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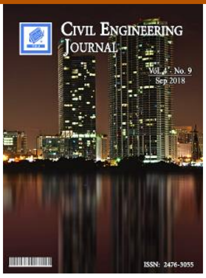

Review on Different Beneficial Ways of Applying Alum Sludge in a Sustainable Disposal Manner

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Abstract

Disposal of waste from water treatment plant is one of the major issues most treatment plants seem not to overcome due to the constant generation of this waste as a result of meeting the demand of water and purification of water for human consumption. The effect of disposing sludge constantly in the environment has called for an economical and sustainable way of reusing alum sludge. However, this paper aimed at reviewing the possible literature on applying waste from water treatment plant in various ways, example; in building material; as brick and tiles, in concrete ; as replacement of cement and aggregate, in Geotechnics; as soil stabilizer and in agriculture; as soil fertilizer, in pottery; use as replacement of clay in flower pot production for sustainable disposal. All the above mentioned categories of uses have reviled an effective and efficient way in managing waste from water treatment plant (alum sludge), also a safer and economical manner of disposal. However, the effects when used and the behaviour when it is incorporated with other materials were highlighted, other reuse and disposal options where discussed and the areas not covered (knowledge gap) was identified.

Keywords: Alum Sludge; Sustainable Disposal; Soil Stabilizer; Soil fertilizer; Building and Construction.

1. Introduction

Water Treatment plants use alum for purification of drinking water. The term Alum means Aluminium sulphate which is the main agent in flocculation and coagulation for pre-treatment process in most water industry in the world for purification of water [1-2]. Aluminium and iron salts have been utilized in this regard over the years, Alum salt is commonly utilized as a coagulant agent due to its availability, effectiveness, easy to use and cheap cost supply [2-3]. Therefore, Alum sludge is a by-product generated from water treatment plant which is basically inevitable when purifying portable water for drinking purposes and it's the core by-product of "coagulation and flocculation" processes basically used by most water treatment plants [4-5]. Alum sludge can also be described as waste generated through the process of water purification process of hydrated aluminium sulphate addition to water. This process produces alum sludge as a waste with a negative environmental impact when disposed in landfill or in watercourse which will cause excessive accumulation of aluminium concentration in human body and harm the aquatic life. Many studies on alum sludge disposal linked aluminium accumulation in river to be responsible for children mental illness and other skin diseases due to some of the heavy metals accumulation in the water bodies [6]. This waste needs to be disposed properly to avoid any harm to human life.

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1.1. Chemical Composition of Alum Sludge

In the purification process of drinking water, alum salts, which is technically an aluminium sulphate, is added to raw water sources and the aluminium ions will hydrolyze into aluminium hydroxide, which is a precipitate. The organic matter and other impurities present in the water will then be absorbed after flocculation and coagulation processes, forming sludge (waste), which is called alum sludge. This sludge is made up of suspended matter, chemical substances, several microbial groups and inorganic matter [2, 7, 8]. "Alum sludge quality is dependent on the water quality source which means the quality and purity of alum with other chemical used for treatment like polymers and powdered activated carbon for odour control and taste that is responsible in flocculation process" [2, 3, 9, 10].

Table 1. Chemical Composition of Alum sludge from different study

Chemical	Composition (%)						
	Khalid et al. [11]	Meuge [12]	Haider et al. [13]	Zhao et al. [14]	Rodriguez, et al., [15]	Ahmad et al. [16]	Mohammed et al. [17]
Silicon dioxide (SiO_2)	43.29	9.41	42.38	33.4	29.63	52.78	43.12
Aluminum oxide (Al_2O_3)	32.19	51.01	35.03	29.3	17.57	14.38	15.97
Iron oxide (Fe_2O_3)	5.52	0.70	4.94	10.5	5.18	5.20	5.26
Calcium oxide (CaO)	0.17	1.31	0.13	2.7	11.85	4.39	5.56
Magnesium oxide (MgO)	0.33	0.22	0.29	0.89	2.15	3.08	0.85
Sodium oxide (Na_2O)	0.13	0.07	0.10	-	6.09	0.97	0.52
Potassium oxide (K_2O)	2.08	0.20	1.87	-	2.85	3.62	0.25
Sulphur trioxide (SO_3)	0.22	-	0.14	-	0.34	-	1.49
Phosphorus pentoxide (P_2O_5)		0.36	0.26	-	0.94	0.17	-
Chlorine (Cl)		-	-	-	0.16	-	0.012

Water treatment plant waste (alum sludge) is made up of organic and inorganic compound in gaseous, liquid and solid states but varies in chemical and physical characteristics depending on the purification agent used and the raw water source. The addition of purification agent in water during water treatment may cause the sludge to be rich in aluminium content. The chemical composition present in alum sludge are Aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3), Calcium oxide (CaO), Magnesium oxide (MgO) sulphur trioxide (SO_3), Sodium oxide (Na_2O), Potassium oxide (K_2O) Chlorine (Cl), Phosphorus pentoxide (P_2O_5), Silicon dioxide (SiO_2) as shown in Table 1.

