

REUSE OF ALUM SLUDGE IN CONSTRUCTION MATERIALS AND CONCRETE WORKS: A GENERAL OVERVIEW

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ABSTRACT

One of the global problems that is associated with production of potable water is alum sludge when aluminum sulfate ($\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O}$) is used as a coagulant. The quantities of over 2.0 million tons of water treatment sludge or residue (WTS) is produced annually by the water operators across Malaysia [1]. It is important to realize that the generation of alum sludge may remain unavoidable in the current processing of drinking water treatment technologies. To comply of disposal of waste standards set by the local/federal authority makes researchers looking for alternative construction materials as a substitute to traditional materials like cement, ceramic, bricks, tiles and aggregates in manner of reducing the impact of these waste on environment. Series of researches aimed to beneficial reuse in an effort to close the gap between enormous amounts of alum sludge and relieve pollution. However, the most common methods of disposal still depend on land application, reuse for agricultural purposes and attempts to reuse it as a coagulant in the primary treatment of sewage. One of the possibilities for the alum sludge is reuse it in the construction sector. The construction sector consumes huge volume of materials every year which gives construction sector potential to reuse alum sludge in making constructional material and concrete works. Thus, there is a need to do more laboratory experiments to determine maximum percentage that could be used as substitution on construction material. Thereby, the growing problem of alum sludge disposal can be alleviated if new disposal options other than of landfill can be found. This paper presents a review of available literature on attempts at beneficial reuses of drinking water treatment sludge as building and construction materials and concrete works and also studied the behavior at fresh and hardened state.

Keywords:

Alum sludge, Construction, Materials, Brick, Disposal

INTRODUCTION

Aluminum sulfate ($\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O}$) is the most commonly used coagulant in drinking water treatment plants and as a result, tons of aluminum hydroxide –containing sludge is unsafely disposed to the open environment daily. Alum sludge as waste materials are mostly sent to landfill. WTS refers to water treatment sludge. It also refers to water treatment residual [2], drinking water sludge [3], waterworks sludge [4] and alum derived water treatment sludge [5]. Figure 1 shows process of potable water treatment and process of sludge, starting with raw water, ending with drinking water and dry sludge.

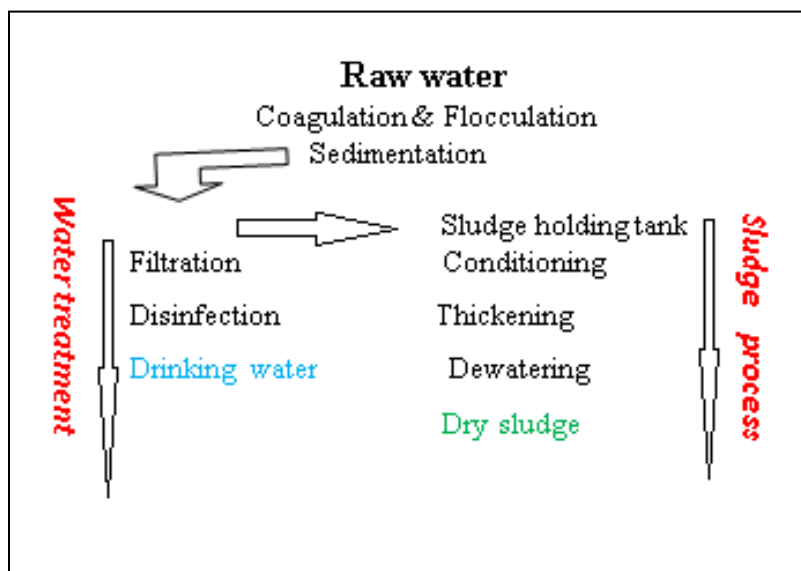


Figure 1: Process of Potable Water Treatment and Process of Sludge

The quantities of over 2.0 million tons of water treatment sludge or residue (WTS) is produced annually by the water operators across Malaysia. Due to the cost of finding new landfill (scarcity land) and the needs for sustainable best practices, sludge disposal becomes a global problem; it is a necessity to look for alternative reuse of sludge. However, the main concern lies in reuse of physical and chemical composition and toxicity. Aluminum can be toxic in aquatic system, but only when the pH of sludge is low enough that the solubility of aluminum hydroxide is high. There are so many potentially harmful substances found in alum sludge particularly heavy metals. Many are known to cause cancer and other diseases. For example Table 1 shows the main component of alum sludge derived from different drinking water treatment plants.

