Jurnal
Teknologi

Full Paper

PROPERTIES AND PERFORMANCE OF WATER TREATMENT SLUDGE (WTS)-CLAY BRICKS

Mohd Asri Md Nor[a*], Alia Syafiqah Abdul Hamed[a], Faisal Hj Ali[a], Ong Keat Khim[b]

[a]Department of Civil Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur, Malaysia
[b]Department of Chemistry/Biology, Centre for Defence Foundation Studies, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur, Malaysia

Article history
Received
15 July 2015
Received in revised form
1 October 2015
Accepted
25 October 2015

*Corresponding author
asrinor@upnm.edu.my

Graphical abstract

Abstract

Every year, large quantity of water treatment sludge (WTS) is produced from water treatment plant in Malaysia. Sanitary landfill disposal of sludge at authorized sites is the common practice in Malaysia. However, searching the suitable site for landfill is the major problem as the amount of sludge produced keeps on increasing. Reuse of the sludge could be an alternative to disposal. This study investigated the reusability of WTS as brick making material. The performance of clay-WTS bricks produced by mixing clay with different percentages of WTS with increments of 20% from 0% up to 100% was investigated. Each molded brick with optimum moisture content was pressed under constant pressure, oven-dried at 100˚C for 24 hours followed by heating at 600˚C for 2 hours and 1000˚C for 3 hours. Scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy dispersive X-ray (EDX) analysis were used to characterize clay, WTS and clay-WTS bricks. The performance of the bricks were evaluated with firing shrinkage, loss on ignition (LOI), water absorption, bulk density, and compressive strength tests. Increasing the sludge content results in a decrease of brick firing shrinkage, and increase of water absorption and compressive strength. The results revealed that the brick with 100% by weight of sludge could generate the highest compressive strength of 17.123N/mm^2. It can be concluded that the bricks with 20 to 100% of water treatment sludge comply with the Malaysian Standard MS7.6:1972, which can fulfill the general requirement for usage of clay bricks in wall construction.

Keywords: Water treatment sludge, clay brick, recycling waste, brick making

Abstrak

Setiap tahun, kuantiti enapcemar yang banyak dihasilkan daripada loji rawatan air di Malaysia. Kaedah pelupusan di tapak pelupusan sanitari enapcemar yang dibenarkan adalah amalan biasa di Malaysia. Walau bagaimanapun, mencari tapak yang sesuai untuk pelupusan adalah masalah utama kerana jumlah enapcemar yang dihasilkan terus meningkat dari tahun ke tahun. Penggunaan semula enapcemar boleh menjadi alternatif kepada kaedah sedia ada. Penyelidikan ini mengkaji tentang potensi enapcemar untuk menjadi bahan dalam pembuatan batu bata. Prestasi batu-bata daripada campuran tanah liat dan enapcemar, dengan mencampurkan tanah liat dengan peratusan enapcemar yang berbeza, iaitu dengan kenaikan sebanyak 20% daripada 0% sehingga 100% telah dikaji. Setiap bata dibentuk dengan kandungan lembapan yang optimum ditekan di bawah tekanan yang sama, di keringkan di dalam ketuhar pada suhu 100˚C selama 24 jam diikuti dengan pemanasan pada 600˚C selama 2 jam dan 1000˚C selama 3 jam. Analisis Mikroskop imbasan elektron (SEM), sinar-X pembelauan (XRD) dan tenaga serakan X-ray (EDX) telah digunakan untuk mengkaji pencirian tanah liat dan enapcemar . Bagi mengkaji prestasi batu bata, ujian seperti pengecutan, kehilangan akibat pemanasan, penyerapan air, ketumpatan pukal, dan ujian kekuatan mampatan telah dijalankan. Hasil kajian menunjukkan, semakin banyak kandungan enapcemar, semakin menurun nilai pengecutan akibat pembakaran dan semakin meningkat nilai penyerapan air dan kekuatan mampatan. Hasil kajian turut menunjukkan, bata dengan 100% mengikut berat enapcemar mampu menjana kekuatan mampatan yang paling tinggi iaitu 17.123N / mm2. Sebagai kesimpulannya, batu bata dengan 20 hingga 100% daripada enapcemar daripada loji rawatan air mematuhi standard Malaysia MS7.6: 1972 , iaitu boleh memenuhi keperluan umum untuk penggunaan bata tanah liat dalam industri pembinaan.

