strength, and tensile strength [35].

Mathye, Ikotun, and Fanourakis used the dry sewage sludge generated from the (Northwest treatment plant) in Johannesburg, South Africa as a partial replacement of sand to produce concrete with different percentages (0, 1, 3, and 5) % by weight. Splitting tensile and compressive strength was tested to assess the influence of utilizing dry sludge on concrete properties at 3, 7, 28, and 90 days. The results revealed that the concrete strengths decreased as the sludge replacement increased compared to the control sample. The study concluded that this sludge could be feasibly used as a partial replacement of
sand in concrete production for non-structural purposes with an optimum percentage less than 3% with (W/b) of 0.67 [36].

2.3 Using Sewage Sludge in Brick Industry
A study was done by Hegazy, Fouad, and Hassanain investigated the feasibility of using sludge incorporated with rice husk ash (RHA) and silica fume (SF) as a complete replacement of brick clay. Three different percentages of (sludge: SF: RHA) were used as (25: 50: 25) %, (50: 25: 25) %, and (25: 25: 50) % respectively after heated at (900, 1000, 1100, and 1200) °C. The properties of the artificial bricks were physically and mechanically investigated and evaluated according to Egyptian Standard Specifications (ESS) in comparison with reference specimens of clay-incorporated bricks. The study concluded that utilizing a mixture of 50% of sludge, 25% of SF, and 25% of RHA at the temperature used in the brick kiln was the optimum percentage for brick production. The properties of producing bricks were obviously superior to the completely clay-bricks and to those available in Egypt [37].

Eliche-Quesada et al. investigated the influence of utilizing different types of industrial wastes containing urban sewage sludge to produce bricks. Linear shrinkage, water absorption, bulk density, and mechanical and thermal tests were investigated to assess the sludge addition on brick properties. The result showed an increase in water absorption and thermal insulation by 35% and 8% respectively, when using urban sewage sludge with a reduction in the compressive strength by 19%. However, the porosity formed and the type of waste showed a change in water absorption and the SEM micrographs [38].

Babu and Ramana performed the effect of using sludge generated from the sand beneficiation treatment facility on the durability of producing bricks. The study resulted that the clay can be replaced with sludge by 40 percent by mass in brick production with acceptable strength and other properties for the traditional purposes of brick usage. The results of the test compared with reference samples which cast with (5% Sludge) at different ages. The lack of weight was found to be more in reference specimens of bricks than that in producing bricks. However, the quality of producing bricks at 5% of sludge replacement is preferable to that of only clay-incorporated bricks and can always be utilized for superior work [39].

Ahmadi et al. investigated the physical and chemical characteristics of sludge from the oil-water separator (OWS) and dissolved air flotation (DAF) clarifier of a Refinery WWTP and disposal options. The results showed that the ash generated from sludge incineration contains high amounts of Fe, Al, Ca, and Si. Therefore, it can be utilized as a raw material in brick production, tile, block, and other construction materials manufacturing. The highest concentration of Al and Fe were in DAF sludge. Therefore, it is potentially good to be used as a raw material for the production of construction materials. The study suggested that if the metal content is above the standard values, such sludge can be blended with a proper amount of uncontaminated soil to solve this problem and reduce the negative health effects [9].

Stabilizing Chromium-rich tannery sludge in clay brick products was investigated by Juel, Mizan, and Ahmed by preparing clay bricks with various percentages of sludge (10, 20, 30, and 40)% by dry mass and evaluating their feasibility as a construction material according to their properties (strength, shrinkage, water absorption, bulk density and loss of weight on ignition). The result showed that the water absorption and compressive strength in the produced bricks (incorporated with sludge) met both ASTM and the Bangladesh criteria for bricks as a construction material. Sludge-incorporated brick was found to be feasible according to volumetric shrinkage, loss of weight and evolution properties, and energy-saving which reached (15–47) % at (10–40) % of sludge replacement. The leaching behavior of various heavy metals such as (Cr, Cu, As, Cd, Ni, Zn, and Pb) from producing bricks had been found to be less than the requirement of Dutch and USEPA regulations. The study concluded that sludge-incorporated
bricks can be sustainably stabilized in Bangladesh, where brick remains an essential building material [40].

A study done by Ukwatta and Mohajerani investigated the leaching behavior of potentially hazardous metals from the green and fired bricks incorporating four different bio-solids specimens. XRD, XRF, TGA, particle size distribution, and organic content were tested to evaluate the samples incorporated with bio-solids. The leaching of several heavy metals such as (As, Ag, Ba, Be, Cd, Cr, Cu, Mo, Ni, Pb, Sb, Se, and Zn) was assessed according to the Australian Bottle Leaching Procedure ABLP and the Toxicity Characteristic Leaching Procedure TCLP for both green and fired bricks. According to the leaching test of heavy metals, the result showed that the value obtained from the green bricks was found to be higher than that from the fired bricks. However, The ABLP method showed that the concentrations of heavy metals were greater than that of the TCLP method [41].

