International Journal of Engineering & Technology, 7 (4.35) (2018) 41-47

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Review on Characterization of Sediments for Green Bricks Production

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Abstract

Accumulation of dredged sediment has raised environmental concern in various countries. Recycling of sediment into bricks is a viable solution to the environmental pollution. Concerning to the utilization of sediment in bricks, this study reviews the needs of characterization on sediment and methods of producing sediment bricks. Particle size distribution was found to be the key criteria for characterization of sediment. Sizes of particles determined the function of the sediments in the bricks. In spite of that, leachability of heavy metals is another important aspect for contaminated sediment. Cementing bricks used cementing materials as the stabilization agent to the heavy metals. It is necessary to conduct leaching test for the end-product of the sediment to ensure the heavy metals leached are within the regulatory limits. In conclusion, method of producing sediment bricks may vary due to the various characteristics of sediment for a promising environmental friendly production.

Keywords: *sediment; characterization; environmental; brick.*

1. Introduction

Reservoir sediment poses an environmental concern for all reservoirs worldwide. Accumulation of sediment in the reservoirs leads to reduction in its capacity. Mitigation measures such as dredging and erosion controls have been a common practice. Some regards dredging as a priority within the environmental recovery. However, dredged sediment can also become secondary pollution when it accumulated in landfill area.

Researchers have taken several approaches in dealing with dredged sediment problems to reduce pollution. Dredged sediment has different properties depending on the source. Sediments from seaports contain majority of sandy particles [1]; dam sediment contains greater amount of silty particles [2]; harbour sediment contains more of clayey particles [3]; lagoon sediment contains predominance of clayey particles [4] and others. Properties of sediment may vary across the locations. Unlike silty sediment from Bakhada dam in western Algeria [2], Shihmen dam in Taiwan has predominantly clayey particles [5]. Differences in the physical and chemical properties of sediment and some that were contaminated with heavy metals emerged to the needs of adding other waste or raw materials such as gypsum [6], steel-manufacturing slag [7], clay [8] and others [9,10] in order to produce safe construction materials such as bricks [11].

2. Review of Research

2.1. The Importance of Characterization of Sediment

2.1.1 Characterization of Sediment

Characterization of sediment is important in order to compare its properties to the natural clay and sand as replacement of primary material in brick production. The characterizations mainly focus on physical properties, mineralogical composition and elemental analysis.

Sediments obtained from rivers are normally characterized and compared to natural sand in terms of particle size distribution and specific gravity. In addition, plasticity is tested for sediment to replace natural clay. River sediments are normally courser as compared to lagoon and lake sediments, dominated by sand size fraction that is angular and light in colour [12]. Dredged river sediments are predominantly sand because of its greater flow velocity while dredged lagoon and reservoir sediments are sludgy and contained high percentage of fines [5]. Mezencevova et. al. [3] reported that dredged sediments extracted from lower and upper reaches of harbour are predominated by sandy particles while clay and silt particles are extracted from middle harbour and sediment basin. For sediments extracted from middle harbour, 38% of weight are found to be of silt, that is slightly higher than silt content in natural clay (34%); clay particles is 47%, which is higher than natural clay soil (40%); sand particles is 15%, which is lower than sand content in natural clay (26%). Silt exhibited non-plastic or slightly plastic behaviour that leads to lesser or no strength