Kata kunci: Enapcemar rawatan air, bata tanah liat, bahan buangan kitar semula, pembuatan bata

1.0 INTRODUCTION

There are more than 450 water treatment plants (WTPs) in Malaysia which produces more than 400,000 million liters per day (MLD) of treated water, and this production of clean water has generated large amount of sludge [1]. It was estimated that 491,902.87 metric tons of water treatment sludge (WTS) was produced and managed in 2013 [2]. Untreated or treated sludge is disposed to surface water, deep well injection, spray irrigation disposal in drain field or borehole, discharge to sanitary sewer collection and land application. However, these approaches may cause environmental hazards in long term application. An alternative to disposal is utilization of sludge which will reduce cost, amount of sludge to be disposed and also reduce the environmental-hazards.

Various waste materials such as, petroleum effluent treatment plant sludge [3], sewage sludge [4], water treatment residual (WTR) and excavation waste soil [5], textile effluent treatment plant sludge [6], cigarette butts [7], water treatment sludge and rice husk [8], paper sludge and palm oil fuel ash [9], silica fume and rice husk ash [10], shipyard repair and maintenance hazardous waste [11] have been incorporated in brick production.

According to Ramadan (2008) , mineralogical composition of the WTS is particularly similar to that of clay and shale, which promotes the application of water treatment sludge in brick manufacture. A number of studies have revealed that sludge can be used as construction materials after being assessed in term of mechanical technique and environmental effects [14 -18]. However, there has been little discussion focusing on complete replacement of WTS in clay brick manufacture. Most of the studies focusing to utilize the WTS proportion up to 50% only and it was concluded that only up to 50 % was the optimum sludge proportion to produce sludge-clay brick.

This study explores the possibility of utilizing local WTS as clay replacement in bricks under the criteria of Malaysian Standard MS 7.6:1972. The clay bricks were characterized using SEM and XRD, whereas the performance of the clay bricks was evaluated using criteria such as firing shrinkage, loss on ignition (LOI), water absorption, bulk density, and compressive strength.

2.0 EXPERIMENTAL PROCEDURES

2.1 Preparation of Clay and WTS

The clay used in this study was collected from a local brick plant located at Kuala Kubu Bharu, Selangor. The WTS was obtained from a water treatment plant in Putrajaya.

Clay and WTS samples were air-dried. The dried clay and WTS were then crushed using hammer. Sieving of both samples were done according to Malaysian Standard MS 7.6:197. These samples were sieved through 3.5-mm sieve size. The fine materials passed through the sieve were collected for research use.

2.2 Preparation of WTS - Clay Bricks

Six WTS-clay ratios were studied. WTS proportion by weight from 0% up to 100 % of total weight with increments of 20 % by were added into clay. The optimum amounts of water to be added for each WTS-clay ratio were determined based on the ordinary compaction test described in British Standard BS 1377:1990 to obtain the optimum moisture content (OMC). Besides, 100% clay samples were prepared as control samples.

After proper proportion of WTS-clay was prepared and hand-mixed, optimum amount of water was added. The mixture was then remixed until uniform moist mixture is formed. The moist WTS-clay mixture was then placed in a steel mould and uni-axially pressed using Universal Testing Machine (UTM) (Instron, 5569A) as shown in Figure 1. The applied pressure was 15kN and application speed was 10 mm/min. Finished size of each moist brick sample was 50mm x 50mm x 50mm. Considering series of brick tests at the end of this research, a total of 72 specimens were prepared in the laboratory by hand where each test was done in triplicates.

The moist brick samples were then oven-dried for 24 hours at 100˚C. If this moisture was not removed, the water will burn off too quickly during firing, causing cracking. For the heating process, the molded mixtures were then heated in laboratory furnace (Nabertherm, LT15/13) from room temperature to a peak temperature of 1000˚C at heating rate of 5˚C/min. Heating profile is as shown in Figure 2. The temperature was held at 600˚C for 2 hours and at 1000˚C for 3 hours. Heating profile used in this study is similarly close to heating profile for novel lightweight bricks produced by Chiang and colleagues [8]. For the cooling process, the samples were then left to cool in open air until reaching room temperature.