1.2. Physical Properties of Alum Sludge

The property of alum sludge differs from water treatment plant to water treatment plant based on the origin or water source as stated earlier. Alum sludge has moisture content of at least 80% and the loss on ignition is usually as high as about 52.0%. This is mostly ascribed to the presence of organic matters, clay minerals and hydroxides in the alum sludge. Facts have been established by past studies that, there are high organic matter content of up to 24.3% in alum sludge, which contributed to the high value of lost on ignition and a surface area at about 106.9 $m^2 g^{-1}$ which indicates it as a porous material [18, 6] see Table 2, for physical properties of alum sludge.

Table 2. Properties of alum sludge (Hanim et al, [19])

Physical Property	Mean ± SD
Bulk Density (g/cm^3)	0.831± 0.061
Particle Density (g/cm^3)	2.66± 0.029
Porosity (%)	68-69
Ash (%)	66.67± 1.155
Moisture (%)	28.67± 0.577
Total organic carbon (TOC):	
- Organic carbon	1570.33± 12.055
- Inorganic carbon	129.97± 2.650
- TOC	1440.37± 14.706
pH of solution	4.28± 0.012
Surface area (m^2/g)	38.92±2.68

Ahmad et al, [16] characterized alum sludge from water treatment plant in Ghaziabad by their particle fraction as; Clay fraction at about 16%. Silt fraction at about 24% content fine Sand fraction at about 60% content, the volume and nature of the waste generated from the treatment process depends on the water source and method of purification [20].

There is the need to note that, the property and composition of alum sludge produced from water treatment plant are unstable, this is due to the wide variation of treatment operation and raw materials used. This makes it differ in their characteristics from time to time even within the same treatment plant and different treatment plant [21].

2. Different Alternative to Disposal or Reuse of Water Treatment Plant Waste (Alum Sludge)

There has been a traditional way of disposing waste from water treatment plant which has drawn the attention of professionals, due to the unsafe way that this waste is disposed. This encouraged them to devise a means to dispose or reuse this waste without exposing the environment to danger, in this case, utilizing alum sludge as building and construction material, in geotechnics, in agricultural application and as a material in pottery. Though these applications have not been totally accepted, it will go a long way in saving cost of disposal and saving the environment from the danger involved in alum sludge disposal. The above mentioned means of disposal or category of reuse will be reviewed in this paper in other to bring to bear how much step has been taken in the past to put this waste (alum sludge) to a better use not limited to reduction in cost of building and construction materials when they are utilized in these aspects.

2.1. Alum Sludge Used in Building

2.1.1. Production of Brick

Clay has been used in the past for the production of building brick and constant demand of clay for production of brick has made this material expensive and source of clay is depreciating with time. However this historical material (brick) is known for its strength, low absorption and fire resistance properties. Alum sludge has been utilized in different procedures as fully or partially as substitute to clay in production of clay bricks, in a study done in Taiwan by Chiang et al, [22], lightweight bricks were produced by incorporating alum sludge and an agricultural waste 20% by weight, using heating method that gave a total organic matter burnout and the result indicates that, sludge from water treatment plant with agricultural waste would be beneficial to the environment and a good substitute to clay in clay brick production. Different clay proportions with sludge in clay brick production have been investigated, which involved the incorporation of sludge with ratio between 50 to 100 percent by weight. Each of the sludge clay sample was fired at different temperatures at 950 to 1100 °C and the properties of the produced brick were then determined. From the result that was obtained, it showed that, 50% was the best optimum sludge content to replace clay in production of good quality building brick [23-25]. Huang et al, [26] discussed that, 15% addition of alum sludge (water treatment plant waste) can be utilized in brick production to achieve a brick that can be compared to the commercial brick.

