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Research Article

Potential uses of Waste Sludge in Construction Industry: A Review

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Abstract: Waste generation and management is becoming a global challenge resulting into increased environmental concern. Waste management and recycle into a sustainable construction materials as proved to be an alternative for waste disposal helping out in the area of environmental pollution and economic. In recent years various type of waste has been used/reused in the development of sustainable construction materials. This study reviews various attempts that have been made to use sludge from different plants in construction industry. The mechanical and physical properties of the products, the environmental effect of the products and possible recommendations for future research was presented in the review.

Keywords: Blocks, bricks, ceramic, compressive strength, concrete, material, water absorption

INTRODUCTION

The increase in demand for construction materials in the recent years as a result of development has called for an alternative way to develop or derive construction materials from other sources. In order to meet the increased demand, attention has been given to the development of sustainable construction material. The usage of improved construction materials in construction industry has been on increase daily which has led to the investigation of its environmental impact and meeting required standards when waste are used in developing sustainable construction material.

Attempts have been made to incorporate waste in the production of bricks; for instance, the use of paper processing residues, cigarette butts, flu ash, textile effluent treatment plant sludge, polystyrene foam, plastic fiber, straw, polystyrene fabric, cotton waste, dried sludge collected from an industrial wastewater treatment plant, rice husk ash, granulated blast furnace slag, rubber, Kraft pulp production residue, limestone dust and wood sawdust, processed waste tea, petroleum effluent treatment plant sludge, welding flux slag and waste paper pulp (Erol *et al*., 2008; Cultrone and Sebastián, 2009; Shih *et al*., 2004; Vieira *et al*., 2006; Monteiro *et al*., 2008; Chiang *et al*., 2009; Montero *et al*., 2009; Alleman and Berman,1984; Tay *et al*., 2002; Show and Tay, 2002; Yague *et al*., 2002; Chin *et al*., 1998; Chiang *et al*., 2000; Chih-Huang *et al*., 2003; Cusido *et al*., 2003; Abdul *et al*., 2004; Chihpin *et al*., 2005).

Researchers have attempted reuse and recycle waste to enhance a sustainable environment. Some of the waste that are have been used in the quest for alternative sustainable construction materials includes red mud, fly ash (Erol *et al*., 2008; Cultrone and Sebastián, 2009), blast furnace slag, industry steel dust (Shih *et al*., 2004; Vieira *et al*., 2006) and several sewage sludge (Monteiro *et al*., 2008; Chiang *et al*., 2009; Montero *et al*., 2009). Reuse or recycling such waste to develop sustainable construction materials as proved to be a practical solution to disposal and environmental problem.

METHODOLOGY

Waste sludge in bricks production: Alleman and Berman (1984) developed bricks using mixture of sludge with clay and shale, called biobrick. It was discovered that conventional clay and shale ingredients could be partially supplemented with wastewater sludge has solid content 15-25% to produce biobricks. The biobrick had the look, feel and smell of regular bricks (Chin *et al*., 1998).

Tay *et al*. (2002) Developed a novel brick using dried waste water sludge and clay, samples with varied sludge percentage was produced and fired in a kiln, the results on the mechanical and physical properties shows that dry sludge can be used with clay at percentage ranges of 0-40 of brick weight and the compressive strength decreases with increase in sludge content. Due to the burnt off organic content of sludge during firing process, uneven texture surface and porosity arises. This problem was solved by introducing or replacing dry sludge with sludge ash which has zero organic content and it was determined that the maximum sludge

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percentage that can be used is 50% and results showed that the bricks containing pulverized sludge ash had a higher strength than bricks containing sewage sludge. Bricks containing 10% of sludge ash have strength as high as normal clay bricks.

Yague *et al*. (2002) investigated the potential use of dry pulverized sludge in brick production. Dry pulverized sludge was introduced in the production of prefabricated bricks using 2% into the prepared samples and the properties of the specimen were tested, the results shows a significant increase in compressive strength, decrease in porosity and water absorption compare to bricks without sludge.

Chin *et al*. (1998) investigated the utilization potential of Sludge and co-generation ashes generated by the paper industry in producing bricks; bricks were fired at 1000°C. The products made from the material have exhibit some good properties in term of water absorption and compressive strength, which met the required standards though the bricks are only recommended for use as non-load bearing spacing construction material.

Chiang *et al*. (2000) examined the potential use of dried sludge from water treatment plant with agricultural waste and rice husk ash in production of novel light weight bricks. The results for the mechanical properties show that bricks with 40% by weight rice husk heated at 1100ºC exhibit a high strength required for lightweight bricks, use in future green building in accordance with Taiwan standards. Results of Toxic Characteristic Leaching Procedure (TCLP), shows that the concentrations of Cu, Zn, Cr, Cd and Pb in the products were lower than allowable level in the standard regulation.