2.3 Characterization of Clay, WTS and Clay-WTS Bricks

2.3.1 Scanning Electron Microscopy/ Energy Dispersive X-ray (SEM/EDX)

The clean and dry samples of clay, WTS and clay-WTS bricks were coated with gold by a sputter coater before analyzed using scanning electron microscopy(SEM) (Hitachi,F3400N) in order to examine the surface morphologies and using electron dispersive x-ray (EDX) (Thermo Scientific, Noransystem6) to determine elemental compositions of the samples.

2.3.2 X-ray Diffractometer (XRD) test

The structures of clay, WTS and clay-WTS bricks samples were investigated using a x-ray diffractometer (XRD) (Bruker, D8 Advance) at voltage of 40 kV and current of 40 mA with Cu radiation of the wavelength in 2θ range from 0 to 80°.The diffraction pattern conforms the peaks of quartz (SiO_2), and kaolinite($Al_2Si_2O_5(OH)_4$) in clay.

2.4 Performance Evaluation of Brick Samples

The performance of bricks samples were evaluated by several tests as listed in Table 1.

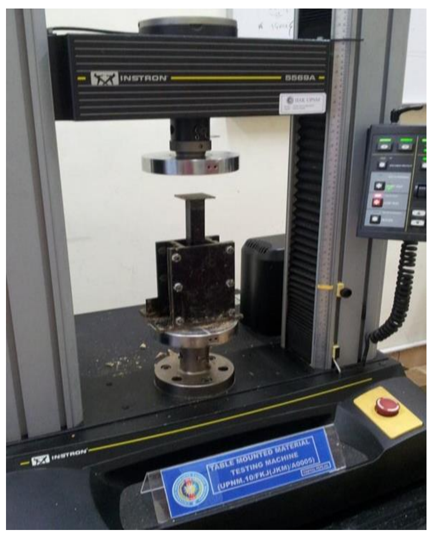


Figure 1 Bricks Compaction Process using Universal Testing Machine (UTM, Instron, 5569A)

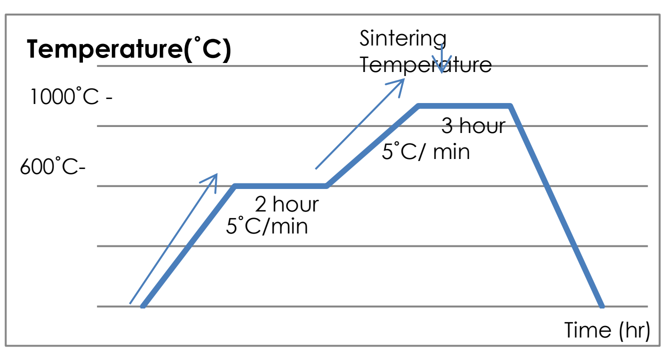


Figure 2 Temperature Profile used to heat sample

Table 1 Method used for testing of samples

Analysis of sample	Test Used
Optimum Moisture Content (OMC)	ASTM D 698
Sieve analysis of soils	ASTM D 422
Compressive Strength, Firing Shrinkage, Water Absorption	MS 76 : 1972

3.0 RESULT AND DISCUSSION

3.1 Characterization of Clay, WTS and Clay-WTS Bricks

3.1.1 XRD Analysis

The diffraction pattern conforms the peaks of quartz (SiO_2), and kaolinite ($Al_2Si_2O_5(OH)_4$) in clay as shown in Figure 3 (a). Similar peaks were observed for WTS (Figure 3 (b), showing that WTS has similar compounds as clay. Figure 4(a)-(f) shows XRD patterns of bricks which prepared from clay and mixture of clay and WTS. Clay brick is mainly consists of silicon oxide and aluminium silicate and quartz as displayed in Figure 4 (a). Bricks which prepared from the mixture of clay and WTS (20 to 60% by weight) mainly consist of quartz and mullite, where as bricks prepared from clay and 80 to 100% by weight of WTS mainly contain quartz and aluminium oxide silicate, quartz and aluminium silicon oxide, respectively.