Johnson et al, [27], mixed water treatment sludge with excavated soil waste to make bricks and the study concluded that, 15% water treatment sludge was the maximum addition to achieve first degree brick. In a research conducted in Netherland by Feenstra et al, [28], the researchers successfully produced brick with clay and addition of sludge in which the assessment was based on "production technique and environmental performance (leaching behaviour)". Another study was done in the UK to investigate the combination of two waste materials for brick production; waterworks sludge and incinerated sewage sludge as partial replacement for the traditional brick raw material up to 5% replacement [29]. Sandeep [30] incorporated sludge in brick manufacturing and discussed that the method of conventional clay brick manufacturing is the same manufacturing procedure to produce sludge bricks and no additional requirement is needed in terms of production of alum sludge brick and the findings was encouraging. The research further showed that alum sludge brick can gain a crushing strength of 6.4N/mm² with an absorption of about 19.4% which passes all requirements of brick. Reddy and Venkata [31] reported in their research which investigated the durability of cast brick with industrial sludge and it was seen from the result that, earth brick can be replaced with sludge up to 40% by weight with satisfying strength. The compressive strength of brick without sludge and 5% of sludge were 11.7 and 17.6 MPa. They further explained that, the compressive strength decreased with the addition of sludge above 5% from 17.6 to 10.5Mpa. Meanwhile, the result of water absorption indicates that there was an increase in water absorption when sludge was added to the brick up to 10% by weight.

Hegazy et al [32], discussed the incorporation of water treatment sludge and rice husk ash (RHA) in clay bricks, where 25%, 50% and 75% by weight of waste from water treatment plant (alum sludge) were mixed in the production of construction brick. The bricks were fired in temperatures of about 900°C, 1000°C, 1100°C, and 1200°C and the compressive strengths were 5.7 to 6.8 MPa for the control brick and 2.82 to 7.84 MPa for RHA-Sludge brick. The result of water absorption test was 9.94% to 11.18% of the control brick and 17.41% to 73.33% for RHA-Sludge brick. It was concluded from the result that, 75% of additional sludge was the optimum sludge content to produce brick. Similar work has also been done to investigate the use of sludge waste in replacing clay for the manufacturing of bricks due to the fact that the sludge has same chemical component as the clay. Hegazy, [33] attempted using water treatment plant sludge to replace clay partially for brick making. Different replacement contents were employed; 50% and 70% and fired under the temperatures of 950, 1000 and 1100ºC. The result showed that less than 70% water treatment plant sludge replacement had an encouraging result which makes water treatment plant sludge a potential material to replace clay in brick production.

Meanwhile, Elangovan and Subramanian [34], reused water treatment plant sludge in production of clay brick and the findings proved that, alum sludge can be utilized as replacement of clay in the production of clay brick up to 20% and fired at a temperature of about 850^0 C for a load-bearing brick. This application is seen as an economical method of disposal since the generation of this waste (alum sludge) is inevitable. It was also concluded that, the presence of aluminium in alum sludge during firing improves its thermal insulation properties due to the total combustion of the organic matter that is present in the sludge (see Table 3).

Table 3. Compressive Strength of Brick Produced with Alum Sludge Replacing Clay

Specimen Designation	% Replacement					Temperature	Compressive strength (N/mm²)	Reference
	Alum sludge	Clay	Silica fume	zeolite	Water			
Control 1	0	100	-	-	-	850^0 C	9.10	Elangovan and Subramanian [34]
2	5	95	-	-	-		5.21	
3	10	90	-	-	-		3.42	
4	15	85	-	-	-		3.81	
5	20	80	-	-	-		3.26	
Control	0	100	0	0	30	1000^0 C	27	Faris and Aiban [35]
Series A	70	28	1	1	30		22.03	
Series B	70	26	2	2	30		25.2	
Series C	70	24	3	3	30		23.3	

* Faris and Aiban [35] used Ball Clay

Dassanayake et al, [10] reviewed that, the utilization of alum sludge in high content when producing brick for building purpose would result in decrease in strength and other properties that a good brick has but recommended that more studies need to be done to establish the suitable alum sludge content in brick production. Faris and Aiban [35] replaced ball clay with alum sludge blended with silica fume and zeolite to control deformation and cracking during firing. The result proved that alum sludge can be used as replacement of clay in an optimum content up to 70 % with 2% silica fume and 2% zeolite content for brick production purpose (see Table 3).

A ceramic brick was produced in a study by Torres et al, [36] using waste from water treatment plant up to 20% which proved that, this proportion of alum sludge in production of brick is reasonable for the manufacture of ceramic brick. An investigation was done in Ireland by Zhao et al [2] with the idea of producing a brick that would comply with the European and Irish standard using alum sludge as replacement of clay in different percentages: 0, 5, 10, 15, 20, 30, 40 by weight, subjected to different temperatures: 800, 1000, 1100, 1200^0 C for a quality clay brick. The product was evaluated using compressive strength and water absorption. The result indicates that, clay brick containing 5 percent alum sludge burned under 1100ºC and 20 percent alum sludge burned under 1200^0 C satisfied every standard set by Eurocode 6 (Design of Masonry Structure). It was then concluded that, high temperature may cause the brick to have a significant damage during burning process and increase in alum sludge content in the brick production reduced the strength and the weight of the brick. Cornwell, [37] stated that, the chemical and physical properties of alum sludge are similar to clay used in brick manufacturing and a potential replacement to clay in manufacturing of brick for sustainable building. Different research study has proven the benefit of reuse of the by-product in manufacturing of brick and the rapid growing market for building in most developing countries whereby employing alum sludge in brick making will be a better sustainable disposal option.