Mohajerani et al. investigated the utilization of the sewage sludge SS obtained from three different sources in fired–clay bricks and its effect on bricks physical, chemical, and mechanical properties with various percentages (25, 20, 15, and 10) percent. The results of Compressive strength were between (35.5 and 12.04) MPa for the artificial bricks. Leachate analysis was performed on the bricks prior to and after firing. The result of Scanning Electron Microscopy (SEM) illustrated that produced bricks had a higher porosity than that of control bricks with lower thermal conductivity values. (43 – 99) % of the tested heavy metals were immobilized in the fired bricks compared with those of control bricks. In addition, the consumed firing energy decreased by up to 48.6% for bricks incorporating 25% of SS due to its higher organic content [5].

2.4 Using Sewage Sludge in Eco-Block Production

Baeza-Brotons et al. studied the possibility of manufacturing concrete blocks incorporated with sewage sludge ash (SSA) as raw material, with the same dosage as it is used to produce blocks. Different percentages of SSA (5, 10, 15, and 20) % by weight of cement were added with an inert material such as marble dust. Thermogravimetric analysis (TGA) was investigated on pastes at 7, 28, and 90 days in addition to physical and mechanical tests on mortars at 28 and 90 days. The study showed that using SSA as an additive in concrete block production resulted from density and strength similar to that of the control sample (without SSA) at 28 days of curing with a significant reduction in water absorption [42].

A study done by Cheng et al. investigated the feasibility of using different waste sludge, including sewage sludge and coal combustion residuals in eco-concrete block manufacturing. The compressive strength of the eco-concrete blocks was 36 N/mm², which met the standard specifications of paving blocks in Hong Kong. The optimal percentage of mixing for aggregates, cementitious materials, water, and fly ash was (1.1:1:0.0:0.5:0.22) by weight respectively. The study evaluated the environmental and toxicological influence of the final products according to the TCLP method. Several heavy metals such as (Hg, Cu, and Pb) were tested according to Standards (US 40 CFR 268.48). The study concluded that sludge and/or wastes produced from water, sewage treatment, and power plants can be feasibly utilized in paving concrete block production [7].

3. The Side Effect of Using Sewage Sludge in Concrete Industry

Several authors have been studying the environmental impact of adding sewage sludge to concrete such as using a leaching test to determine the concentration of heavy metals leached from concrete elements incorporated with sludge [17]. The probability of pathogens' pathogens existence in sewage sludge such as viruses, bacteria, and protozoa may adversely affect the concrete structure and cause health risk [41]. In addition, the existence of organic matter is not suitable for concrete production due to contamination impacts [42].
4. Summary
Table 2 summarizes the previous studies and their results according to what they had been tested and resulted as follows:

| Items                  | Researchers                                       | Results                                                                 |
|------------------------|---------------------------------------------------|------------------------------------------------------------------------|
| Using Sewage Sludge as additive | Yagüé, Valls and Vàzquez, 2002                    | - The reduction in strength was increased with the increase of sludge percentage to the concrete mixture. |
|                        | Al-Nasrawi, 2003                                  | - Dry and wet sludge can be feasibly utilized in concrete mixtures to 15%. |
|                        | Jamshidi et al., 2012                             | - No significant changes were made to the pore structure of the pastes when replacing cement with SSA till 10%. |
|                        | Mohammed et al., 2013                             | - Utilizing SSA together with GC could produce acceptable mechanical, durability, and leaching properties. |
|                        | Al-tersawy and Sergany, 2016                      | - Physical properties of the produced aggregate incorporated with sewage sludge are similar or better than that of the commercial type especially for water absorption. |
|                        | Mourtada Rabie, 2016                             | - Reduction in concrete strength due to using artificial aggregate in comparison with granite aggregate. |
|                        | Chen and Poon, 2017                              | - Workability of concrete decreased with the addition of waste dry sludge as a partial replacement of fine and coarse aggregate with the optimum percentage of 15%. |
|                        | Mandlik and Karale, 2018                          | - Utilizing a mixture of 50% of sludge, 25% of SF, and 25% of RHA at the temperature used in the brick kiln was the optimum percentages for brick production. |
|                        | Chen, Li and Poon, 2018                           | - Increase in water absorption and thermal insulation with a reduction in the compressive strength of produced brick. |
|                        | Rabie et al., 2019                               | - The quality of produced bricks at 5% of sludge replacement is preferable to that of only clay-incorporated bricks. |
|                        | Krasinikova et al., 2020                          | - The ash generated from sludge incineration, which contains high amounts of Fe, Al, Ca and Si can be utilized as a raw material in brick production. |
|                        | Mun, 2007                                         | - The consumed firing energy decreased by up to 48.6% for bricks incorporating 25% of SS due to its higher organic content. |
|                        | Jamshidi et al., 2013                             | - Using SSA as an additive in concrete block production resulted from density and strength similar to that of the control sample (without SSA) at 28 days of curing with a significant reduction in water absorption. |
|                        | Tay et al., 2014                                  | - Sludge and/or wastes produced from water, sewage treatment, and power plants can be feasibly utilized in paving concrete block production. |
|                        | Nagar and Bhargava, 2016                          | - Physical properties of the produced aggregate incorporated with sewage sludge are similar or better than that of the commercial type especially for water absorption. |
|                        | Mathye, Ikotun and Fanourakis, 2020               | - Reduction in concrete strength due to using artificial aggregate in comparison with granite aggregate. |
|                        | weer, 2017                                        | - Workability of concrete decreased with the addition of waste dry sludge as a partial replacement of fine and coarse aggregate with the optimum percentage of 15%. |
| Using Sewage Sludge as aggregate | Eliche-Quesada et al., 2011                        | - Utilizing a mixture of 50% of sludge, 25% of SF, and 25% of RHA at the temperature used in the brick kiln was the optimum percentages for brick production. |
|                        | Hegazy, Fouad and Hassainain, 2012                | - Increase in water absorption and thermal insulation with a reduction in the compressive strength of produced brick. |
|                        | Babu and Ramana, 2013                             | - The quality of produced bricks at 5% of sludge replacement is preferable to that of only clay-incorporated bricks. |
|                        | Ahmadi et al., 2013                               | - The ash generated from sludge incineration, which contains high amounts of Fe, Al, Ca and Si can be utilized as a raw material in brick production. |
|                        | Juel, Mizan and Ahmed, 2017                       | - The consumed firing energy decreased by up to 48.6% for bricks incorporating 25% of SS due to its higher organic content. |
|                        | Ukwatta and Mohajerani, 2017                      | - Using SSA as an additive in concrete block production resulted from density and strength similar to that of the control sample (without SSA) at 28 days of curing with a significant reduction in water absorption. |
|                        | Mohajerani et al., 2019                           | - Sludge and/or wastes produced from water, sewage treatment, and power plants can be feasibly utilized in paving concrete block production. |
| Using Sewage Sludge in Brick Industry | Baeza-Brotons et al., 2014                       | - Utilizing a mixture of 50% of sludge, 25% of SF, and 25% of RHA at the temperature used in the brick kiln was the optimum percentages for brick production. |
|                        | Cheng et al., 2019                                | - Increase in water absorption and thermal insulation with a reduction in the compressive strength of produced brick. |
|                        | Eliche-Quesada et al., 2011                        | - The quality of produced bricks at 5% of sludge replacement is preferable to that of only clay-incorporated bricks. |
|                        | Hegazy, Fouad and Hassainain, 2012                | - The ash generated from sludge incineration, which contains high amounts of Fe, Al, Ca and Si can be utilized as a raw material in brick production. |
|                        | Babu and Ramana, 2013                             | - The consumed firing energy decreased by up to 48.6% for bricks incorporating 25% of SS due to its higher organic content. |
|                        | Ahmadi et al., 2013                               | - Using SSA as an additive in concrete block production resulted from density and strength similar to that of the control sample (without SSA) at 28 days of curing with a significant reduction in water absorption. |
|                        | Juel, Mizan and Ahmed, 2017                       | - Sludge and/or wastes produced from water, sewage treatment, and power plants can be feasibly utilized in paving concrete block production. |
5. Conclusion
From the mentioned previously, this study concluded the following:
1. The studies were mostly specified using dry sewage sludge in concrete production by its incineration at a temperature ranging between (200-600 °C) to minimize the organic matter.
2. The local investigation in this field was very restricted and the sludge utilization in the construction industry is considered recent due to the population expansion, which has put great pressure on the availability of raw materials.
3. The environmental problems associated with the treatment and management of sludge as well as the absence of national determinants except that of its use in agriculture forced researchers to find alternative strategies to use sludge in order to benefit from it and reduce its quantities and negative impacts on the environment.
4. Such studies will encourage researchers in Iraq to expand their work to prove the feasibility of using sludge in concrete.