The results clearly indicated that similar substances were found in both clay and clay-WTS bricks. Hence, it can be said that the clay-WTS brick could be a good brick candidate in construction field

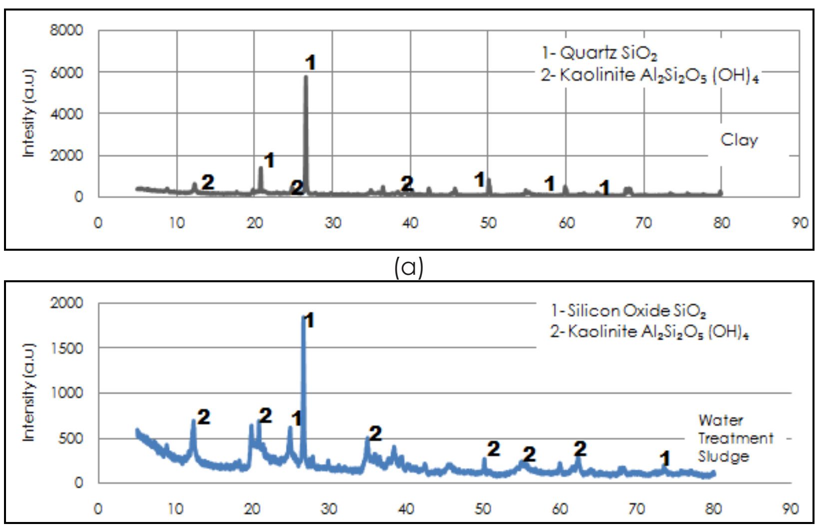
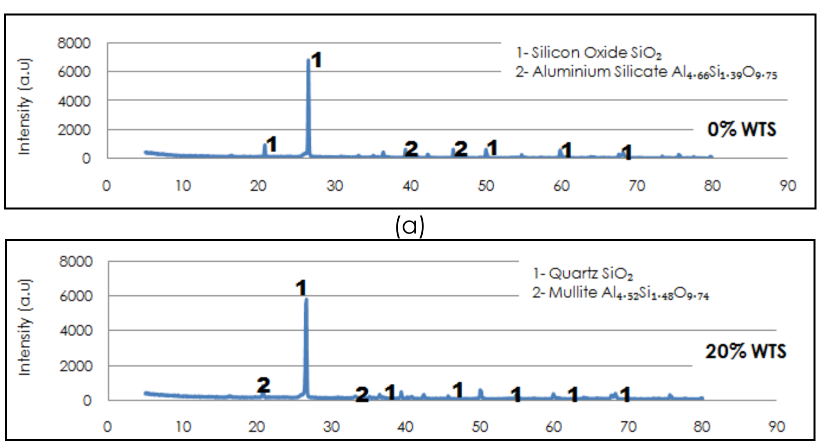


