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A Review: Uses of Additives in the Development of Water Treatment Plant Sludge Bricks

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***Abstract*- Water treatment plant sludge generation and management has becoming a global problem, leading to increased concern for the environment. Sludge management and recycling into safe building materials have proven as an alternative to waste disposal to reduce environmental and economic pollution. Reused of sludge with additives in brick making industry is a sustainable solution due to increasing demand for bricks in construction works nowadays. This study reviews development of water treatment plant sludge bricks and different additives implemented in brick making process. The study addressed the characteristics of water treatment sludge, the advantages of natural and chemically made additives, as well as the compressive strength and water absorption properties of bricks.**

***Keywords*- water treatment plant sludge, bricks, additives, compressive strength, water absorption.**

I.INTRODUCTION

Water Treatment Plant Sludge (WTPS)is classified as a scheduled waste by the Department of Environmental (DOE) Malaysia under the Environmental Quality (Scheduled Wastes) Regulations 2005 (DOE, 2005). The sludge is coded with SW 204 according to the regulations asit contains carry-over of metal traces including aluminium and inorganic constituents resulting from the water treatment processes for instance coagulation, flocculation, sedimentation, filtration, and disinfection (Ahmad *et al.*, 2016).

Increasing clean and treated water demand due to population growth generates simultaneous amount of sludge over the years, which makes the sludge management a worldwide issue of significant concern (Hidalgo *et al.*, 2017; Lee *et al.*, 2018). To reduce disposal cost, the sludge is disposed directly into waterways or landfill of which pollutes the water and soil (De Carvalho Gomes *et al.*, 2019). However, recently ways in reducing the environmental impact from WTPS has been explored and one of it is by reuse the WTPS into bricks.

The reusability of the WTPSin brick making has been reviewed with addition of additives to enhance the properties of bricks. Due to the clay insufficiency, many studies focussed on designing and developing new sustainable materials using less conventional raw resources with available local materials that follow the standard specifications (De Carvalho Gomes *et al.*, 2019). In this way, blending of WTPS with clay in brick making was suggested. The WTPS is used to reduce the use of clay as crude materials used in the normal development of bricks.Since clay and WTPS have alike chemical composition (essentially hydroxides and silica oxides, aluminium and ferric), the use of WTPS has been highly encouraged to partially substitute the clay used for fabrication of brick (Toya*et al.*, 2007; Cremades*et al.*, 2018).

The addition of aluminium-based sludge decreases compressive strength and increases the water absorption of the bricks (De Carvalho Gomes *et al.*, 2019). The characteristics of bricks with high water absorption and lower strength are unfavourable. This is where the addition of additives is needed to improve the strength and water absorption of sludge bricks.This paper will review few types of natural and chemically made additives used in WTPS bricks.

II. COMPOSITION OF WATER TREATMENT PLANT SLUDGE

In treated WTPS, elements such as Silicon (Si), Aluminium (Al), Ferum (Fe) and Calcium (Ca) make it desirable to be used in producing eco-building materials, particularly in the brick productions. Sand, silt and clay are some of the essential ingredients in the manufacture of building materials (Wang *et al.*, 2019) and the total amount of sand, silt and clay present in WTPS is estimated to be about 40% (Ahmad *et al.*, 2016).

Since these elements constitutes approximately 40% to 70% like the raw brick manufacturing material (Ahmad *et al.*, 2016; Hwang *et al.*, 2017), it enhances the consistency of the brick by forestalling the shrinking and cracking process besides improving its bricks binding and moulding ability (Wang *et al.*, 2019; Chakraborty *et al.*, 2017).

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III. GEOTECHNICAL PROPERTIES OF WATER TREATMENT PLANT SLUDGE

Geotechnical properties are referred to as critical properties for the identification of WTPS as a soil material and for predicting the future behaviour of the materials' application (Komlos*et al*., 2013). Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Loss on Ignition (LOI) and specific gravity are common examples of geotechnical properties. The main geotechnical properties of the WTPS are shown in Table 1.