Table 1: Chemical composition and physical test of different samples from different plants of alum sludge by X-ray fluorescence (XRF)

CHEMICAL ANALYSIS %						PHYSICAL TEST					
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O ₃	K ₂ O	P ₂ O ₃	LiO	Specific gravity	Moisture content
42.32	35.03	4.94	0.13	0.30	0.14	0.10	1.87	0.26	11.80	2.34	0.85
29.63	17.57	5.18	11.85	2.15	0.34	6.09	2.85	0.92	22.70	-	-
54.70	24.10	6.90	0.50	1.30	0.60	0.60	3.20	-	-	-	0.13
64.30	21.20	10.40	2.05	1.06	-	0.17	0.79	-	08.04	-	-
29.60	28.02	8.05	1.48	0.38	-	-	0.84	-	22.60	-	19.97
43.12	9	5.26	5.56	0.85	1.49	0.52	0.26	-	26.79	-	-
33.23	15.97	4.94	0.64	0.63	-	0.42	0.43	0.40	26.10	-	-
22.3	31.98	4.70	38.3	2.70	0.70	0.50	1.00	-	-	-	0.75
9.30	26.00	23.3	27.2	1.31	0.33	-	-	-	38.00	-	-
27.6	0.26	26.4	33.06	0.53	-	-	0.33	-	-	-	76.43
	6.50										

These results of chemical composition and physical test vary from country to country depending on water treatment plant resource. Dry alum sludge have been utilised as a component in the manufacture of several materials such as concrete, cement mortars, clay materials and fired ceramic products (e.g. bricks, pipes and tiles), as geotechnical works material, as a potential material for use in fertilizing the forest and agriculture and for phosphorus (P) removal from aqueous solutions [6].

ALUM SLUDGE, HEALTH AND ENVIRONMENTALS EFFECTS

Influences of alum sludge resulting from the water treatment on environment can also leads to damage to human health. There are some studies that confirm this correlation presence of sludge with Alzheimer's disease. Some of these effects may occur immediately and others may take some time to impact (with a cumulative effect), therefore, health effects generally associated with environmental pollution that includes the use of chemicals should be examined and tested for the potential contamination of the environment. Alum sludge is a by- product of the treatment plants that use aluminum as a coagulant. AS is as scheduled waste material governed by stringent regulations on waste management by the department of environment (DOE) [7], and must be disposed accordingly. In Malaysia, more than 2.0 million tons of water treatment sludge is produced annually by the water operators throughout the country. The increasing cost of landfill (limited available land), the needs for sustainable best practices, and the increasing demand for high quality of drinking water causes the daily vast amount production of alum sludge that may remain unavoidable. Thus, the research that involves using alum sludge in construction and concrete works contribute to reduce the environmental impact. Increasing amount of alum sludge as a waste is not only difficult to dispose but they also cause serious health hazards. Therefore, efforts are to be made for controlling pollution arising out of the disposal of alum sludge by conversion of these unwanted wastes into utilizable raw materials in construction sector in beneficial uses.