2.1.2. Production of Tiles

Due to the environmental risk attributed to disposal of alum sludge, different alternative means of disposal have been employed in order to eliminate this short coming in disposal. Alum sludge has been used in the production of tiles in different studies and the results have proved that, sludge is a good material in tiles manufacture. Tiles are regarded based on their structural soundness, physical and dimensional properties. Because of these features, a good tile is supposed to satisfy the required standard of both breaking strength and water absorption, and these are done to understand the durability of the tiles. Mishulovich and Evanko, [38] classified tiles with absorption rate lower than 0.5% as impervious, vitreous at absorption rate within 0.5 and 3%, semi-vitreous with water absorption rate within 3% to 7%, while water absorption above 7% as non-vitreous. This parameter is essential in knowing a quality tile for building purposes.

Alqam et al [39] conducted an experimental study on the use of alum sludge for paving tiles. Alum sludge was employed in different proportions of 10, 20, 30, 40 and 50% in tile manufacture. The tiles were then subjected to the breaking strength test and water absorption. The result proved that, all the tiles satisfied the required standard strength of 2.8 MPa minimum breaking strength (see Table 4) and the result of water absorption shows that, the tiles had an absorption rate above 7%, which makes it "non-vitreous".

Table 4. Braking Strength of Tiles Produced with Alum Sludge (Alqam et al [39])

Replacement (%)	Braking Strength (MPa)		
	14 days	21 days	28 days
0	2.55	3.20	3.40
10	2.50	3.10	3.35
20	2.45	2.90	3.15
30	2.05	2.10	2.95
40	1.80	1.90	2.90
50	1.55	1.70	2.40

Al-Hamati and Faris, [40] reused alum sludge in clay roof tiles, the aim was to derive a possible means of replacing clay (ball clay) with alum sludge in different proportions in roof tiles production. The result derived from this study proves that, alum sludge can be used as replacement to clay in clay-roof tiles production and at the same time serve as a solution to disposal problem facing alum sludge and also cut down on price of building material when reused adequately for building purposes.

2.2. Alum Sludge Used in Geotechnics

2.2.1. For Soil Stabilization

Soil stabilization is said to be a permanent chemical and physical modification of soil to better improve their physical properties. Stabilization also improves engineering properties of the soil, for instance, the soil shear strength, controlling the shrinkage of the soil, reducing absorption rate and improving the load bearing of the soil to support any engineering structure; be it bridge, building, road etc [41]. Due to settlement and instability of some unsound soil therefore, improvement of the engineering behaviour of soil is seen to be of high importance. However "soil stabilization can be used to improve different subgrade soil from granular materials to expensive clay and this have been in practice for long and the most popular binding agents used for this sole purpose are lime and cement. The said binding agents "strengthen and bind" weak soil" [41, 42]. However, the application of alum sludge in geotechnical and geoenvironment purposes will offer a wide range of advantages to both the treatment plant and the environment at large.

Balkaya, [43] studied the possible beneficial use of alum sludge in geotechnical and geoenvironment and concluded that, alum sludge, incorporated with zeolite, could be utilized in various geotechnical applications that need high shear strength due to the mechanical stability of these materials when subjected to direct shear test, compressibility and hydraulic conductivity test. Ayininuola and Ayodeji, [44] used alum sludge as a stabilizing agent to understand the engineering behaviour when applied in soil as a stabilizer. The alum sludge used in the study was fired under a temperature of 1120^0 C in different percentages of 0, 3, 5, 7, 10 and 15 applied to 3 different soils. The result proved that, the soil attained its highest maximum dry density and shear strength at 7% alum sludge content. The major reason for this behaviour was due to the chemical reaction (pozzolanic effect) of the alum sludge with the soil in the presence of moisture; thereby producing a cementitious property, improving the soil particle binding that gave rise to increase in the share strength of the soil. It was concluded that, the addition of 7% thermally treated alum sludge (under 1120^0 C) would improve the soil strength, while the increase of the alum sludge above 7% will reduce the strength of the soil.