References
[1] 2016 Instructions for the use of treated sludge in agriculture No. 1 of 2016. Iraqi Chronicle, No 4417.
[2] Li Z, Leung C, Xi Y. 2009 Structural renovation in concrete. (Abingdon: CRC Press).
[3] Noël M, Sanchez L, and Fathifazl G. 2016 Recent advances in sustainable concrete for structural applications. Sustainable Construction Materials & Technologies, 4(10).
[4] Merritt F S and Ricketts J T 2000 Building design and construction handbook. Choice Reviews Online. (New York:McGraw-Hill Professional).
[5] Mohajerani A, Ukwatta A, Jeffrey-Bailey T, Swaney M, Ahmed M, Rodwell G, Bartolo S, Eshtiaghi N and Setunge S 2019. A proposal for recycling the world’s unused stockpiles of treated wastewater sludge (biosolids) in fired-clay bricks. Buildings, 9(1).
[6] Jamshidi M, Jamshidi A and Mehrdadi N 2012 Application of sewage dry sludge in concrete mixtures. Asian J Civ Eng, 13(3):365–75.
[7] Cheng W N, Yi H, Yu C F, Wong H F, Wang G, Kwon E E and Tsang Y F 2019 Biorefining waste sludge from water and sewage treatment plants into eco-construction material. Frontiers in Energy Research, 7 pp 1–9.
[8] Fytili D and Zabaniotou A 2008 Utilization of sewage sludge in EU application of old and new methods-A review. Renew Sustain Energy Rev.,12(1):116–40.
[9] Ahmadi M, Jaafarzadeh N, Teymourni P, Tamimi Zand Maleki R. 2013 Characteristics and disposal options of sludge from a steel mill wastewater treatment plant. J Adv Env Heal Res., 12(2):9–112.
[10] Angelakis A N and Snyder S A 2015 Wastewater treatment and reuse: Past, present, and future. Water; 7(9):4887–95.
[11] Smol M, Kulczycka J, Henclik A, Gorazda K and Wzorek Z 2015 The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy. J Clean Prod., 95:45–54.
[12] Matar M. 2008 Use of wastewater sludge in concrete mixes. the islamic university. Faculty of Engineering Civil; http://hdl.handle.net/20.500.12358/19154 a.,
[13] Kadir A A and Rahim A S A 2014 An Overview of Sludge Utilization into Fired Clay Brick. Int J Environ Ecol Geol Mar Eng., 8(8):528–32.
[14] Raut A N and Gomez C P 2016 Utilization of waste as a constituent ingredient for enhancing thermal performance of bricks - A Review paper. Indian J Sci Technol., 9(37).
[15] Sahu M K and Singh L and Bhilai D R C E T 2017 Critical Review on Types of Bricks Type 1: Sludge Clay Burnt Bricks. Int J Mech Prod Eng [Internet]; (5):2320–2092. Available from: http://iraj.
[16] Costa C P, Emilio P and Gómez I 2014 Analysis of possible use of sewage sludge in cement based
composites mix design.

[17] Yusuf R O, Noor Z Z, Din M F M d and Abba A H 2012 Use of sewage sludge ash (SSA) in the production of cement and concrete - A review. *Int J Glob Environ Issues*, 12(2–4):214–28.

[18] Vouk D, Serdar M, Nakić D and Anić-Vučinić A 2016 Use of sludge generated at WWTP in the production of cement mortar and concrete. *Gradjevinar*, 68(3):199–210.

[19] Vouk D, Nakic D, Stirmer N and Cheeseman C R 2017 Use of sewage sludge ash in cementitious materials. *Rev Adv Mater Sci.*, 49(2):158–70.

[20] Godoy L G G de, Rohden A B, Garcez M R, Costa E B da, Dalt S and Andrade J J de O 2019 Valorization of water treatment sludge waste by application as supplementary cementitious material. *Constr Build Mater [Internet]*, 223:939–50. Available from: https://doi.org/10.1016/j.conbuildmat.2019.07.333

[21] De Almeida Lima D and Zulanas C 2016 Use of Contaminated Sludge in Concrete. *Procedia Eng [Internet]*, 145(480):1201–8. Available from: http://dx.doi.org/10.1016/j.proeng.2016.04.155

[22] Yagüe A, Valls S and Vázquez E 2002 Use of cement portland mortar of stabilised dry sewage sludge in construction applications. *WIT Transactions on Ecology and the Environment*, 52:7–36.