Table 1. Geotechnical properties of WTPS

Properties	Unit	Type of WTPS		
		Alum sludge	**Ferric sludge**	**Lime sludge**
Liquid limit	%	80-550	108	38-72
Plastic limit	%	60-325	47	32-53
Plasticity index	%	20-225	61	4-19
Specific gravity	g/cm^3	1.86-2.33	2.26-2.72	2.57-2.62
Soil classification (USCS)	-	High-plasticity clay	High-plasticity clay	Low-plasticity silt
Loss on Ignition	%	15-57	24-50	35-40
References	-	(Komlos*et al*., 2013; Wang *et al*., 1992)	(Wang *et al*., 1992)	(Kashyap&Datta, 2017)

The alum and ferric sludge have high plasticity index in which it is useful to indicate the soil properties. High plasticity index increases the ability to resist liquefaction. Alum sludge that can have a plasticity index of up to 225% will typically also have a high clay content. This is the prominent characteristicsof alum sludge since alum based sludge is the most abundant WTPS that are found in most developing countries such as Malaysia. Malaysia for example, chose alum as coagulant in water treatment process because it is low cost.

WTPS characterization studies have shown some important similarities with clayey soils, especially alum and ferric sludge (De Carvalho Gomes *et al*., 2019) but with high concentration of chemicals (Lee *et al*., 2018).The sludge bricks forms with high plasticity clay are very stable and durable. Compared to lime sludge, the alum and ferric sludge is more suitable for use because they have been classified as high plasticity clay. The development of plasticity when mixed with water and hardening under the influence of fire, which drives off the water content, are the significant properties of clays that make them highly desirable as brick materials (Abdul &Mohajerani, 2011). The surfaces of clays are negatively charged, and so they be likely to adsorb the positively charged cations in water (Ural, 2018). It is, therefore important to take note on the amount of sludge added in brick making to avoid shrinkage depending on the load applied onto it. Otherwise the addition of silica fume and calcium carbonate analytical grade can be opted to reduce the absorption of water (Odimegwu*et al*., 2016; Martirena*et al*., 2006).

IV. DEVELOPMENT OF WATER TREATMENT PLANT SLUDGE BRICKS

Brick making begins by mixing WTPS with clay with a further phase of drying (Feenstra*et al*., 1997).The advantage of using WTPS is that they contained iron components that could be used as red pigment agent for bricks, generated from the coagulation process. Excess iron content, however, decreases the compression strength.

A study by **Anderson *et al*., (2003)** investigated the properties of bricks for both fired and non-fired conditions by the assimilation of WTPS and incinerated sewage sludge ash. The incinerated sludge ash was used as additive to avoid irregular surface texture and porosity because it has zero organic content which does not burnt off organic content of sludge during firing process (Johnson *et al*., 2014). The experimental bricks have been found to have 10.5% water absorption and 44.2 N/mm^2 compressive strength when fired under a maximum temperature of 1050°C over a 46 hours' period (Anderson *et al*., 2003).

Another study conducted by **Huang *et al*., (2005)** used composite of 2 wastes from water industry which are WTPS and Excavation Waste Soil (EWS) to replace conventional raw materials used in brick manufacture. Based on the firing shrinkage between materials EWS and WTPS, EWS shows much milder compared to WTPS. This proves that EWS sinter is another additive that could enhance the brick property. With less volume shrinkage to

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brick mixture, the distortion and breakage of bricks can also be prevented. The compressive strength of bricks is increasing by adding EWS. Sintering process will help to close the open pores and hence, reduce the water absorption. However, up to 1000℃sintering temperature is required for WTPS due to higher Al_2O_3 and lower SiO_2 content. At intense temperature, the completion of crystallization procedure can be achieved.

According to **Ramadan *et al*., (2008),** the higher alumina and lower silica content in WTPS affects the strength of bricks. Therefore, the sintering and addition of EWS to the mixture can increase the compressive strength. There are few more examples of additives used in WTPS bricks. For instance, calcium carbonate, rice husk ash, silica fume and mineral nanopowder. In the brick mixture, calcium carbonate was used as a source of calcite (Martirena*et al*., 2006). Owing to the fluxing effect associated with the presence of calcite, the presence of small quantities of calcium carbonate increases the compressive strength of the bricks, which helps better sintering reactions to take place. Due to a full crystallisation reaction with the addition of 2% and 5% calcium carbonate, the resulting bricks are stronger and denser.

The compressive strength of bricks made with 5% addition calcium carbonate was the same as that made of 40% recycled glass **(Day & Huizer, 1994)**. Changes in the mechanical properties of the bricks are likely to be correlated with changes in their mineralogical composition due to the inclusion of calcite in calcium carbonate, as well as the development of physical changes in the microstructure due to new reactions.The different grain size between clay and calcium carbonate will show different result in bricks properties. A bigger grain of calcium carbonate with a less specific surface, which would potentially slip through in the processing of bricks would not mix with clay minerals and instead undergo decarbonation, resulting in the formation of Calcium Oxide. This could then lead, to volume instability and microcracking in the solid matrix as water is absorbed into the pore structure. A smaller grain of calcium carbonate, with a higher specific surface, will probably be combine with clay minerals instead of decarbonating to form other phases. According to the chemical and mineralogical composition of the materials combined, Anorthite is one of the main phases expected to be present in the fired bricks, as referred in the literature **(Traore*et al*., 2003; Cultrone*et al*., 2004).**