Figure 3 X-ray Diffraction of (a) Clay and (b) WTS



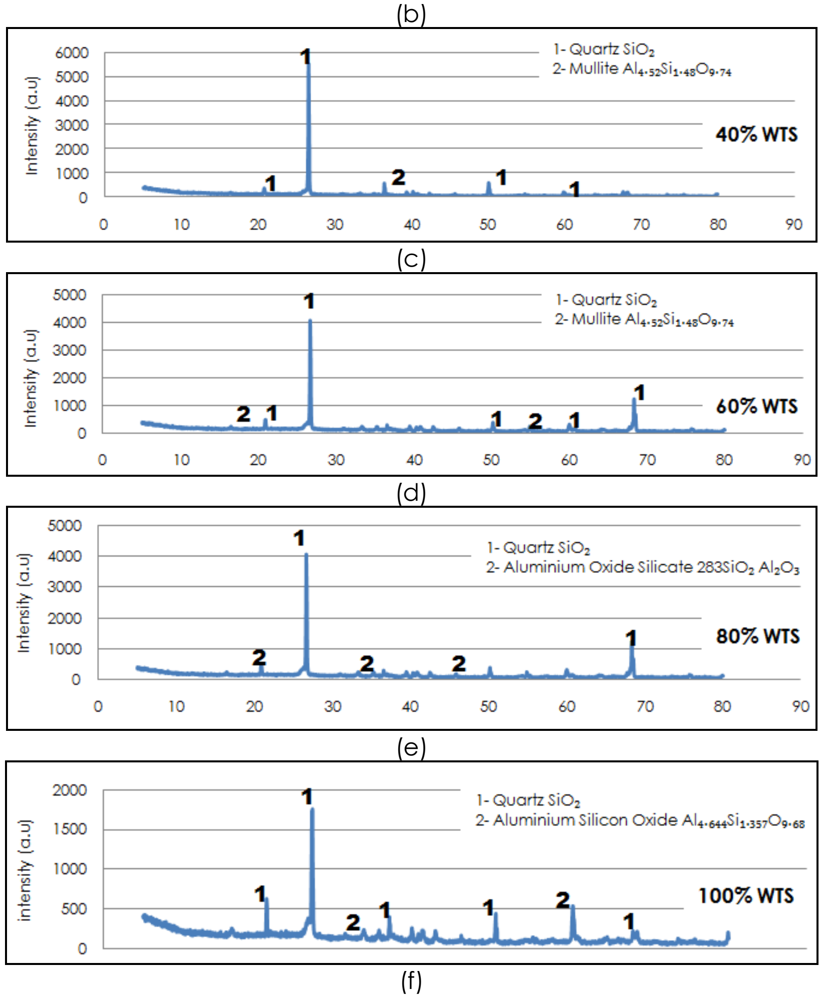


Figure 4 XRD pattern for sintered bricks for sintered bricks: (a) 0% WTS ratio, (b) 20% WTS ratio, (c)40% WTS ratio, (d) 60% WTS ratio, (e) 80% WTS ratio, and (f) 100% WTS ratio

3.1.2 Scanning Electron Microscopy (SEM) Analysis

The surface structures of clay and WTS can be observed from SEM micrographs at 3000x magnification as shown in Figure (5) (a) and (b), respectively. The results showed that the surface of clay is porous and has different sizes of granular, while the surface of WTS also porous and has irregular shapes and sizes of flakes.

Table 2 presents the elemental compositions of clay and WTS. The results revealed that the main elements found in both clay and WTS are aluminum, silicon and oxygen. Hence, it can be concluded that WTS has similar elemental composition with clay.

SEM micrographs of clay-WTS bricks are displayed in Figure 6(a)-(f). The results revealed that its microstructure consist of irregular shape material and contained lots of pores on the surface. The SEM images shows that brick with higher WTS content had more small pores compared to clay brick samples. This factor causing the increase of water absorbed and can be proved by the water absorption results in Figure 9. Due to the large amounts of open pores, sintered products also have good thermal insulation properties for future green building applications.

3.2 Particle size distribution and Optimum moisture content of Clay and WTS

The sieve analysis test consists of mechanically separating different soil particle ranges by using a stack of standard metal sieve meshes [12]. Figure 7 shows the particle size distribution of clay and WTS used in this research. According to AASTHO classifications, both samples were classified as sandy clay and uniformly graded soils.

The optimum amounts of water were determined from compaction test described in British Standard BS 1377:1990) to obtain the optimum moisture content (OMC). Table 3 shows the result of the optimum moisture content (OMC) tests. The clay used in this study has OMC value 18% and the WTS have OMC value 36%. The higher amount of WTS, more water needs to be added in WTS - clay brick.

3.3 Compressive strength of brick

The compressive strength test is the most crucial test to determine the engineering quality of building materials. In this study, Universal Testing Machine (UTM, Instron, 5569A) was used to measure the compressive strength of bricks.