However, Carvalho and Antas [45], suggested that, alum sludge should be at least thermally treated at temperature of about 450^0 C and ground before being used. Another study by Ronald and Donald [46] studied the possibility of using sludge to stabilize sub-base material in road works and the findings revealed that, within 0.5 to 3 percent sludge addition will result in significant increase in strength in 7 days (using unconfined compressive strength test) when compared to the reference mix. Meanwhile, a high increase will result in decrease in strength due to the increase in fine material in the mix when alum sludge was increased in the mix.

2.3. Alum Sludge Used in Agriculture

2.3.1. As Soil Fertilizer

The utilization of alum sludge in agriculture is another effective manner for a sustainable disposal, which in turn benefit the environment and crop production. Numerous studies have been done on the use of sludge as soil amendment and as fertilizer, while other investigations into the impact of sludge on soil have also been reported in the past [21, 47, 48, 49]. Though, Elliot and Dempsey [50] discussed that, alum sludge may be used to modify the PH and water retention capacity of soil, notwithstanding the fact that they have little fertilizing value, but due to the substantial amount of organic matter and micro nutrient present in the alum sludge, it could be used to improve soil organic matter and level of nutrient in the soil not limited to improving soil structure and water retention [51-53]. Kluezka et al [48] suggested that, soil with any sludge should meet some specific standards, whereby they must not have a high content of heavy metal.

In an investigation by Dayton and Basta, [54] the result shows that, the application of alum sludge to soil in high content above 10 percent will result in the reduction of crop yield and available phosphorus. Several investigations have proved that, appropriate application of this by-product will not pose any negative effect on the soil properties or on plant when they are used as soil fertilizer with appropriate sludge content. However, for these facts to be justified, there should be an appropriate approach towards its short term and long term effects on the crop [9, 55-57]. Alum sludge has been used on acidic soil but the result shows that it is safe to apply alum sludge on acidic soil knowing that it is advantageous for plant growth [58].

Furthermore, it has been seen from some reviewed studies, how the addition of alum sludge have improved soil PH, good crop growth and other qualities [53, 59]. Some other studies had also underscored some negative impacts of this sludge on some plant [60, 61]. Thus, applying different by-product or residual materials based on their physical and chemical properties will reduce the negative effect on soil and plant growth, and this proper application of sludge to soil will tend to produce a good result [9, 62]. This application was proved reliable when Goldbold et al, [63] utilized sludge with lime and it was found that, this combination showed a significant advantage to the growth of plant, while there was more or less no leaching of aluminium from soil that was amended by alum sludge for agricultural purpose. Lin and Green [21], carried out a study on corn and soybean, and they found out that, alum sludge could be applied to agricultural soil. Novak et al [64] investigated the effect of aluminium content in alum sludge on the growth of corn and wheat after alum sludge was introduced to the soil. The result showed that, alum sludge application to Agricultural soil or "forestland" at 1.5 to 2.5 percent loading weight had no negative effect on the growth of these plants.

Similar investigation was done in Australia by Rigby et al, [65] to study the application of alum sludge to agricultural soil, and it was found that, alum sludge gives the plant the necessary "nitrogen" it needs and adequate plant nutrient for the growth of wheat. This shows that, the use of alum sludge for soil enhancement is harmless and of benefit to the growth of some plants. Alum sludge utilized in soil improvement as reported in several literature pose no negative influence in plant growth and nutrient content, although proper application to soil is needed to avoid the sludge having a negative effect to plant as long as its amount of application is feasible. It was also noted that, this form of reuse can be a sustainable form of disposal.

2.4. Alum Sludge used in Concrete

2.4.1. As Fine Aggregate

Thaniya, [66] conducted experimental investigation on the utilization of water treatment plant sludge replacing fine aggregate in production of concrete block, and evaluation of the cost savings when this waste is utilized as an aggregate in concrete. Different concrete mixtures was opted in percentages of 10 and 20, which were the best sludge contents in replacing fine aggregate for the production of non-load bearing hollow concrete blocks, with cost reduction of up to 0.64 baht to 1.05 baht per block. However, the addition of 50% will be more economical, with reduction in cost of block up to 2.35 baht for each block. The compressive strength result that was reported shows that, all the percentage replacements with alum sludge 10, 20, 30, 40 and 50 passed the minimum requirement for compressive strength for non-load bearing concrete block, according to the Thai Industrial Standards (TIS 109) as shown in Table 5.