when subjected to air dried, while high fraction of clay demonstrated higher surface area that requires higher amount of water to achieve the plastic state. In fact, higher ratio of silt to clay fraction in material resulted to weak and porous brick. On the other hand, insufficient sand content in the dredged sediment as compared to natural clay (26%) can be revamped by adding natural sand to the mix. This is important as the coarse fraction is significant in brick production to reduce shrinkage in firing. Moreover, sand is generally stronger than clay, that prompted to increase the compressive strength of the product [14]. Higher clay particles have indeed increased the plasticity behaviour and vice versa. For instance, sediment that has lower plasticity index such as that obtained from Dampremy-Charleroi (Belgium) lowers the plasticity nature of the mixture and decrease the bonding ability [15].
Mineralogical analysis conducted using X-ray diffraction (XRD) is important for the sediment to achieve the similar role as natural sand and clay. Sediments of Dampremy-Charleroi region (Belgium) deposited from several industrial activities areas such as coal mining, steel industry, glassworks, chemicals and electrical engineering composed mainly of quartz and marked the presence of iron oxide, calcite, feldspar, mica and sulphates. This indicated a possibility of replacing natural sand in brick production [15]. Similar to river sediment from Qinhuai River in Nanjing, China [16] and main rivers near Jacarepagua lagoon, Brazil [4] has quartz as its main mineral with lower contents of other minerals such as kaolinite. Iron and feldspars act as fluxes that promote fusion of the particles at lower temperature and possess good fluxing properties. In addition, Quartz and kaolin group (such as kaolinite, dickite, and nacrite) maintain the shape of the product during the firing process of bricks [3].
Mezencevova et. al [3] mentioned that the presence of water soluble salts are related to the formation of whitish scrum or efflorescence during the drying of bricks. The soluble salts such as sulfates of magnesium, sodium and potassium reacted with silicates during firing except for calcium sulfate ($CaSO_4$) that persisted through the firing process. Subsequently, sulfuric acid formed when SO_3 gaseous adsorbed at internal silicate surfaces tend to dissolve magnesium, sodium and potassium from crystalline phases. Salt deposition occurred when these solutions migrated to the brick surface. Furthermore, chlorides and sulphates that are present in the sediments such as SO_2, SO_3 and HCl can cause gaseous pollution during firing process.
Loss of ignition (LOI) is associated to the dehydroxylation of clay minerals, oxidation of the organic matter, decomposition of carbonates, sulphides, hydroxide and etc. [3]. Appropriate amount of organic matter contributed to the plasticity and act as pore during firing process. Nevertheless excessive amount of it will cause uneven surface texture of bricks and attraction of pollutants [15,17].

2.1.2 Heavy Metals in Sediment

Heavy metals pollution is another concern in sediments. The problematic cationic metals (positively charged cations in soil) include mercury, cadmium, lead, nickel, copper, zinc, chromium, and manganese. In addition, anionic metals (negatively charged anion in soil that combined with oxygen, eg: MoO_4^{2+}) include arsenic, molybdenum, selenium, and boron [3]. It is essential to investigate the characterization and contamination assessment of sediments in order to maximize the use of sediments as primary materials in bricks production [18–20].
Geotechnical properties and metals concentrations are mostly correlated to the distinct particle size distribution of the sediments. In finer sediments, metal concentrations are higher and plately clay materials are present in particles fraction at less than 75 µm [4,13]. Usually, coarser sediments are deposited at the rivers banks while fine sediments are transported to the reservoirs or lagoons and suspended in the water causing siltation [3]. For these reasons, heavy metals pollution in reservoirs or lagoon sediments is found to be higher than river sediments.
Locally, Khairiah et. al. [21] have studied several soil samples at Cameron Highlands in the state of Pahang and found that the soil samples are contaminated with heavy metals such as Iron (Fe), Zinc (Zn), Cadmium (Cd), Manganese (Mn), Copper (Cu) and chromium (Cr) as a result of active agricultural activities. It was also found that there are lower organic content because of the long term farming activities and use of fertilizers and farmyard manure. Organic materials formed complexes with the metals in the soil. Hence, the lower the organic matters in the soil, the higher the rate of leachable metals. Abdullah et. al. [22] found that phosphate level at Ringlet river is eight (8) times higher than the allowable standard, while nitrate is six (6) times higher due to the heavy usage of fertilizers. Besides that, soils in Brinchang and Tanah Rata, Cameron Highlands contained Cu and Cd at above level of background values [23]. Chemical control is the main approach for crops pest and diseases control in Cameron Highlands. Use of fertilizers such as phosphate fertilizers contributed to Cd content in the soils while pesticides such as fungicidal sprays contained copper sulphate and copper oxychloride contributed to Arsenic (As), Copper (Cu), and Plumbum (Pb) in the soils [21,23]. High concentration of heavy metals in the soil of Cameron Highlands has contributed to heavy metals concentration in the rivers and reservoirs sediments. Huge sizes of open farming in the areas have accelerated soil erosion due to rain splashing practises. Higher concentration of metals in the reservoirs sediment was attributed by finer grain particles with higher surface area to particles size ratio [21].
Characterization on granulometry, mineralogy, and concentration of heavy metals are always the priority while contamination indexes are being used to evaluate the anthropogenic contamination of the sediment. Several metal pollution assessment tools were used to evaluate the sediment's contamination status. Geo-accumulation (I_{geo}), contamination factor (CF) and degree of contamination (DC) are frequently used indexes that compare the total concentration of metals with background concentrations. Geo-accumulation (I_{geo}) and contamination factor (CF) are using single metal approach. Degree of contamination (DC) considers the sum of all contamination factors (CF) [18,19,24]. The contamination indexes are commonly used for classification of heavy metals pollution but they do not present adverse biological effects due to the contaminated sediments. Indeed, contamination indexes were not design for that purpose. The biological effects are usually estimated using the sediment quality guidelines (SQGs) [18]. Total concentration of heavy metals in the contamination indexes calculation can be determined by various procedures. Pena-Icart et. al. [18] calculated I_{geo} for the sediment using total concentration of metals from digestion method by HNO_3, HF and HCl solutions, while Ruiz et. al. [25] and El-Sayed et. at. [19] used concentration of metals from X-Ray Fluorescense. The contamination levels are determined by referring to the natural background values in earth's crust sedimentary rocks (regional of local) or the pre-industrial background values. The common regional background metal values in average shale by Turekian and Wedepohi [26] have been adopted for regions with no established local background metal values. These values have been adopted in various sediment contamination investigations [19,27,28].
Management of dredged sediment disposal has become an environmental and financial issue [29]. The dredged sediment may be polluted when it is associated with toxic industrial areas. It cannot be used as a direct geo-material in the construction and building sectors [10,16]. Contaminated sediments were treated before used, such as utilizing method of Novosol® process that stabilizes the heavy metals in solid matrix through phosphatation and destruction of organic matters by calcination [30]. The available fractions from anthropic sources are leached easily upon disposal where it is usually lower than the total concentration. This is due to the fraction of metals originated from rock producing sediments that are not easily leached with weak acids [4]. In addition, various treat-

