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Utilization of Sewage Sludge in the Manufacturing of Lightweight Aggregates: A Review

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Abstract: *Sewage sludge management is one of the major environmental issues these days. Sewage sludge is generated from the sewage treatment plants, and this by product is something that is not going to stop getting produced. As a result, it has become extremely important to manage this sewage sludge in a proper well defined manner. One of the best alternatives for managing this sludge is to use it as a raw material in some other industry. In this paper, we will review various papers on the use of sewage sludge as a raw material. The effects of using sewage sludge as a raw material in making lightweight aggregates is reviewed in this paper.*

Keywords: *Eco-Friendly, Lightweight Aggregates, Sewage Sludge, Environmental Issues*

1. Introduction

Sewage Sludge can be defined as a material that is obtained as a by-product in sewage treatment plants. The main source of sewage sludge is the human community. It is produced because of our day to day activities. So, there is no doubt that there will be any reduction in the produced sewage sludge.

Classes of treated sewage sludge:

1. Class A sludge is dried and pasteurized and known as exceptional sludge.
2. Class B sludge includes undigested sludge.

Also nowadays, we are experiencing population expansion, which will eventually lead to the increased amount of sewage sludge to be dealt with. Few of the most common method used for dealing with sewage sludge are landfilling, incineration, using as a raw material, and so on.

Among these methods, landfilling is normally used. The main problem with this method is the availability of land for dumping of sludge. With the problem of increasing population at our door step, it is quite difficult to get some spare land for sewage disposal these days. Also, disposal of sewage sludge by incineration is not so much economical and also it requires brand new technology for its success.

This is the reason; management of sewage sludge has become a very important issue these days. Lots of research work is going on in this sector to find a desirable alternative for disposal. That is where; the third method of sewage sludge management comes into picture, which is, use of sewage sludge as a raw material.

If we use sewage sludge as a raw material, it will relieve us from the trouble of managing that sewage sludge; because that sludge is being already used up as a raw material.

2. Critical Literature Review

Following are the critical literature reviews on papers of eco-friendly brick production using different type of industrial solid waste:

Wainwright et al. (2002) described a newly developed rotary kiln for the production of synthetic aggregates from a variety of wastes. The main waste used is quarry fines mixed with paper sludge, clay or dredged harbor sediments. Results showed that compressive strength of concrete made using this aggregates at 28 days interval was well beyond desired limit which proves this aggregates are reliable to be used in concrete work.**[32]**

T.W. Cheng et al. (2003) studied the production of CaO–Al2O3–SiO2 system glass ceramics of incinerator fly ash prepared by vitrification and then heat treated in different conditions. Treated samples in general showed good leachability characteristics and also chemical durability with an exception in the HCl solution. For both processes, higher temperature treatments showed crystal growth; hence poor properties were attained. Good physical and mechanical properties achieved at the heat treatment temperature of 900–950 degree C in this study prove that the treated samples have attractive potential for engineering applications. **[36]**

Samad et al. (2004) investigated the bricks produced from sewage sludge for various sludge proportions. Results showed that quantity of sludge is the key factor which determines the brick quality. It was also found that with the increase in the quantity of sludge added, water absorption of bricks increases. At 10% by wt of sludge, density of brick was 2.43g/cm^3 which reduced to 0.33 g/cm^3 for 40% by wt of sludge. This downward trend was due to the associative loss of water and organic matter from the sludge in the bricks when treated by firing in the kiln. Sludge addition in the range of 10% to 40% by wt was considered to be suitable for brick production as per the results. **[1]**

Cheeseman et al. (2005)studied the production of LWA from incinerator bottom ash, and study the physical and leaching properties of the same. Lightweight aggregates with densities, water absorption and crushing strength as good as commercially available aggregates are obtained. Hence, it is feasible to use IBA for the manufacturing of LWA.**[8]**

M.M. Jordán et al. (2005) studied the application of sewage sludge in the manufacturing of ceramic tile body. Clay was substituted by sewage sludge in different proportions in ceramic body. Results showed that with the increase in sludge proportion, water absorption increases.**[19]**