RESEARCH ON REUSE SLUDGE TO PRODUCE BRICKS

Due to the demand of bricks as building material, studies have investigated the mixing incinerated sludge ash into fired clay bricks. It is important to realize that the compressive strength and shrinkage of new made brick from alum sludge are the most two properties. Several experiments using alum sludge in brick making had been reported in many countries. Patricia et al. conducted ceramic brick manufacturing from drinking water treatment plants [8]. They carried out experiments to get a sand replacement by 10% of sludge and this percentage is considered appropriate for ceramic brick. It indicated an interesting potential for reuse alum sludge as construction material. Elangovan and Subramanian produced a publication that deals with reuse of alum sludge in clay brick manufacturing. Alum sludge with commercial local clay were blended in various proportions and sintered at different temperature to produce clay-sludge brick. Their result indicated that alum sludge could be used as partial substitute in commercial clay bricks to maximum of 20% without compromising the strength of brick [9]. Dunster and Wilson conducted experiments on water treatment residues as a clay replacement and colorant in facing bricks. They also found that the results from laboratory trials demonstrated that water treatment residue could be used as a colorant and partial clay replacement in brick [10]. Badr El-Din et al. presented some results from brick manufacturing by mixing water treatment sludge with rice husk ash. They were able to measure the optimum sludge addition to produce brick from sludge which was 75%. Their results based on the

experimental program and the produced brick obeyed the required values of compressive strength, water absorption and efflorescence assigned by the standard specifications [11]. Chiang et al. investigated experimentally light weight bricks manufactured from water treatment plant sludge and evaluated the environmental safety of sintered leaching produce concentration [12]. Mohammed et al. indicated that sludge could be mix as partial substitute for clay in brick manufacturing and they also found the best of replacement proportion of sludge from clay is 50% to produce sludge- brick-mixture [13]. Babatunde and Zhao produced a publication that deals with a comprehensive review of available literature on attempts at beneficial reuses of water treatment plants. The study investigated the percentage of incorporation when the sludge is substitute into the brick at different levels by many studies that studies that were reported [14]. Quesada et al. carried out ceramic brick manufacturing from various industrial such as urban sewage sludge, bagasse, sludge from the brewing industry, olive mill wastewater and coffee grained residues. These wastes were blended with clay to produce bricks. Because of the compressive strength of ceramic materials is the most important engineering quality index for using as building materials. The results indicated that the waste addition decreased the compressive strength of the clay but still at range of standard specifications [15]. Cusido produced paper that showed some leach ability and toxicity test (outgassing and off gassing) which demonstrated the environmental compatibility of these ceramic products to be used in building construction and for this case their results showed the sludge addition ranging from 5% to 25% in weight content of sludge included in structural ceramics seems to have no influence on the environmental characteristics of these products [16]. Vicenza et al. produced a publication on evaluation of alum sludge as raw material for ceramic products. The percentage (10 – 30) % weight of alum sludge was added to clay and the results showed properties comparable to similar commercial products. The findings lead to potential for reusing alum sludge as raw material for ceramic products [17]. Kung et al. tried to reduce the density of the brick by sintering mixes of dewatered treatment sludge with rice husk with 0, 5, 10, 20, 25% by weight. The samples produced from sintering up to 11000C low bulk density and obeyed to the standards specifications [18]. Raut et al. presented some results from many researchers that used various waste materials in different proportions and also adopted various methodologies to produce bricks and showed the results in table which contained design and development of waste- create bricks [19]. Liew et al. had undertaken the study on production of bricks from sewage sludge. They indicated that the sludge proportion is a key factor in determining the brick quality which depends on brick shrinkage, bulk density, compressive strength and loss on ignition. The percentage replacement of dried sludge was 10 to 40%. Their results complied with standard specification of bricks. The percentage up to 40% demonstrated that sludge can be constructively and successfully incorporated into brick. According to findings, percentage of sludge up to 40 wt. % in clay follows the specified requirements for clay brick could be used for general wall construction [20]. Lianyang tried to present a state – of the – art review of research on utilization of waste materials to produce bricks. The different methods to produce bricks from different waste including sludge lead the researcher to make study into three categories based on the method (firing, cementing and geopolymerization) [21]. Kevin et al. investigated the potential for reusing desalination sludge by using it as a partial replacement material in clay bricks. They focused on compressive strength and initial rate of absorption as well as the potential to efflorescence and lime pitting. The bricks were made by mixing incinerated sludge ash into clay at different ratios corresponding to 0%, 10%, 20%, 30% and 40% dried desalination sludge content by weight. The results showed that the compressive strength decreased with increasing dried desalination sludge could be produced, but the produced bricks were very fragile. It is possible to use in non-load-bearing walls [22]. Silva and Fungaro tried to evaluate the feasibility of the use of the