ment methods have been used on contaminated soils, such as removal technique and immobilization technique. Removal technique removed metals from the soils by separation of contaminated particulates in hydrocyclones, phytoextraction or leaching methods, while immobilization technique changed the metals fractionation in the soils thus minimize its mobility. Immobilization technique includes increase of soil PH by soil liming, introducing absorbents such as clays or organoclays, addition of phosphates that formed insoluble salts with metals and soil solidification by using various hydraulic binders to stabilize metals within the soils [31].

2.2. Pozzolonic Materials in Bricks

Pozzolonic materials served as source of alumina and silica in addition to cement or lime hydration in reactions to strength development. 16-20% of calcium hydroxide (CaOH) or sometimes called portlandite is produced from Ordinary Portland Cement (OPC) during hydration process. Addition of pozzolonic materials to the mixture produced additional cementitious gels when reacted with CaOH [32]. Used of pozzolonic materials from waste is one of the alternatives in reducing usage of cement for sustainable and green manufacturing.

Alternative materials to replace cement must contain siliceous and aluminous materials. Clays are commonly used as pozzolonic materials to substitute cement in the construction materials [33]. Nurchasanah [34] has substituted cement by 10%-20% of Tulakan soil and found that it increased the concrete compressive strength at about 3%. In addition, thermally activated kaolinitic clay is found to be optimized to 30% of the blended cement [35].

In spite of evaluating alternative materials for its pozzolanic characteristics, performance of construction materials such as mortar, concrete or bricks have been tested. Some researchers showed contradictions between performance of the pozzolan in products with the specifications of the standards in order to evaluate the natural pozzolans (ASTM C618) [36]. Therefore, performances of natural pozzolans have to be tested in construction materials in addition to characterization as in accordance to the standards.

2.3. Method of Producing Brick

Development of bricks started with moulded adobe in Mesopotamia since 5000 BCE and later with fired bricks at around 3500 BCE. The use of bricks spread to Greeks, Rome, across northern Africa and later to Europe by the early thirteenth century. It became relatively inexpensive and was used by all levels of societies in the seventeenth century. Later, it was produced in large scale, shipped across long distances and was widely used as building material since the nineteenth century [37].