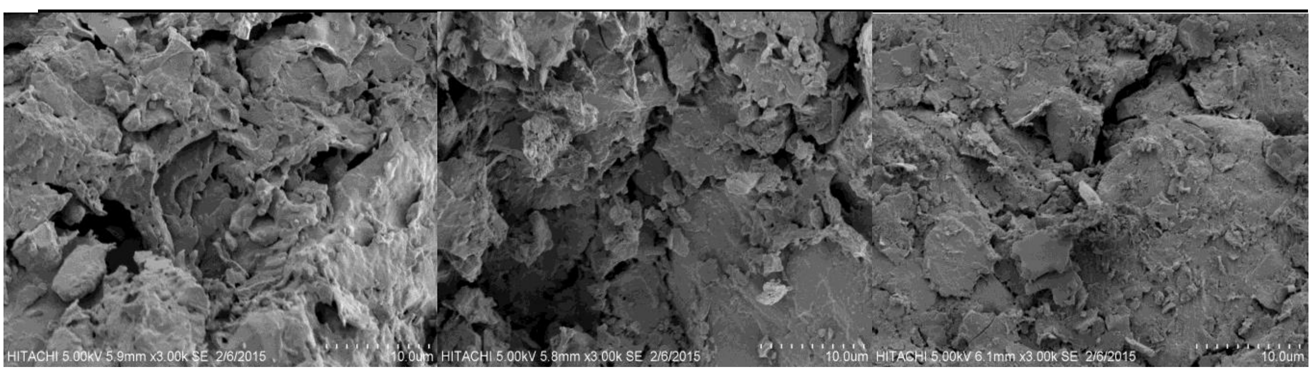
Figure 8 shows the results which indicate that the compressive strength of WTS-clay bricks is increased as WTS was increased up to 100% addition. The compressive strength was found to be increased from 4.52 to 17.123 N/mm², for brick containing 20 %, to 100% WTS respectively. The plot of graph reveals that the strength of WTS-clay brick is higher than the control brick for WTS replacement of more than 60 %. According to MS 7.6:1972, bricks with this WTS content also complied with the minimum limits of class 1 and 2, load bearing bricks as shown in Table 4.

On top of that, bricks with up to 40% WTS content can also be used as construction material for one and two storey dwelling houses and internal walls. 20% WTS content brick satisfied the minimum requirement for non-load bearing partition bricks and making all the bricks complied with minimum limits for compressive strength of MS 7.6:1972.

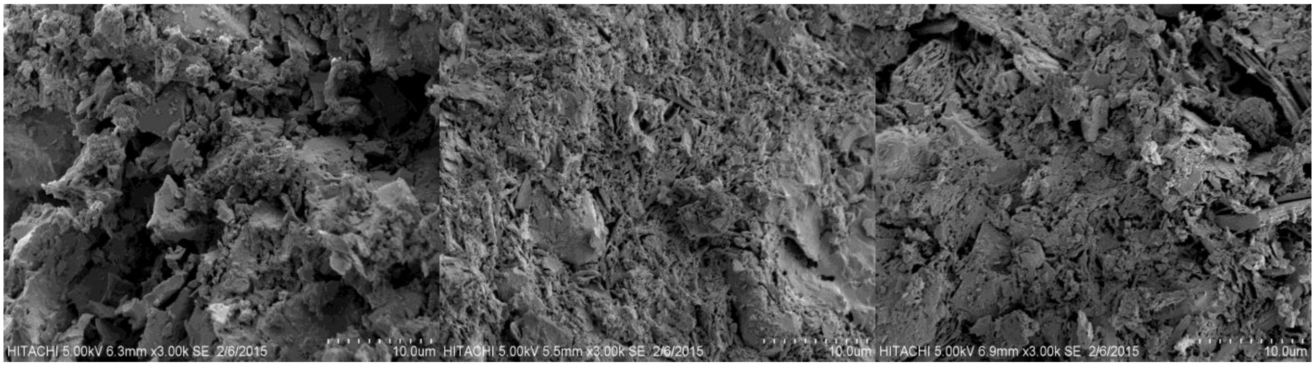
Figure 5 Scanning Electron Microscopy (SEM) Micrographs of (a) Clay and (b) WTS

Table 2 Elemental composition of Clay and WTS

Compound (%)	*O*	*F*	*Al*	*Si*	*K*	*In*
Clay	64.65	2.11	14.58	16.91	1.76	---
Water Treatment Sludge (WTS)	65.75	---	11.42	15.52	---	7.31



(a) (a) 0% WTS ratio (b) 20 % WTS ratio (c) 40 % WTS ratio



(d) 60% WTS ratio (e) 80% WTS ratio (f) 100% WTS ratio

Figure 6 Scanning Electron Microscopy (SEM) micrograph at 3000X magnification for sintered bricks :(a)0% WTS ratio,(b) 20% WTS ratio, (c)40% WTS ratio, (d) 60% WTS ratio, (e) 80% WTS ratio, and (f) 100% WTS ratio