sludge from water treatment plant in Brazil with coal ashes produced by burning of coal in coal-fired power station. They found that none of the bricks produced in the studies conditions has obeyed Brazilian Standard Specification for quality of compressive strength [23]. Krishna et al. identified the possibilities of using the sludge obtained from different plant in India as a brick material. They were studies on the engineering properties by conducting tests on brick specimens of different percentage of changing clay by sludge. The results showed that the absorption increased by 18% when percentage of sludge increased beyond 60%. At the same time the compressive strength of bricks decreased by 10.85%. The researcher tried to solve this decreasing in compressive strength by addition of cement, fly ash and sisal fibers, the compressive strength increased by 30% and the properties of the bricks improved. This manner can open an appropriate technology to use sludge without losing the original engineering properties of bricks [24]. Anyakora conducted a laboratory experiment for the use sludge generated from purification process. The results demonstrated that the sludge could be used as a colorant and clay supplement in brick making. The percentage of exchanging clay by sludge was 0, 5, 10, 15, and 20 of the total weight of sludge. Brick was fired in a heat controlled furnace at evaluated temperature of 850 °C, 900 °C, 950 °C, 1000 °C, and 1050 °C. The percentage up to 20% can be applied into brick without losing its plastic behavior and environmental sustainability [25].

RESEARCH ON REUSE SLUDGE IN CEMENT MORTAR AND CONCRETE WORKS

The increased importance of the reuse of different types of wastes becomes very useful to reduce the environmental impact. Alum sludge as a waste material can be used in cement manufacture by the reuse sludge as cement partial.

Haider et al. studied on high performance concrete using alum sludge in concrete mixes. They investigated using alum sludge from 0 to 15% by weight of cement. Viscocrete-2044 as superplasticizer was used to improve the workability at constant w/c ratio. Compressive strength of concrete with 6% alum sludge increases with all ages. Density of alum sludge concrete mix decreases as the replacement levels increases but it was opposite with workability [26]. Hanim and Abdull here conducted various tests on sludge produced from drinking water treatment plant had been performed in term of structural identity, leach ability of heavy metals, chemical composition and other properties that are important for its potential reuse and safe disposal into the environment. They were able to get their results of its physical and chemical properties [27].

Ing published a paper that addresses the recovery of alum sludge in the water treatment plant. He mentioned that alum sludge can also be used as secondary raw materials [28]. For brevity, only statement is given here, while full details were given by Arlindo et al. incorporation of sludge from a water treatment plant to produce cement mortar. Mortar were prepared with 5%,10% and 20% replacement of the mass cement by dewatered sludge and by sludge after thermal treatment at 105 °C, 45 °C and 85 °C. Tests conducted on these concrete demonstrated that only with temperature at least 450 °C and above can incorporate alum sludge with mortar [29]. Maha et al. recommended the percentage replacement up to 50% of of water treatment sludge to replace cement in production of paving tiles for external use. The replacement of sludge was 10% to 50% from cement by weight. All the results obtained showed breaking strength of 2.8 MPA above of the minimum breaking strength required of the standard specification [30]. Yen et al. studied the replacement of clay, lime stone, sand and iron slag by drinking water treatment plant sludge, marble sludge and basic oxygen furnace sludge respectively, as a raw material for the production of cement in order to produce eco-cement. There is considerable replacement up to 50% of lime stone as well as other materials. Uses of

three wastes sludge succeed in the consideration of benefits for conventional cement raw materials. Likewise, a considerable increase in the hydration of eco-cement paste due to the mass amount of Ca(OH)_2 [31].