Firing method has been used as the traditional way for making bricks. Clays are mainly used in conjunction with Kiln firing of temperature of more than 1000°C. Before the firing process, homogeneous clays were mixed with 14%-20% of water and were then shaped by either pressing, extrusion or moulding. Later, drying of the shaped bricks was conducted progressively to remove moisture from the clay matrix until constant weight is achieved. The drying process could be air, oven or tunnel dried. The final stage is the firing and cooling process. In firing process, manufacturer used either tunnel kiln or combustion chamber. The firing and cooling were conducted progressively. Firing temperature were found to produce huge impacts to brick's properties [9,38]. Commonly, the brick manufacturers used traditional big ovens or chambers that are not able to control air distribution and fire conditions [39]. Researchers have conducted tests on firing temperature of up to 1200°C despite of the energy consumption. It was found that kaolinites and illite or montmillorite formed mullite at temperature 950°C and 1050°C respectively. This has increased the mechanical resistance of the bricks. However, mullite dissolved after 1200°C thus decreases the mechanical resistance of the bricks. On the other hand, the bricks showed high density upon melting of the mullite, hence at low porosity. In fact, many researchers have conducted tests on the potential use of waste materials in fired clay bricks. The temperature gradient of the firing has highly effected the brick porosity since various minerals in the waste materials and clays dissolved at different temperatures [39–41]. Subsequently, firing temperature of higher than 850 degree caused speedy and irreversible decay of the clay bricks [37].

An alternative to fired brick is by using pressurized vessel and elevated curing temperature at less than 100°C for alkali activated aluminosilicate brick [42–44]. This method does not produce pollution like firing method. Villagers in Senegal, Africa used seawater instead of commercially produced silicates. Curing of bricks is conducted under a heavy tarp in the sun. Optimum molarity of 8M Sodium Hydroxide (NaOH) produced durable bricks that compromised between strength and cost [45]. Nevertheless, this method is limited to raw materials or wastes containing aluminosilicate materials such as red mud, coal ashes, metal processing slag and others. On the contrary, fuel wastes such as biomass, petroleum residues, paper mill sludge and others are not suitable for geopolymer bricks [46].

Carbon dioxide emissions from firing processes of natural gas combustion released 248-271 kg CO_2/t of fired products. It is one of the main energy consumptions [9,47]. For geopolymer bricks, heating chambers or electric ovens that consumed energy are required when space for curing under hot sun is not available. Hence, compressed earth brick technology is another alternative to clay fired bricks or geopolymer bricks that has the advantage of not requiring high temperature curing and compaction that can be achieved by using hydraulic rams or levers [14]. In the compressed brick technology, cement is normally used as the binder and water is added for cement hydration. It is also frequently used as plasticizer to aid the particle flow, rearrangement and deformation. Compaction is essential to enhance cement stabilization and improves the strength development at minimum cement content. Study has found that 3 to 7 MPa pressure is sufficient to produce cemented soil blocks [48]. However, increasing pressure upon compaction of soil blocks leads to increase of soil density, decrease of void ratio, reduce of soil porosity and water permeability, increase of water resistance and thus enhance its durability [49]. Wattanasiriwech et. al [48] used pressure of up to 75 MPa and it was found that by increasing the degree of compaction, the bricks met the required compressive strength within 14 days instead of 28 days for bricks that were compressed by 25 MPa pressure.

In short, the aforementioned methods have its drawbacks regardless of pollution caused by the firing, large carbon footprint associated to the usage of cement and restriction of raw materials containing solid aluminosilicate for geopolymerization. As far as the energy consumption is concerned, many studies have been conducted to reduce the energy consumption [46]. For example, Saikia et. al. [50] found that the use of dried sludge with calorific value of 18,213 kJ/kg could reduce energy consumption for fired ceramic. Therefore, it can be concluded that there is no best method of producing bricks but rather subjected to the availability of raw materials and facilities in the area.

2.4. Sediment in Bricks

Many studies were conducted on contaminated sediments that are mixed with clay to form bricks by firing or pressing method [6,8,10,16,30,40,46,51]. The following sub-sections described the use of sediment in bricks using both manufacturing methods.

2.4.1. Sediments in Fired Bricks

Fired bricks are commonly used as building materials for decades. Many researchers have been working on utilization of waste materials in fired bricks. Reviews of studies on this subject matter have been conducted by several researchers such as Raut et. al [52], Zhang [40] and Monteiro and Vieira [46]. However, limited studies were found on utilizing sediment in fired bricks [3,5–8,15,16,53].