P. A. Bingham et al. (2006) studied vitrification of ashes collected from the incineration of municipal solid waste (MSW) and sewage sludge from the point of view of their composition, glass melting and reuse potential. The main reason leading to vitrification is the landfill cost. Although the technical challenges related with vitrifying wastes have been met, the economic and social issues related with waste separation remain a significant issue to the large scale adoption of vitrification for dealing with hazardous wastes.**[31]**

Ramamurthy et al. (2006) studied the effect of three binders namely, cement, lime and bentonite on the properties of sintered fly ash aggregates. It can be seen that water absorption in sintered fly ash aggregates without binders is about 21%-22%. Water absorption seems to reduce with the addition of lime as binder. Cement performs better than lime in reducing water absorption. With the addition of 20% bentonite, water absorption reduced to 15%-16%. Also, addition of 20% bentonite results in optimal strength and minimum water absorption.**[16]**

Fakhfakh et al. (2007) studied the effect of addition of sand on the lightweight aggregates production. Twelve Tunisian smectite-rich claystone–marlstones were studied. The addition of quartz sand by 15% found to give better expansion properties to some of the aggregates. On the other hand, addition of 1% of used automobile oil to clay and quartz sand mixture, found to form more gas and drop in bloating temperature. It was found that the addition of quartz sand was necessary to avoid LWAsexplosion and to eliminate thermal pre-treatment. Approximate quartz addition required was about 15%. Also, addition of sand caused some changes in the porosity of the aggregates; numerous interconnected pores were observed in the core of the aggregates. While addition of used automobile oil showed variable results. Pore size increased considerably with no change in firing temperature. When sand was added, water absorption increased to 25%, and this value rose to 50% with the addition of oil.**[10]**

Meng-Feng Hung et al. (2007) investigated the recycling of the fine sediments of Shih-Men Reservoir to make lightweight aggregates. The particle density of sintered lightweight aggregate decreases as the sintering temperature increases above 1200°C due to phase transformation and formation of a vitrified layer on the surface. Fine sediment from Shin-Men Reservoir prove to be suitable raw material for manufacturing expanded lightweight aggregate at temperatures in the range of 1200 to 1300°C and sintering time of 10 to 12 minutes. **[27]**

D. Fytili et al. (2008) presented past and future approaches in sludge handling, mainly focused at thermal processes and the utilization of sewage sludge in cement manufacturing. As per the paper, agricultural use is considered to be insecure. In case of incineration scrubbing cost of produced gases is more. Therefore, the alternative methods such as pyrolysis, wet oxidation, etc have definite advantages over previously mentioned methods. **[9]**

Guoren et al. (2009) investigated the stabilization of heavy metals in ceramsite made from waste water treatment sludge and drinking water treatment sludge. The study implied that the heavy metals in the ceramsite are stable and will not cause any secondary pollution. WWTS and DWTS can be used as a harmful ceramsite and it solves the problem of sludge management. **[12]**

M.A. Montero et al. (2009) studied the effect of addition of marble sludge and urban sewage sludge to clay in ceramic body. Bending strength of the ceramic tile body met the standard requirement when the sludge content is kept at 16% to 22% of the clay. Hence, it was found that addition of these residues is a convenient way of sludge management, but care should be taken to use it in a controlled manner. **[18]**

M. Rodas et al. (2009) studied the lightweight aggregates produced from mining and industrial wastes. Lightweight aggregates were manufactured using 50% washing aggregate sludge and 50% clay-rich sediment was studied. Only aggregates with this proportion showed expansion. The expansion mainly depends on the formation and release of gases. LWAs with the lowest bulk density and dry particle density are produced with 75% sewage sludge and 25% washing aggregate sludge.**[6]**

Min Yue et al. (2010) studied the characteristics of ultra lightweight aggregates prepared from dehydrated sewage sludge. From the studies, optimum conditions for the production of ULWC was found to be as, 25%-35% addition of DSS, preheating temperature of 400◦C for 20 minutes and sintering into electric furnace at 1150 ◦C for 10 minutes. **[39]**

Chao-Wei Tang et al. (2011) studied the lightweight aggregates prepared from fine sediment deposits dredged from the Shihmen River in Taiwan. Result shows that particle density of LWA prepared is 1010 to 1380 kg/m3, quite lower than the normal aggregate. Also, 28-days compressive strength of LWA concrete meets the strength requirements for structural light weight concrete. Hence, manufacturing LWA aggregates from fine river sediments is feasible. **[9]**