Chih-Huang *et al*. (2003) examined bricks produced from industrial waste water treatment plant sludge, all necessary properties test were performed. Results show that the quality of the product depends on sludge proportion and the firing temperature. Strength of bricks with up to 20% sludge content at temperature ranges of 960-1000°C met the required Chinese standards. The leaching result on the product shows a low metal leaching level.

Cusido *et al*. (2003) used sewage sludge and forest debris were used as raw materials in producing clay-bricks, the product is lighter, more thermal and acoustic insulating when compared with conventional clay-bricks. The bricks were dried at 100°C and then fired at 1000°C. The result shows significant increase in the level of greenhouse gas emission up to 20 times more as compare with conventional ceramic firing (though still within allowable level approved by environmental Protection Agency).

Abdul *et al*. (2004) produced bricks using sewage sludge as a raw material. The bricks were tested for physical and mechanical properties. Results show that the products met the required standard, though the use of sludge content more than 30% was not recommended for it high brittleness.

Chihpin *et al*. (2005) investigated the effect of using Water Treatment Residual (WTR) and the excavated soil in production of ceramic bricks and artificial aggregates on the product properties. Though the sintering temperature required by WTR was higher than what is normally used in brick works due to the higher Al_2O_3 and lower SiO_2 content. Results of specific gravity, water absorption and compressive strength of the ceramic bricks established its usage feasibility in construction.

Kae (2006) investigated the use of Municipal Solid Waste Incineration fly ash slag (MSWI) on fired clay bricks, bricks were fired at 1000°C. The mechanical properties and environmental effect of the leachate from the products were tested. Results indicate that the mechanical properties satisfy the Chinese National Standard code for second-class brick and leachates were within acceptable level. Result also shows that increase in the MSWI content leads to increase in the compressive strength though will decreased the water absorption of the sintered bricks Eliche-Quesada *et al*. (2011) produced bricks from the mixture of clay and recycled industrial wastes. The result shows that compressive strength increased with the increase of sintering temperature. The products satisfy standard requirement for the water absorption and compressive strength.

Cheng-Fang *et al*. (2006) used water treatment sludge and Bottom Ash (BA) in the production of water permeable bricks. The mechanical properties of the sintered bricks were tested in accordance with available standards. Results shows that product with 20% content of BA, sintered at 1150°C temperature produces a reliable compressive strength, a good water absorption ratio and a good permeability. The bricks could be used as water permeable, environmentally friend product as pavement brick in an urban area.

Kung-Yuh *et al*. (2009) manufactured lightweight bricks by sintering mixes of dried water treatment sludge and rice husk. Bricks products with up to 20% by weight of rice husk were fired to obtain effective organic burn-out. Addition of rice husk increased the porosity of sintered samples and increase in sintering temperatures leads to increased compressive strengths. Materials containing 15% by weight of rice husk sintered at 1100°C produced low bulkdensity and higher compressive strength that were compliant with relevant Taiwan building code standards for use as lightweight bricks.

Luciana *et al*. (2011) proposed the production of bricks using textile laundry wastewater sludge and clay. Bricks were produced with different quantities of the sludge, dried at 100°C then firing was done at 900°C and the mechanical properties were determined. Mechanical properties of ceramics as flexural strength and water absorption were satisfactory within the Brazilian legislation. The obtained results showed that bricks with 20% sludge content give the best mechanical properties and the leaching test conducted show that the product is safe without any adverse health effect on the user.

Joan and Lázaro (2012) examined the environmental effect of the use of bricks manufactured from sewage sludge, considering the leach ability and toxicity the results show that the sludge can be successfully incorporated into bricks with sludge additions ranging from 5 to 25% in weight (and even more if we do not consider mechanical properties), Without any significant adverse effect on the health of the user and the environment.

Badr *et al*. (2012) explored the replacement of clay brick using sludge, agricultural and industrial wastes (such as Rice Husk Ash (RHA) and Silica Fume (SF)). Bricks samples were fired at different temperatures. The properties of the product were investigated and compare with conventional brick in accordance with Egyptian standard specification. Products with 25% SF and 50% sludge showed superiority over the conventional bricks.

Waste sludge as artificial aggregate: Tay *et al*. (2002), presented some results from using dried industrial sludge with low organic content and clay which were pulverized separately to fine size before mixing with water to form a paste. The resulting paste was formed aggregate shape and then sintered at high temperature.

The performance of artificial aggregate was evaluated by measuring the compressive strength of concrete samples containing these aggregate compared with granite aggregate. The results showed that 28-day compressive strengths of concrete samples with artificial aggregate ranged between 31-38.5 N/mm^2 while concrete with granite gives 38 N/mm^2, though, the artificial sludge clay aggregates exhibit higher porosity and lower density compared to granite aggregates.