Rice Husk Ash (RHA) is one of the most common agricultural waste that contains a high silica content and may be mixed with sludge in the production of bricks (**Hegazy*et al*., 2012).** By sintering mixes of dried WTPS and RHA, novel lightweight bricks have been made. By using RHA samples of up to 20% weight with a heating schedule that encouraged successful organic burn-out. The porosity of sintered samples was increased by RHA addition. Despite the lightweight bricks, the water absorption performance is poor. The bricks will allow more water absorption due to increased porosity of RHA. To overcome this, the effect of firing temperatures on the absorption of water is due to the fact that rising firing temperature ensures that the crystallisation process is completed and the open pores in the sinter are closed.

Table 2. Additives used in manufacturing of WTPS.

Additives	Strengths	Compressive strength	Water absorption	References
2 and 5% analytical grade calcium carbonate	Increase compressive strength	19 to 23 MPa	15%	(Martirena*et al*., 2006)
Rice husk ash	Its role as filler and pozzolan	28.78 to 79.96 kg/cm^2	21.19% for 50% sludge brick and fired at 1200℃; and of 75% sludge brick fired at 1100 and 1200°C	(Hegazy*et al*., 2012)
6 and 10% Silica fume	Improve strength of brick	28.4 and 28.7 MPa	11.7 and 13.5%	(Odimegwu*et al*., 2016)
Mineral nanopowders, 5 mass % Cr_2O_3	Improve in sintering and mechanical .	35 kg/cm^2	15%	(Algamal*et al*., 2018)

Although the effect of the WTPS ratio is explained by the fact that the proportion of silica in the brick mixture decreases while increasing the sludge ratio **(Ramadan *et al*., 2008),** which reduces the intensity of the sinter and increases the open pores, the proportion of RHA particles decreases, which is distinguished by its flabby nature. The influence on increasing water absorption of the flabby nature of the RHA particles, which severely increases the open pores in the sinter, is much greater than that of reducing the content of silica.

Addition of silica fume with mix proportion of WTPS and clay result met the requirement of load-bearing brick as specified in British Standard **(Odimegwu*et al*., 2016**). Silica fume is a by-product of the development of silicon metal or ferrosilicon alloys in smelters through the use of arc furnaces. Based on its chemical composition, silica fume is a very useful and essential material for most concrete industries **(Farisi & Aiban, 2014).** It contains approximately 60.08% of silica. Since silica fume has higher silica content than in WTPS, so it can help in giving greater strength of alum sludge bricks. This is supported by **Hegazy*et al*., (2012)** stated that the silica content plays a role in giving strength to bricks.

Bricks with additives mineral nanopowder such as Cr_2O_3 shows lower linear shrinkage against temperature **(Algamal*et al*., 2018).** In addition to those containing no additives, samples containing nano additives could persist against firing. This is due to relatively higher refractories of added oxide that sustain the high temperature deformation of the bricks. Relatively higher bulk density values for the bricks corresponded to a relatively lower apparent porosity.In the modified bricks, tests water absorption test decreases. The lowest percent of water absorption is shown by Cr_2O_3. In the studied samples, low water absorption values can be explained by the degree of total porosity. As the rise in firing temperature brings out the end of the crystallisation process that covers the open pores in the sintered matrix, the increase in firing temperature results in a decrease in water absorption. The observed pattern for both WTPS and improved bricks is affected by their porosity and increased firing temperature, increasing their weathering resistance and mineral logical composition **(Farisi & Aiban, 2014).** Therefore, it can be concluded that each additive can enhance the properties of WTPS as compared to the mixture without any additives. Table 2 shows summary of additives used in the making of WTPS bricks.

V. CONCLUSION

This study showed that different additivesin compatible to be used with WTPS in brick making. The modification of sludge bricks with specified firing temperature and materials proportion is clearly feasible without compromising bricks quality. It can be concluded that the possible use of additives in the brick manufacturing industry, given the immense expense involved in treatment, is an alternative to the treatment and disposal of sludge. The application of alum sludge in building industry will offer a complete solution to the waste problem and encourage an environmentally sustainable practice with reduced or low-cost raw materials. Future studies are recommended to draw findings on the method used to lower the firing temperature which can save energy use in brick making process.

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