Zamora evaluated of using drinking water treatment sludge as a supplementary cementations and sand substitute. The maximum replacement of sludge was as 90% by weight. They aimed to study the mechanical performance when using sludge of water treatment plant in USA also [32]; Rodríguez et al. investigated the reuse of drinking water treatment plant sludge as an addition for the cement industry. They found that the drinking water treatment plant sludge has a chemical composition and a particle size similar to Portland cement. The mortars that were made with 10 to 30% atomized sludge showed lower mechanical strength than the control cement and decline in slump. The results indicated that the properties of drinking water treatment in majority depend on chemical compositions that are important for its potential reuse [33].

Sahu et al. investigated the feasibility of using drinking water treatment plant residue with fly ash to prepare mortar. Testing on compressive strength of the cement mortar made by sludge from drinking water treatment plant, fly ash from the thermal power plant and cement with or without admixture was carried out. The results showed, the highest strength was 0.47 kN/mm^2 at 1% gypsum content due to the influence of gypsum on the strength of mortar. The higher strength of 2.84 kN/mm^2 and 2.05 kN/mm^2 was observed for hot curing and lime water curing, respectively. The lower strength was detected by decreasing the content of sludge and increasing the fly ash content [34]. Reis and Cordeiro proposed a solution for sludge generated by chemical, physical and biological steps to treat water for public supply. A solution for this sludge is used after removing its water, recycling the water removed and using the dried sludge in other activities. Possible uses as a raw material in construction sector were studied. They could be developing a natural system of dewatering. In this technology the sludge is stored in large unit which are shaped as a big bag. It is made of geotextile woven high strength polypropylene. By filling this unit and decreasing the percentage of liquid of the sludge it is considered as a natural thermal drying which may be open. This suggests possibilities for novel investigative studies with natural thermal drying. Finally, the dewatering sludge can be used [35].

Varela et al. studied the utilization of several industrial wastes to be reused in different stages of cement making. They examined wastes from a drinking water treatment plant sludge (DWTP), sewage sludge (SS) and a spent activated carbon. Both DWTP sludge and sewage can be used as a raw material in cement making. They noted that the unsuitability of atomized DWTP sludge and SS as components of blended cements has been demonstrated [36]. Haider et al. used nondestructive testing of concrete to estimate compressive strength of high performance concrete with thermally curing sludge multiple blended high performance concrete (HPC). The wastes used for HPC were AAS, silica fume (SF), ground granulated blast furnace slag (GGBF) and palm oil fuel ash (POFA). The results indicated a very positive exponential relationship between compressive strength and ultrasonic pulse velocity for binary and ternary blends of HPC mixture, with coefficient correlation (R^2) equal to 0.889. Concrete quality is generally assessed by measuring its cube (or cylinder) crushing strength. Instead of expressing the strength in terms of cube strength; it is preferable to obtain a direct relation between the strength of a structural member and the pulse velocity, whenever this is possible [37].

Choa tried to produce self-consolidating light weight concrete by manufacturing light weight aggregate from municipal solid waste incinerator fly ash. The results showed that the maximum content of municipal solid waste incinerator fly ash should be less than 30% light weight specific gravity in the range of $0.88\text{-}1.69 \text{ g/cm}^3$ and crushing strength as high as 13.43 MPa can be produced [38]. Thniya Kaaosol examined experimentally reuse water treatment

sludge from water treatment plant as fine aggregates. 10% and 20% of water treatment sludge ratio in a mixture to make a hollow load bearing concrete block can reduce the cost and 50% of water treatment sludge ratio in mixture to make a hollow non-load bearing concrete block and also to reduce the cost. This could be a profitable disposal alternative in the future and will be of the highest value possible for the foreseeable future [39].