Wojciech et al. (2011) studied the use of spent glauconite in the production of lightweight aggregates. Results showed that the use of glauconite for removal of zinc ions is a feasible approach. Also, use of spentglauconite as an additive increases the porosity of the aggregates. **[39]**

Joan et al. (2012) studied the environmental suitability of using sewage sludge for making clay bricks, by carrying out leachability and toxicity studies. From the study, it can be said that sludge can be successfully used into bricks with quantity in the range of 5%-25% by weight, higher than this would result in insufficient mechanical properties. Leaching tests suggest that there are no environmental restrictions on the use of clay bricks made from either of the sludge. **[16]**

Angelo et al. (2012) examines the potential use of fly ash in the production of lightweight aggregates. It is found that good quality of lightweight aggregates can be produced with fly ash with high free lime content. Also, the concrete produced from this LWA meets the standard requirements. **[4]**

J.Monzó et al. (2012) studied the effect of reusing of sewage sludge pellets (SSP) obtained from drying sludge process and sewage sludge ash (SSA) obtained from incineration of wastewater sludge, in building materials manufacturing. Experimental results indicated the feasibility of the partial replacement of cement by 15 and 30% by SSA in mortars. **[14]**

Min Yue et al. (2012) examined the chemical, thermal and toxic properties of dried sewage sludge (DSS), the production and characteristics of lightweight sludge ceramic (LSC) produced and the process of action of the organic and inorganic foaming agents. Preparation lightweight sludge ceramics (LSC) by sintering sludge added to clay was found to be favorable. The addition of DSS lowered the rate of expansion of the clay ceramic pellets. When the DSS dosage was above50 wt%, the body of the LSC showed shrinkage. The heavy metal concentrations released from LSC are much lower than the levels stated in environmental regulations.**[29]**

Małgorzata et al. (2012) studied the basic physical and mechanical properties of lightweight aggregates produced from sewage sludge and clay. Aggregates obtained were of apparent density of 0.812 g/cm3 and bulk density of 0.415 g/cm3, water absorption of 16.2%, porosity of 40%, void content of 52%, no coloring compounds. This result shows that light weight aggregates modified with MSW can be used for the production of light weight concrete. **[23]**

Guangyin et al. (2013) studied the ways to reuse dewatered sludge and municipal incineration bottom ash. Results showed that DS and MSWI bottom ash both can be used for the production of controlled low strength materials. Leaching test revealed that leachable substances in the leachate are quite less and the product formed is environmentally friendly. **[12]**

Bui Le et al. (2014) studied the potential of lightweight aggregates produced from wastes and its application in lightweight concrete. LWA were prepared from wet sewage sludge and reservoir sediments, and was used as coarse aggregates in preparing lightweight concrete. The unit weight of concrete prepared by using LWA as coarse aggregates reduced more than 18%, which results in considerable weight loss. Also, the compressive strength is in the desirable limit. Hence, the use of reservoir sediment showed a positive effect on the overall properties of LWA and also on lightweight concrete. **[7]**

Na Wei et al. (2015) studied the stability of heavy metals in lightweight aggregates made from sewage sludge and MSWI fly ash. Various ratios of MSWI fly ash and sewage sludge were tried and leaching test was conducted for these ratios. Also, leaching test was conducted for various sintering temperature and sintering time. From the test results, it was found that the optimal MSWI fly ash and sewage sludge ratio, sintering temperature and sintering time are 2.8, 1100 °C and 8 minutes respectively. **[31]**

Małgorzata et al. (2016) studied the properties of Lightweight aggregates modified by the addition of used motor oil. 1% to 2% of motor oil addition showed maximum porosity in the LWA. With the increase in the proportion of motor oil beyond this limit, decrease in porosity is observed. Mineral composition of LWA does not depend on oil addition and also not on zeolitic admixtures. **[25]**

Małgorzata et al. (2016) studied the use of sewage sludge in the production of lightweight aggregates. Mixture of sewage sludge and clay was used to prepare lightweight aggregates. Two samples were made as per their sintering temperature, 1100 °C and 1150 °C respectively. Both the prepared aggregates were than compared with commercially available aggregates. It was found that the prepared aggregates were lighter than commercial aggregates and, also with increase in sintering temperature porosity of aggregate increases. In other words, aggregate with higher sintering temperature is lighter. A part from this, compounds formed in the aggregates were those available in nature and hence, there is no risk of leaching of heavy metals from the prepared aggregates. **[22]**