Relatively high chloride content in the sediment such as harbor sediment poses concern to the environment where it causes dioxin/furan emission when subjected to high temperature [7,53]. Wei et. al. [7] have tested harbor sediment mixed with steel slag and discovered that specimens fired at 1100°C showed that level of dioxin/furan is seven (7) times higher than that sintered at 950°C. The authors suggested two possible explanations for this observation. It is either due to the escape rate or formation rate of the dioxin/furans upon sintering.

Sediments that comprised of fine sands and silty clay were utilized at 50-80% of amount in fired clay bricks [8,54] where some are mixture of gypsum instead of clay [6]. The bricks were mostly heated at temperature 105°C to evaporate the moisture, then sintered at 1000°C [3,15], 1100°C [6,7,53,54] or up to 1150°C [8]. Wei et. al. [53] found that the new crystalline phase formed at the sintering temperature of 1050°C. High temperature leads to loss in crystalline composition, at the same time it also formed a new phase of crystalline composition. These newly formed glassy phases could provide envelope capturing the bloating gases that leads to formation of pores in the specimens' core regions. Thus, lighter specimens were formed. The formation of glassy phases then covered the surface pores and connects the surface pores with the inner pores, thus impeded the water absorption [7,53].

In addition, densification is found to occur at the temperature range of 1000-1050°C, thus this increased the compressive strength, bulk density and thermal conductivity. Moreover, sediment melts at high temperature and has considerable viscosity properties (thermoplastic glass-phase) [6]. Although Xu. et. al. [54] reported that thermal conductivity of the brick decreased by 40% with addition of river sediment, but the total porosity of the brick has increased. Macro pores are formed during the combustion of the organic matter in the sediment at earlier stage of firing temperature below 1000°C, which is responsible for the significant decrease of the thermal conductivity and compressive strength. The specimen was further improved by firing with temperature of up to 1050°C and resulted in higher bulk density and modified micro structure.

Sediment was found feasible to be used as sand or clay replacement in fired bricks depending on the properties of the sediment. Efforts to maximize the utilization of sediment are not limited to partial replacement in fired brick. Studies have also been conducted in using 100% sediment in producing lightweight aggregate pellet by preheating at 500-700°C followed by expansion at 1100-1200°C. The sintering process produced a significant vitreous phase that resulted in porous synthetic aggregates containing isolated and irregular pores. The lightweight aggregates were used to produce concrete masonry units [5].

2.4.2. Sediments in Unfired Bricks

Unfired bricks rely on the degree of compaction to densify the bricks and cementing materials to bind and solidify the materials. A review has been conducted by Zhang [40] on the production of bricks through cementing using waste materials. Waste materials such as fly ash, sludge, recycle paper mill, gold mill tailings, recycle aggregates and etc were mixed with cementing materials such as OPC, hydrated lime, alumina cement, slag cement and etc, moulded in conjunction with certain degree of compaction or some were heated in ventilated oven. However, none of the dredged sediments were discussed in this review on the production of blocks through cementing. This review [40] covered only on the use of river sediments in brick production through firing up to 1000°C by Samara [15] and Mezencevova [3] as aforementioned sub-section.

Method through cementing is basically establishing hydration reactions forming Calcium Silicate Hydrate (C-S-H) and Calcium Aluminate Sulphate Hydrate (C-A-S-H) phases that contributed to the strength [40]. Table 1 shows studies conducted on bricks made of sediment through cementing method. The sediments' sources are either from water dam, harbors, reservoirs or water channels. Cementing materials such as cement or lime production waste were used together with compaction and some in conjunction with vibration. These bricks do not need to be sintered, steam or water cured. This method is energy conserved and reduced CO_2 footprint [55]. Solidification or stabilization using cement immobilized the heavy metals within the sediment through fixation and physical retention, which limits the availability and mobility of the contaminants by forming monolithic products [31].

Serbah et. al. [2] amended the highly plastic silt sediments from Bakhada water dam in western Algeria with 30% of natural sand to produce compressed earth blocks by using modified optimum proctor with increasing compacting energy by 25 blows. It was found that decreasing water content at about 11% showed increased in unconfined compressive strength by three times.