David indicates that when aluminum water treatment plants sludge is dried, they form essentially insoluble rocks and are inert (like gravel, though not strong / hard). With these qualities, dried aluminum sludge has been used as road fill or road grade or aggregate. Dried aluminum sludge can also be poured, and so have use for back-filling beneath fiberglass swimming pools [40]. Kazberuk discussed the incineration of the sludge from water treatment plants. He considered that incineration of sludge is not a final solution since it generates ash that must be disposal of and proposed to use the ash derived from sludge as light weight aggregate. By studying the influence on mechanical and physical properties of concrete with ash can determine the maximum acceptable replacement which was 25% of natural aggregate volume. These results confirmed the feasibility of using sludge light weight aggregate to produce light weight aggregate concrete and creating a go towards new studies to get commercial sludge [41].

Lee et al. studied on nature of particle size of dried sludge and the effects of these ultrafine particles (smaller than 3.2 μm) on concrete performance. the reasons that motivated them to find alternative for the reuse are the limited land available for sludge disposal and environmental impact to overcome the effects of too many fine of particles on workability, water demand, compressive strength and drying shrinkage. They tried to use solidification agents and they succeeded in that by choosing a suitable quantity of solidification agent. They contributed to reduce the problem associated with high water demand of sludge and also involved in the hardening process. By this way, the use of sludge in concrete mix could be considered a trend to the solution and needs more future studies [42]. Seco et al. reviewed the main available pozzolanic wastes useful as binder materials that was (fly ash, ground granulate blast-furnace slag, silica fume, rice husk, phosphogypsum, ceramic wastes and sewage sludge). The review included the most interesting construction materials created from pozzolanic waste such as bricks, blocks and masonry mortars. They aimed to improve knowledge on the application of different industrial wastes in the construction sector. This type of studies contributes in acceptance of using waste [44].

Chen et al. had undertaken the study on production of light weight aggregates (LWA) from reservoir sediments. The proposed manner of the manufacturing process which included the dredging, depositing and dewatering, air drying, crushing, graining, heating, conveying, stock piles and packing, respectively. A rotary kiln is used in making the synthetic aggregates. According to the carried out test, the reservoir sediments can be used as primary resource materials at a range of density (1.01 g/cm^3 to 1.38 g/cm^3). The produced aggregates obey the requirement of ASTM C330 with bulk density less than 880 kg/m^3 for coarse aggregates and engineering properties of concrete of structural light weight concrete [45]. Also Haung et al. proposed a way to produce light weight aggregates from water treatment sludge (WTs) which is generated during the water treatment process of chemical coagulant. They were able to get light weight aggregates that comply with ASTM C330 by laboratory experiments, including two phases. The first phase assessed the feasibility of manufacturing LWA from LWs and thermal cycle and the second phase investigated the particle density of aggregates. The engineering properties of concrete made from LWA comply with ASTM C330 [46].

Khalid et al. encouraged through the publication of a research under title of behavior of self-compacting concrete using different sludge and waste materials. They focused on review of researches on reusing of alum sludge in concrete and the feasibility of use in accordance to its chemical composition in self-compacting concrete [47]. Faris and Earn carried out an

experiment on reuse alum sludge which is a by- product from drinking water treatment process for pottery manufacturing. They were able to get an ideal ratio by incorporate 85% of alum sludge with 15% silicon dioxide without any deformation during modeling under thermal curing of 110 °C and 110 °C [48].

CONCLUSION

For all studies on sludge generated from water treatment plants. It could be concluded that sludge can be used in manufacture of bricks and the result, the quantity of sludge generated will be minimised. It must be studied the different engineering properties about water treatment sludge which depend mainly on the quality of raw water and the type of treatment chemical used in the treatment processes. The aluminum content in the sludge is high due to use of aluminum –based coagulants. Other compositions are insignificant amount. The percentage of sludge in the mixture and the temperature of the fire are the main factors that the effect on final product. On other hand, the potential reusing of alum sludge as a substitute material in construction sector can be a promising solution. Thus, there is a need to do more laboratory experiments to determine maximum percentage that could be used as substitution on construction material. This paper will also encourage the utilization of alum sludge derived from drinking water treatment plants. Finally, all researchers strive to make their works more environmentally friendly.

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