Table 5. Strength and Cost Comparison of Concrete Block with Alum Sludge Replacing Fine Aggregate (Thaniya, [66])

Sample No	Compressive Strength (ksc)				Production Cost for Hollow Concrete Block (baht/block)
	Sludge content	7 days	14 days	28 days	
Conventional Hollow Concrete Block	-	-	-	-	5.73
Mix 1	10	83.74	82.58	84.90	5.09
Mix 2	20	48.85	50.01	52.35	4.68
Mix 3	30	38.38	41.87	43.05	4.25
Mix 4	40	34.89	73.22	73.23	3.83
Mix 5	50	25.59	26.75	27.92	3.38

While Zamora et al [67] carried out an investigation using sludge from Loss Berros drinking water facility (water treatment plant) in Mexico as replacement of fine aggregate in mortar. The experimental work was divided into stages "sampling and characterization of the water treatment sludge, production of mortar specimen with water treatment sludge in different proportions and comparison of the result from compressive strength and dry contraction values of the various sample with the Mexican technical criteria to design and building masonry. The results obtained from the characterization of the sludge indicates that water treatment sludge can be used as fine aggregate in mortar because the sludge comprises of 46.83% of sand. While the mechanical properties of the sample shows that addition of treatment plant sludge up to 75% gave a significant improvement in compressive strength, the binary blending of sludge/mortar (90 to 10%) had a comparable strength in both curing age with the sample made 100% mortar. For technical economic feasibility higher sludge content of 90% was proposed to be an ideal content due to the huge volume of sludge that will be utilized in production of mortar. In the case of shrinkage 90% and 75% showed a higher shrinkage value than its counterparts and this was attributed to the high moisture content of the sludge, however it was then advised that a proper drying is necessary for a better shrinkage value.

2.4.2. As Light weight Aggregate Material

Alum sludge has been used in different concrete works; one of which is, as aggregate. This application has generated results that show that, alum sludge as aggregate is feasible and a sustainable manner of disposal. Different studies have used alum sludge as aggregate. In a study conducted by Hoppen et al, [68] on use of centrifuged water treatment plant sludge in Portland cement concrete matrix to reduce environmental impact, centrifuged water treatment plant sludge partially replaced aggregates and cement. They produced a normal concrete and 4 other concrete mix with sludge. Two mixes had 4 and 8% sludge contents that where analyzed in different test methods and properties; compressive strength, physiochemical analysis, X ray fluorescence, Thermogravimetric analysis, and X ray diffraction. The results gathered show that, sludge content of 4 and 8% resulted in significant strength value higher than 27 MPa at 28 day curing age and, this is a promising outcome for the use of sludge as new material in concrete. Thus, due to lack of knowledge on the Behaviour of this sludge on long-time performance, its application will be subjected to a non-structural concrete like concrete cover for pit, residential floors and sidewalks, blocks and sealing plates etc.

Haung and Wang, [69] anticipated a method of manufacture light-weight aggregate from 10 different water treatment plant in Taiwan and with the method that was applied, they were able to produce a light weight aggregate which met the standard specification for light weight aggregate as required by ASTM C330. Different laboratory experiment was employed to achieve this result, which included two stages. First stage assessed the feasibility of manufacturing light-weight aggregate from water treatment sludge and their thermal cycle. The second stage studied the particle density of aggregate. The compressive strength of the light weight alum sludge concrete where found to be higher than the minimum strength requirement as specified in ASTM C330. The sludge sample from Shin-Zu, Lin-Nai, Pin-Din, Cau-Tang and Tzien-Chin Lake treatment plant was found to be suitable for the production of structural and nonstructural light-weight aggregate concrete. This method of reuse, rather than disposal in the environment, gave the hope that, this waste can still be put to good use for the purpose of saving the environment and at the same manner reducing the cost of concrete material and reduce the rate of consuming natural aggregate (see Table 6).

Another study by Nur Quraatu'Aini and Hamid, [70] on Mechanical Properties of Lightweight alum sludge aggregate in concrete, with the aim of utilizing alum sludge, to partially replace natural granite in percentages of 0, 5, and 10 by mass, with water cement ratio of about 0.65 to produce a lightweight aggregate concrete. The alum sludge water absorption rate was 22.06%. They recorded a decrease in compressive strength, slump, density and split tensile strength of the lightweight alum sludge aggregate concrete, as the alum sludge content increased. The result of density for 10% alum sludge aggregate was 2185.3 kg/m^3, with compressive strength decreasing from 25.6 MPa (control) to 16.7 MPa and 14.2 MPa in percentage replacements of alum sludge at 0, 5 and 10 respectively, while for the result of tensile strength, the control sample had a decrease of 1.53 MPa at replacement of 10% alum sludge aggregate. However, while in the case of flexural strength, there was a significant increase from 5.42 MPa control sample to 5.55 MPa and 5.63 MPa in percentage replacements of alum sludge at 0.5 and 10 respectively (see Table 6).