Mymrin et. al. [1] utilized small sandy particles of seaport sediments from Paranagua Port, Brazil with construction and demolition debris, and lime production waste that cured in open air to produce a composite civil construction material. The experiment showed that up to 60% sediments can be used in combination with 20-35% construction and demolition debris and 15-30% lime production waste.

Lei Wang et. al. [56] combined 15% of harbor and water channel sediments with binary cement which contained magnesium oxide cement and ordinary Portland cement, later curing with CO_2 for one day and subsequently at 7 days of air curing were conducted. The binary cement provided sufficient magnesium hydrates for metal sequestration but the used of magnesium oxide cement has weakened the compressive strength and increased the water absorption of sediment bricks. Therefore, the authors introduced curing by CO_2 to transform the soluble magnesium hydrate into stable carbonates and densify the microstructure. It also reduced the porosity that enabled a substantial enhancement in strength as well as carbon sequestration. The subsequent air curing resumed the carbonation and hydration of the binary cement, thus increase the strength.

Cheng et. al [57] proposed to use hydropower plant reservoir sediment and cement to produce non-sintered cured brick by high pressure and 28 days of natural conservancy curing. It was observed that the bricks produced have higher density and lower water absorption than clay bricks. It was also found that the higher

Table 1: Studies on production of bricks using sediment through cementing method.

	Sediment source	Cementing materials	Type of samples	Compaction method	Curing method	Various test conducted
[2]	Water dam	-	Compressed earth blocks	Modified optimum proctor +25blows	Wrapped with plastic film	Drying-wetting paths and unconfined compressive strength test.
[1]	Seaports	Lime production waste	Composite civil construction material	10 MPa compaction	Open air	Uniaxial compression strength, linear expansion, water absorption and density, XRD, SEM, EDS, and LAMMA.
[56]	Harbors and	Binary cement	Paving blocks	30 MPa compac-	1 day CO_2	Compressive strength, water

	water channels	(magnesium oxide cement and OPC)		tion	curing and 7 days air curing	absorption, TCLP, porosity, SEM, Thermogravimetric analysis and XRD.
[17]	Harbor	Cement	60mmx198mmx163mm paving blocks	High frequency vibration and compaction of 120 bars pressure applied simultaneously	1 day in open area then transported to storage area	Splitting tensile strength, water absorption, leaching, and abrasion resistance.
[57]	Hydropower plant reservoir sediment	Cement	240mmx115mmx53mm bricks	High pressure	28 days of natural conservancy	Density, compressive strength, water absorption, dry shrinkage and relative moisture content, frost resistance, carbonation coefficient and softening coefficient, size variations, appearance and quality.

the moisture content in the brick, the more shrinkage can occur.

Said et. al. [17] utilized marine sediments from Rades Harbor which are characterized as sandy silty clay (semi-spread distribution) with high plastic silt and soft consistency as partial replacement of quartz sand. It was mixed with cement and was applied with high frequency vibration and compaction of 120 bars pressure simultaneously to produce paving blocks. The blocks were cured in open area for one (1) day before being transported for storage. The authors found that the early strength (initial setting) of blocks was delayed due to the presence of organic matter in the sediment. Water absorption is lower in the blocks due to the well compacted particles when sediment is added. This is also due to the mineralogical composition of the sediment that is comparable to the material used as fillers. Furthermore, carbonation increases the impermeability of the blocks due to blockage of some pores by carbonate, thus the capillary absorption is reduced. Incorporation of sediment has improved the abrasive performance of blocks due to the presence of fines that enhanced the compaction of granular particles. Besides that, metal concentrations in blocks have remarkably decrease as compared to gross sediment metal concentrations. This is justified by the trapping of sediments in mortar matrix due to stabilization of cement.

3. Discussions

In general, characterization of sediments emphasized on the heavy metals assessment and organic pollution [24,27,28,58–63]. Nevertheless, particle size distribution of the sediments is the significant characteristic and certainly an important criterion for utilization of sediment in brick production [2], with heavy metals assessment that focused on the leachability of the heavy metals [17].

Particle size distribution determined percentage of the granular that further indicate its functionality, either to replace sand or clay in brick production. Nonetheless, other characterization such as plasticity, mineralogy, organic content and etc. are also important and essential for the characterization. Fired clay bricks mainly favor to kaolinite (clay) and high plasticity sediments while medium to low plasticity or high silica content (sand or silt) sediments are preferable for compressed bricks with addition of other pozzolonic materials as the binding agent. Presence of clay is required in compressed bricks as natural binder, however excessive amount of clay would cause shrinkage [2].