B. Gonzalez et al. (2016) studied microstructure and mineralogy of lightweight aggregates prepared from washing sludge, sewage sludge and clay rich sediment. Eight different types of lightweight aggregates with different Sewage sludge, washing sludge and clay rich sediment proportions were formed and studied. From the study, following relationships can be formed: Microstructure - bloating index, Microstructure - dry particle density, Mineralogy - dry particle density, Microstructure - water absorption, Mineralogy – water absorption, Microstructure - crushing strength and Mineralogy - crushing strength.**[5]**

Mingwei et al. (2017) investigated the effect of mass ratio (K) of basic and acidic oxides on lightweight aggregates. Results showed that when K was kept at 0.2, it resulted in the formation of LWA with maximum compressive strength of 17.07 MPa. Also, it became evident from the results that with the K value in the range of 0.15-0.3, LWA aggregates of high quality can be obtained. **[30]**

Pao-Ter et al. (2016) investigated the recycling of electric arc furnace slag waste into heavy duty green ceramic tiles. Results showed that as weight percentage of EAF slag increases up to 60% by wt, the percentage of apparent porosity and water absorption increases too, with a reduction in tile flexural strength and increased porosity. **[34]**

The following table 1 shows the literature review papers and its comparison.

Table1. *Literature review papers and its comparison*

Author	Year	Utilization Area	Material Used	Addition/ Replacement	Tests	Increase/ Desirable
Mingwei	2017	Lightweight Aggregates	sewage sludge	Replacement	Compressive strength	Desirable
Pao-Ter	2016	Green Ceramic Tiles	Electric Arc Furnace Slag	Addition	Water Absorption	Increases
B.Gonzalez	2016	Lightweight Aggregates	Sewage Sludge	Replacement	Compressive strength	Desirable
Małgorzata	2016	Lightweight Aggregates	Sewage Sludge	Replacement	Particle density Water Absorption	Desirable Desirable
Małgorzata	2016	Lightweight Aggregates	Used Motor Oil	Addition	Microtomography	Desirable
Na Wei	2015	Lightweight Aggregates	Sewage Sludge and MSWI fly ash	Replacement	Leaching test	Desirable
Bui Le	2014	Lightweight Aggregates	Sewage Sludge	Replacement	Unit Weight	Decreases
Guangyin	2013	Lightweight Aggregates	Dewatered Sludge and MSWI bottom ash	Replacement	Leaching test	Decreases
Małgorzata	2012	Lightweight aggregates	Sewage Sludge and Clay	Replacement	Water absorption and porosity	Desirable
MinYue	2012	Lightweight ceramics	Dried Sewage Sludge	Addition	Leaching test	Desirable
J.Monzó	2012	Sewage Sludge Pellets	Sewage Sludge Ash	Replacement	Feasibility	Desirable
Angelo	2012	Lightweight Aggregates	Fly Ash	Replacement	Feasibility	Desirable
Joan	2012	Clay Brick	Sewage Sludge	Replacement	Leaching test	Desirable
Wojciech	2011	Lightweight Aggregates	Spent Glauconite	Replacement	Porosity	Increases
Chao-Wei Tang	2011	Lightweight Aggregates	Sediment Deposit	Replacement	Particle Density	Decreases
Chee Ming	2011	Clay Brunt Brick	Natural Fibre	Addition	Compressive Strength	Desirable

3. CONCLUSION

Based on literature review the following conclusions are drawn:

- Sewage Sludge is used as an effective raw material for the production of various construction materials.
- Using sewage sludge as a raw material will help to solve the most critical problem the world is facing these days i.e. sewage sludge management.
- This will eventually lead to the conservation of our natural resources. Because manufacturing of aggregates by conventional method leads to the destruction of our natural topographical features.
- LWAs with the lowest bulk density and dry particle density are produced with sewage sludge and washing aggregate sludge.
- Use of sewage sludge for the manufacturing of various materials provides us with the materials with desirable physical and mineralogical properties.
- The lightweight aggregates produced showed lowest leachability. Most of the metals found in the aggregates were stable and hence safe to be used.

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