Table 6. Compressive strength of light-weight aggregate produced with Alum sludge

Sample	Alum sludge Replacement		Water content		Compressive strength (MPa)		Reference
	(%)	(Kg/m³)	W/C	(Kg/m³)	7 days	28 Days	
L40	-	550	0.40	168	-	43.2	Haung and Wang, [69]
L45	-	562	0.45	168	-	39.9	
L50	-	569	0.50	168	-	39.0	
L55	-	566	0.55	175	-	33.8	
L60	-	523	0.60	175	-	29.0	
L65	-	528	0.65	175	-	24.8	
Control	0	0	0.65	190	18.5	25.6	Nur Quraatu'Aini and Hamid, [70]
5% Sludge	5	56.8	0.65	190	14.5	16.7	
10% Sludge	10	113.5	0.65	190	12.7	14.2	

A similar work was done by Sales et al, [71]. Studied on combination of two waste materials to produce a lightweight concrete composite with cement: sand: composite: water mass of ratios 1:2.5:0.67:0.6. The result obtained shows a water absorption rate of 8.8%, axial compressive strength of 11.1 MPa, with diametric tensile strength of 1.2 MPa and specific mass of 1.847 kg/m^3. They concluded that, the mechanical properties demonstrated in this study prove that, the two-waste material is suitable for non-structural elements.

Verrelli, [72] stated that, proper drying of alum sludge waste from water treatment plant is a beneficial reuse as aggregate in concrete and for filling in road construction, this is due to the fact that they form insoluble rock and become inactive (soft gravel). A self-consolidated light weight concrete was produced in an investigation by Choa-Lung et al, [73] by producing a light weight aggregate using sludge and treated (incinerated) fly ash. The result revealed that, sludge and treated fly ash content must be less than 30%, having a light weight specific gravity of about 0.88-1.69 g/cm^3 which will achieve a crushing strength of about 13.43 MPa.

Sales et al [74] studied the production of light-weight concrete produced by different waste product (sawdust and water treatment plant sludge). They determined the thermal properties and the environmental effect of future residue of the said product. Two different concrete were prepared; a conventional concrete with cement: sand: crushed stone: (1:4.8:5.8:0.8 in mass), a lightweight composition dosed of cement: sand: composite: water (1:2.5:0.67:0.6 in mass) "hot wire parallel technique" was used to study the thermal property while the environmental impact was determined by the Brazilian Association of Technical Standards – ABNT procedure. The result showed that, the lightweight concrete with waste had 1894 W/m K of thermal conductivity which was lower than the conventional concrete with thermal conductivity of 2465 W/m K in. Thus, it was reported that, the concrete produced with this waste material can be utilized in building and construction and at the same time reduce environmental pollution caused by ill manner of disposal by utilizing them as an aggregate in concrete.

2.4.3. Alum Sludge as Cement Replacement

Water treatment plant waste (alum sludge) has also taken a significant stand as a substitute in cement. There have been obvious proofs from several studies in the past that, alum sludge can be used as partial replacement to cement in concrete production more especially when it is treated thermally, forming cement-like property according to ASTM C618, [75]. Ing, [76] experimentally explored the reuse of water treatment plant waste. It was highlighted that, if alum sludge can be recovered in the water treatment, it can also be utilized in the production of cement and other raw materials. Thereby, freely utilized as an admixture for cement production. Haider, et.al [13] studied the use of water treatment plant sludge to replace cement partially. In the study splitting tensile strength, compressive strength and flexural strength of concrete was evaluated and cured in different days (3, 7, 18 and 28). A chemical test was conducted on the sludge before it was used as cement replacement in other to establish the similarities in their chemical content. The sludge replaced cement in percentages of 0, 6, 9, 12 and 15% in weight of cement and with a water cement ratio of 0.33. From the result, it was observed that, 6% addition of sludge was higher in strength due to the presence of ferric oxide alumina and silica in both sludge and cement.

Meanwhile, Goncalves et al., [77] carried out a study on the use of alum sludge after it had been conditioned thermally in temperature at about 105ºC, 450ºC, 700ºC and 850ºC. It was reported that, alum sludge can be employed in cement mortar in temperature above 105ºC due to the fact that, oven dried alum sludge at 105C slows down the setting time and hardening time of cement paste and mortar. It was suggested that, alum sludge should be at least thermally treated up to 450C and above to make it suitable for cement replacement in mortar which will help to improve the consistency of the thermally treated alum sludge and improve the consistency of the mortar. Rodríguez et al [15] found out that, water treatment plant sludge has a similar chemical composition and particle size (after crushing) with Portland cement which makes it an ideal material for the cement industry. They made mortar with 10 to 30 percent alum sludge which shows a mechanical strength that is lower than the control sample with a decline in slump. It was further explain from the findings that "the properties of sludge from drinking water treatment plant in majority depend on chemical compositions, which is essential for its potential reuse". Therefore the chemical property of alum sludge is what makes it an ideal prospective material to replace cement partially. Some study have shown that, the percentage addition or replacement of cement with alum sludge should be taken into account due to the fact that, high replacement will result in reduction in strength of the concrete.