Chou *et al*. (2006) examined potential use of sintered sewage sludge and sludge ash combination for producing synthetic aggregate. The results showed that combination of sewage sludge ash and clay was better for the production of normal weight aggregate, while mixture with 20-30% of sewage sludge was more adequate to produce lightweight aggregate.

Sewage sludge ash was used as a portion of the fine aggregate in hot mix asphalt paving. The results indicated that there was no visible difference between the pavement containing sludge ash at percent varying between 2 to 5% of aggregate weight and conventional materials (Sewage sludge ash-user guidelines-asphalt concrete, http://www.rmrc.unh.edu/Partners/User Guide/ss2.htm.).

Shane *et al*. (2008) developed sustainable, low-energy construction products that beneficially use Incinerated Sewage Sludge Ash (ISSA). Materials used were from major UK sludge incinerators are being used in this research. Appropriate standard test were performed on the product and the result shows that ISSA is likely to increase the reactivity and workability compare with conventional products.

Leda *et al*. (2013) investigated the usage of 10 wt% sewage sludge in modifying road base layers. Procedure involved in soil stabilization was employed for the material to meet the required standards. The stabilized soil strength was evaluated. Sludge-soil mixtures with different additive were prepared, compacted and then tested. The optimum mix design was determined using the mechanical test. Results show that soil stabilization with sewage sludge has potential for usage in highway construction. Yu *et al*. (2009) explores the usage of lime sludge produced during water purification procedures. The impact of different types of mix procedure (dry and wet), optimum lime sludge content and the effect on durability of the stabilized soil were determined. Results indicate a significant improvement in the mechanical properties and the durability.

Milica *et al*. (2012) explored the possibilities of using industrial sludge in masonry industry and the environmental effects of leaching potentials were investigated. Sludge used was collected from a hot-dip galvanizing process after waste water neutralization. Though it contains some hazardous material due to the presence of toxic elements, the results from leaching test shows a negligible level after firing at 102°C. The results show that sludge can be used to produce eco-friendly bricks.

Waste sludge as cement-like material: Tay *et al*. (2002) investigated the utilization potential of digested and dewatered sludge in the production of cement like material. Specimens were prepared using dried sludge mixed with limestone powder. The resulted mixture was grounded and incinerated. The showed that sludge cement was found to have high water demand and quick setting time compared to ordinary cement. Evaluation of mortar cube strength showed that it was possible to produce masonry binder made of cement sludge that would satisfy the strength requirements of the ASTM standard for masonry cement. Further studies were needed to evaluate long term properties such as durability prior to acceptance as a suitable masonry binder.

Monzo *et al*. (2004) investigated the potential use of Sewage Sludge Pellets (SSP) as replacement for material in raw mix formulation in manufacturing process of Portland cement. Sewage Sludge Ash (SSA) was substituted for cement at 15 and 30% by weight in mortar. The results indicated that the mortar containing 15% of (SSA) has a compressive strength similar to reference mortar. When (SSA) content increased up to 30%, a significant decrease was observed, 11% of cement clinker dry weight was replaced with (SSP) without any problem or larger differences comparing to cement made with normal clinker contents.

Goh *et al*. (2003) used pulverized sludge ash blended with cement in concrete mix. The sewage sludge treated at 55°C to remove organic materials for using as filler in concrete. The presented ash was collected and pulverized to finer than 150 µm, then incorporated into the cement. The results indicated that concrete workability was improved as sludge ash content increased. The 28-day compressive strength of concrete cubes with 10% sludge ash in cement was about the same of ordinary concrete, but when sludge ash increase up to 40%, the strength drops by 50%.

Arlindo *et al*. (2004) examined potential use of sewage sludge treated at different temperature as replacement material of cement in mortar preparation. A dry sludge at 105°C was used as replacement of cement by 20% of dry weight. The result showed that there was no setting occurred. Another trial was done but by using treated sludge at 450, 700, 85°C as replacement of 5% and 10% of cement weight, respectively. The results indicated that the presence of any kind of previous treated sludge caused decreasing in mortar compressive strength.

Yiming *et al*. (2012) studied the effects of dried sewage sludge as an additive on cement property in the process of clinker burning. Samples were produced from dried sewage sludge and were heated at certain temperature. The results show that there are similarities between the ordinary Portland cement and the eco-cement clinkers components. Though the compressive strengths recorded from the samples were a slight lower than the plain paste; the leaching results of the samples were within the acceptable standard of Chinese current regulatory.