The trend of using sediment in cementing/ non-sintered bricks started on 2014 [57]. The sediment was first used as sand replacement and later used as substitution of sand. In perspective, the study of full utilization of sediment as the primary material in cementing brick is essential. Table 2 shows characterization outcome of sediments for cementing bricks. Particle sizes are matters for replacing natural materials such as sand and clay or for the sediment to be amended or treated. It can be seen that leachability of heavy metals is important for contaminated sediments.

Y.L Cheng et. al. [57] defined green production as production towards zero pollution by restricting conservation of raw materials and energy. Sintering process is generally not a choice for green production due to the CO_2 and dioxin/furan emission that caused secondary pollution. However, S. N. Monteiro and C. M. F Vieira [46] proposed of using waste materials as fuel to reduce energy consumed for the fired brick production thus increase the possibility of fabricating fired bricks with lower embodied energy than cemented brick. Hence, assessment tools such as the Life Cycle Analysis (LCA) and the Carbon Footprint Analysis could be used for the environmental evaluation [64].

Table 2: Sediment characterization outcome for cementing bricks

	Sediment source	Year of Publication	Particle size distribution	Heavy metal leachability	Outcome of characterization	Modification/Use of the sediment
[2]	Water dam	2018	10% sand, 56% silt, 34%clay.	No leaching test conducted.	Sediments are much finer than the standard recommendation.	Amended with natural sand.
[1]	Seaports	2017	76.72% particles nearly 0.149 mm diameter; 10.3% particles larger than 0.149 mm diameter and 10.62% smaller than 0.149 mm diameter.	No heavy metals detected from XRF analysis.	Brazilian standard classify the sediment as small sands.	Recycled as fine aggregates, mixed with construction & demolition debris and lime production waste.
[56]	Harbors and water channels	2017	6.1% sand, 74.8% silt, 19.1% clay	Sediment were highly contaminated but the heavy metals leaching from the bricks were accordance to USEPA.	TCLP results indicated that the contaminated sediment was unacceptable for site formation purpose (i.e. use as fill materials).	Recycled as fine aggregates, mixed with natural coarse aggregate and binary cement (OPC and magnesium oxide cement).
[17]	Harbor	2015	Gross sediment (GS) -	GS was classified	GS was found to be weakly	Pretreatment has been con-

			sandy silty clay with 90% fines. Sandy soil (SS) - no cohesive and friable sands.	as non-hazardous wastes according to Netherlands standard. Leached metals concentrations of PS remarkably decreased compared to leached metals concentrations of GS.	organic soils (3.25% organic matter); high plastic silt with soft consistency; high sulfate content (1900mg/L) that could be harmful to be reuse in cementitious or concrete material.	ducted onto GS and SS and produced pretreatment sediment (PS) which slightly gravelly sand with relatively high percentage of fines compared to crushing sand, moderately aggressive of sulfate content. PS was used as sand replacement with substitution ratio of 19% in paving blocks.
[57]	Hydropower plant reservoir sediment	2014	Sediment were mixed with other uncontaminated solid wastes such as masonry waste, demolition waste, stone dust etc. and cement to produce non-sintered bricks. No characterization of sediment been conducted.			

4. Conclusion

The importance of sediment characterization, method of producing bricks using sediment and utilization of sediment in fired and unfired bricks has been reviewed. Characterization of the sediment is one of the fundamental aspects in brick production since the source of the sedimentation could be from various backgrounds due to the overwhelmed development. This includes heavy metals assessment that is essential to determine suitable pozzolan or treatment that could stabilize the heavy metals. Cementing and geopolymerization are other options as compared to firing method in producing sediment bricks. The advantages include lower embodied energy method that evade carbon dioxide and dioxin/furan emission and densification issues due to minerals in sediment and clay that dissolve at different temperatures. However, methods to produce bricks are very much dependent on the resources of primary material which include wastes and local facilities. As a result, this will incur high impacts on the local economic and environmental aspects

Acknowledgement

This study is sponsored by MyBrain scholarship 2012. The authors would like to thank TNB Research Sdn. Bhd and TNB Sultan Yussuf Jor Power Generation Station for granting the project under code U-SN-CR-13-21.

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