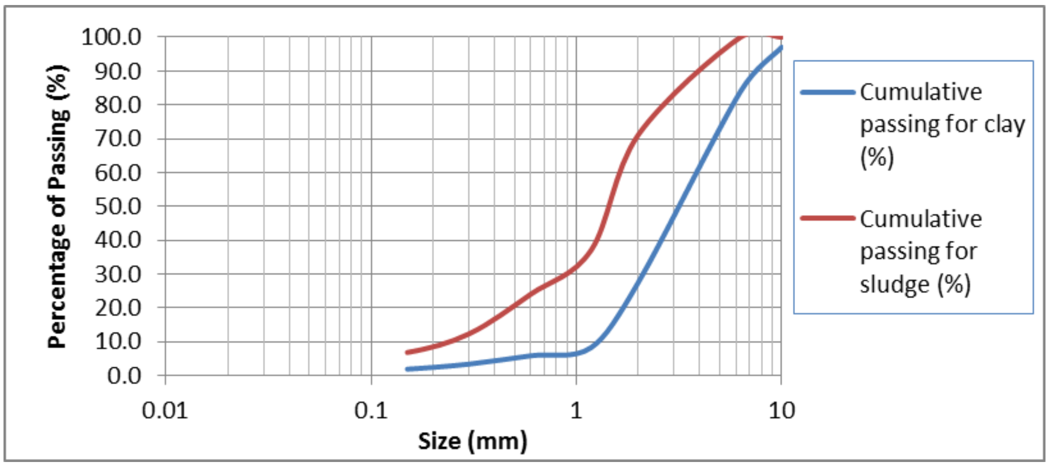


Figure 7 Particle size distribution of clay and WTS

Table 3 Optimum Moisture Content for brick production

WTS to Clay Proportion (%)	0%	20 %	40 %	60%	80%	100%
Optimum Moisture Content (%)	18	22	25	29	32	36
Dry Density	1.93	1.74	1.56	1.42	1.33	1.21

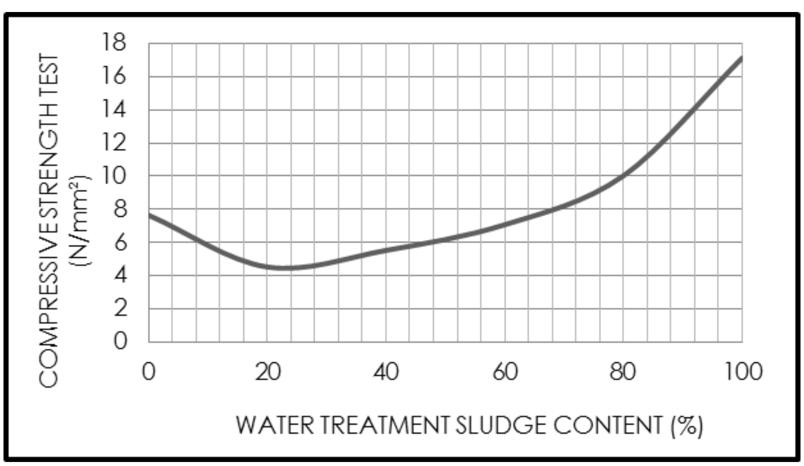


Figure 8 The compressive strength test result

3.4 Water Absorption Of Brick

For water absorption test as mentioned in MS7.6:1972, the specimen were kept submerged in electronic water bath (Chemopharm, Julabo f34), boiled continuously within 5 hours, and then cooled at room temperature for 19 hours. This test is important as a key factor affecting the durability of brick. More durability of the brick and resistance to the natural environment is expected, when lesser water infiltrates into the brick [17]. Thus, the internal structure of the brick must be intensive enough to avoid the intrusion of water.

Figure 9 shows that the water absorption for the bricks is increased with the increase of WTS composition. When the bricks contain high percentage of WTS, the adhesiveness of the composition will decrease and the internal pores of the brick will increase. This factor causing the increase of water absorbed. The SEM images in Figure 6 proved that brick with higher WTS content had more small pores compared to clay brick samples. Referring to Malaysian Standard MS7.6:1972, the bricks in this research meets the load bearing brick requirement, but not for engineering brick and damp proof brick as shown in Table 5.