Waste sludge in concrete mixtures: Valls *et al*. (2005) investigated the potential usage of dry sludge as additive in concrete. The sewage sludge was dried to reduce its humidity to a certain limit and remove microorganisms. Dry sludge was added to concrete mix as fine sand at percent various from 0-10%. The use of sludge in concrete was beneficial in that when sludge reacts with cement and comes to form of binding matrix, the sludge components were stabilized and quantity of leachable heavy ions was reduced compared to free dry sludge. The results showed that the compressive strength of concrete decreased as the sludge content increased. Sludge content of 10% or more cannot be used because the setting time was delayed and the concrete mechanical properties were reduced significantly.

Yaque *et al*. (2004) examined the durability of concrete samples with sludge as additive to concrete to evaluate long term performance. A sample was subjected to accelerated attack. These attacks involved a combined wet-dry cycles using fresh and sea water, accelerated aging in an autoclave and accelerated carbonation. The results indicated that sludge concrete has durability similar to reference concrete.

Waste sludge water in concrete mixtures: Chatveera *et al*. (2005) investigated the replacement of tap water with sludge water in concrete production. The study reveals that the sludge water can be used as replacement at percent range of 0-100%. The compressive strength of concrete mixed with sludge water is in the range of 85-94% of concrete with normal water, but sludge water has an adverse effect on drying shrinkage and resistance to acid attack of concrete.

Al-Ghusain and Terro (2003) evaluate the usage of treated waste water in concrete. Concrete cube specimens are prepared using different water type. The water used in this study is Tap Water (TW), Preliminary Treated Waste Water (PTWW), Secondary Treated Wastewater (STWW) and Tertiary Treated Wastewater (TTWW). The results showed that mix water type do not have any effect on concrete slump and density. Lower compressive strength were recorded from specimens made from (PTWW) and (STWW) and also slower strength development, higher setting time and higher corrosion potential, than specimens made with (TW) and (TTWW). The specimens prepared with (TTWW) exhibit higher strength than specimens prepared with (TW).

Waste sludge in ceramic and glass production: Suzuki *et al*. (1997) produce ceramic samples by adding limestone to sewage sludge incinerated ash. The sludge ash is presented as fine dust, so it can be directly mixed with other ceramic paste components. Ceramic samples containing 50% sludge ash showed strength, acid resistance and absorption coefficient within the normal range for ceramic.

Ferreira *et al*. (2003) investigated the leaching properties of ceramic containing sludge ash. The results showed minimum diffusion values of heavy metals.

Montero *et al*. (2009) investigates the usage of sludge and the effect of its properties in ceramics. Urban sewage sludge and marble sludge was added to clay in a ceramic body in different proportions, giving off varying products of ceramic material characterized by different mineralogical composition and technological behavior. The properties of the product were determined, such as linear contraction, bending strength and water absorption. The result shows that added residues (sewage sludge and marble sludge) possesses great reactivity and can react easily with the clay minerals and quartz, providing better sintering of original powders.

Joan and Cecilia (2011) studied the use of sewage sludge in building industry to produce a lightweight clay ceramic. Result shows that the product had a low thermal conductivity, though the results from the leaching test conducted indicates that the leachate contains significant amounts of hazardous metals even after thermal treatment.

Martínez-García *et al*. (2012) used sludge to substitute clay in a ceramic body at different percentage contents replaced clay. The mechanical properties of the products were tested. Results shows that products with 5% sludge content displayed a good mechanical properties in term of water absorption, compressive strength and water suction.

DISCUSSION

Application of waste sludge in construction industry has been proven by various researchers in various ways. It is evident from the reviewed literatures that the major application of waste sludge in construction is in the production of bricks while the least application is in the ceramic and glass production. Various test carried out to ascertain the properties of the end product satisfied all the available requirements in accordance with standards. The major properties investigated by most of the researchers were compressive strength and water absorption, while the environmental effect of the leachable materials from the end product were also investigated by some. In addition to the fact that the use of sludge in construction industry contributed to the sustainability of limited natural resources, it is also environmentally friendly. A new use of sludge in the construction industry without high energy consumption as compare to what we have in the production of fired bricks should be explored so as to develop energy saving products for future use. More study should be done on the use of different type of sludge in production of construction materials that are economical and environmentally friendly in term of energy usage and emission.

Since waste sludge comprises of all industrial and agricultural solid wastes, in which petroleum sludge is one of the greatest major solid wastes generated in oil industry, the generation of this waste is on the increase as far as petroleum exploration and production is in operation and it disposal is creating serious threat to the environment, effort should be directed not only on the treatment but on how the waste can be used without treatment in the development of sustainable construction material.

CONCLUSION

This review study demonstrated that usage of various type of sludge as a raw material in construction industry is clearly feasible without compromising the material requirements according to available standard. It can be concluded that the potential use of sludge in construction industry is an alternative to the treatment and disposal of sludge considering the huge cost and complexity involved in the treatment. Considering the economic and environmental factors a technical application of various type of sludge in construction industry would provide a complete solution to the waste problem and promote eco-friendly environment with a reduced or low-cost raw material.

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