[23] Al-Nasrawi S T. 2003 Using Treated Sewage Sludge as Partial replacement of Cement to Enhance Production and Minimize Pollution. university of Technology, Iraq.

[24] Mohammed H, Hamid R, Rozaimah S, Abdullah S, Tan N and Raihan M 2013 Physical and Mechanical Properties of High Performance Concrete with Alum Sludge as Partial Cement Replacement. *J Teknol.*, 7:105–12.

[25] Al-tersawy S H and Sergany F A El 2016 Reuse of Water Treatment Plant Sludge and Rice Husk Ash in Concrete Production. *Int Journa L Eng Sci Ences Res Technol [Internet]*, 5(12):138–52. Available from: http://www.ijesrt.com/issues pdf file/Archive-2016/December-2016/20.pdf

[26] Mourtada Rabie G 2016 Using of Wastewater Dry and Wet Sludge In Concrete Mix. *J Civ Environ Eng.*, 06(01):1–7.

[27] Chen Z and Poon C S. 2017Comparative studies on the effects of sewage sludge ash and fly ash on cement hydration and properties of cement mortars. *Constr Build Mater [Internet]*, 154:791–803. Available from: http://dx.doi.org/10.1016/j.conbuildmat.2017.08.003

[28] Mandlik A D and Karale S A 2018 Sludge Use in Concrete as a Replacement of Cement. *Int J Res Eng Appl Manag.*, 4(10):22–7.

[29] Chen Z, Li J S and Poon C S 2018 Combined use of sewage sludge ash and recycled glass cullet for the production of concrete blocks. *J Clean Prod [Internet]*, 171:1447–59. Available from: https://doi.org/10.1016/j.jclepro.2017.10.140

[30] Rabie G M, El-Halim H A and Rozaik E H 2019 Influence of using dry and wet wastewater sludge in concrete mix on its physical and mechanical properties. *Ain Shams Eng J [Internet]*, 10(4):705–12. Available from: https://doi.org/10.1016/j.asej.2019.07.008

[31] Krasinikova N, Stepanov S and Makarov D 2020 Cement stone, modified by chemical water treatment sludge. *IOP Conf Ser Mater Sci Eng.*, 890(1).

[32] Mun K J. 2007 Development and tests of lightweight aggregate using sewage sludge for nonstructural concrete. *Constr Build Mater.*, 21(7):1583–8.

[33] Jamshidi A, Jamshidi M, Mehrdadi N, Shasavandi A and Pacheco-Torgal F 2013 Mechanical performance of concrete with partial replacement of sand by sewage sludge ash from incineration. *Mater Sci Forum.*, 730:462–7.

[34] Johnson O A, Napiah M and Kamaruddin I 2014Potential uses of waste sludge in construction industry: A review. *Res J Appl Sci Eng Technol.*, 8(4):565–70.

[35] Nagar B and Bhargava V P 2016 Experimental Study on Effects of Sludge waste in concrete. 5(10):54–63.

[36] Mathye R P, Ikotun B D and Fanourakis G C 2020 The effect of dry wastewater sludge as sand
replacement on concrete strengths. *Mater Today Proc [Internet];*(xxxx):0–6. Available from: https://doi.org/10.1016/j.matpr.2020.05.493

[37] Eliche-Quesada D, Martínez-García C, Martínez-Cartas M L, Cotes-Palomino M T, Pérez-Villarejo L, Cruz-Pérez N and Corpas-Iglesias F A 2011. The use of different forms of waste in the manufacture of ceramic bricks. *Applied Clay Science, 52*(3):270-6.

[38] Babu G R and Ramana N V 2013 Durability of Bricks Cast With Industrial Sludge. *IOSR J Mech Civ Eng.;*6(4):43–6.

[39] Juel M A I, Mizan A and Ahmed T. 2017 Sustainable use of tannery sludge in brick manufacturing in Bangladesh. *Waste Manag.* 60:259–69.

[40] Ukwatta A and Mohajerani A 2017 Leachate analysis of green and fired-clay bricks incorporated with biosolids. *Waste Manag [Internet];*66:134–44. Available from: http://dx.doi.org/10.1016/j.wasman.2017.04.041

[41] Baeza-Brotons F, Garcés P and Payá J, Saval J M 2014 Portland cement systems with addition of sewage sludge ash. application in concretes for the manufacture of blocks. *J Clean Prod [Internet].*82:112–24. Available from: http://dx.doi.org/10.1016/j.jclepro.2014.06.072

[42] Vasudevan G 2019 Performance of Alum Sludge as partial replacement for cement adding superplasticizer. *IOP Conf Ser Mater Sci Eng.,* 652(1).