Pan et al [78] reported that, the utilization of alum sludge in cement clinker could better the concrete without compromising the integrity of the concrete; long term strength and durability. Alum sludge from water treatment plant have been extensively utilized as ingredient to cement in concrete and mortar which most study recorded high replacement content. Vaishali and Niragi, [79] studied the utilization of by-product from water treatment plant (alum sludge) and another industrial by-product (fly ash) for mortar and cured in different method (Hot curing and lime water curing) and compressive strength test of sludge mixed with fly ash and cement was used to evaluate its potential reuse. The findings from this study revealed that, the strength of mortar decreased when alum sludge content decreased and fly ash content increased.

2.5. Alum Sludge used in Pottery

2.5.1. In Production of Flower Pot

Different applications towards reusing alum sludge have been highly established in different studies, and those applications were feasible in areas they were applied to. There have been an attempt to use alum sludge in pottery making. Faris and Earn [35] employed a sustainable way towards utilizing alum sludge in order to reduce the future accumulation of this waste in the environment. The study aimed at producing pot with thermally treated alum sludge that was burnt under temperatures of about 1100 and 1200ºC. Alum sludge was added in different proportions of 50, 60, 70, 75, 85, 90 and 100% and fine granular silicon dioxide of percentages, 50, 40, 30, 25, 15, 10 and 0% to produce flower pot and at the same time making significant impact towards a sustainable environment. The result from this study showed that, alum sludge up to 85% content can be used in manufacturing flower pot. Meanwhile, addition of alum sludge above 85% failed and deformed when the pot is still in the mold forming stage.

3. Conclusions

A review of different alternative means of disposing water treatment plant sludge (alum sludge) for a sustainable environment has been described. In the majority of works described herein, alum sludge has been used mainly in building as material for brick and tiles manufacturing, in geotechnics as soil stabilizer, in construction as cement and aggregate and in agriculture as soil fertilizer due to its richness in aluminium. Not much work has been done on it in concrete as a fine aggregate material in concrete (in different sludge condition). This might be probably due to its reactive properties when treated. However the physical properties are somewhat similar to sand, it can be applied to concrete as replacement of fine aggregate. From the preceding sections, the following conclusions can be made:

- The use of alum sludge in manufacturing of brick has been explored and in studies reviewed, it is seen that, utilization of this waste material in building purposes (brick and tiles) will contribute in minimizing the cost of disposal and the existing problem with disposing waste in the environment. Notwithstanding that, the engineering properties of the end product should be rigorously studied to understand its durability and long-time effect when they are used to produce this green building materials and research is still needed in this area.

- The use of alum sludge in concrete has been studied (used in cement production and replacement of cement in concrete, used in concrete as coarse aggregate replacement) but not fully explored as replacement of fine aggregate in concrete. The past literature lack information on the condition of the sludge before used as replacement of fine aggregate in mortar or concrete. However there is need to further carryout study on alum sludge beyond 28day to understand its long-term behaviour and a proper proportion of concrete mixed with alum sludge needs to be established for a sustainable concrete structure, thus, in some conditions, it may be combined with other types of waste material as filler in concrete or mortar. The behaviour or properties under these conditions were not fully understood and need further study to establish its feasibility.

- The physical and chemical composition of alum sludge varies from treatment method to treatment method and from treatment plant to treatment plant, so there is always a need to establish its physical and chemical properties before it is applied or reused in any of the reuse option. Whereby, establishing a possible standard for each reuse option reviewed in this study is rather difficult.

- Utilization of alum sludge in land application as soil low grade fertilizer will be one of the most economical options of sludge disposal. This practice has shown significant values in improving some of the soil properties that promote plant growth, having known that this reuse option will help in reduction of future pileup of this waste material. More studies need to be conducted to establish the rate of conditioning that will be suitable for its reuse so as to improve soil fertility.

- Application of alum sludge, as soil stabilizer, is another beneficial option to dispose sludge waste and at the same time improve the soil properties to a more stable soil, however, the reuse of waste from water treatment plant will drastically eliminate cost of disposal, reduce future pile-up of waste disposed in the environment and eliminate any negative impact associated with the present disposal practices.

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