Table 4 The compressive strength test result and the minimum limits according to MS7.2:19.72

Water Treatment WTS Content Composition (%)	Minimum limit for Compressive Strength (N/mm²)									Value obtained
	Engineering brick		Load bearing brick					Non- load bearing partition bricks	Damp-proof course bricks	
	A	B	1	2	3	1 and 2 storey dwelling houses	Internal walls			
0	>69.0	>48.5	>7.0	>14.0	>20.5	>5.2	>5.2	>1.4	As required	7.636
20										4.520
40										5.523
60										7.072
80										10.020
100										17.123

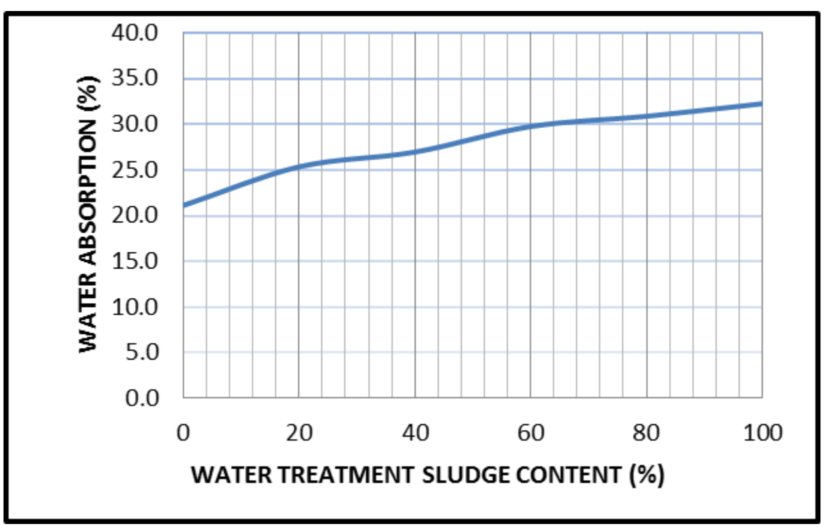


Figure 9 The water absorption test result

Table 5 The water absorption test result and the maximum limits according to MS7.2:19.72

WTS Content Composition (%)	Maximum limit for (N/mm²)				Value obtained
	Engineering brick		Load bearing brick	Damp-proof course bricks	
	A	B			
0	<4.5	<7.0	No specific requirement	<4.5	21.068
20					25.298
40					26.911
60					29.711
80					30.823
100					32.199

3.4 Density of Brick

Figure 10 shows the result of density for WTS-clay brick before (blue line) and after sintering process (red line). The density of brick is calculated as mass per unit volume. As shown, the density of brick is decrease with the increase of WTS proportion. The density of brick before sintering process is decrease from 2.345 to 1.882 g/cm^3 as the WTS proportion is increase, and the density of brick after sintering process also decrease from 1.885 to 1.328 g/cm^3 as the WTS proportion is increase.

This finding closely related to the water absorption test as shown in figure 9. When the bricks have higher water absorption value, the brick exhibits a larger voids size, resulting in a light density bricks [18]. As shown in figure 11, it can be seen visually that the bricks decreased in size with the increase of WTS content. Water loss due to high temperature applied during sintering process is the one of the reason the density is decrease as the increase of the WTS proportion.

Low density brick produce a lightweight bricks, which have become an important trend for green buildings. This is because lightweight bricks reduce the building weight. The numbers of inner pores in lightweight bricks are much greater than in traditional bricks. Lightweight bricks have a relatively low thermal conductivity property that can be applied to reducing the building's energy use. [8]

3.5 Brick Weight Loss On Ignition

Figure 12 shows the effect of WTS content on the weight loss on ignition after sintering. It is shows that increasing the WTS content resulted in increases in brick weight loss on ignition. The weight loss was increased from 19.6% to 36.9% for WTS content up to 100% respectively. Apparently, this occurs because of the contribution of organic and inorganic matter being burnt off from WTS during the firing process.

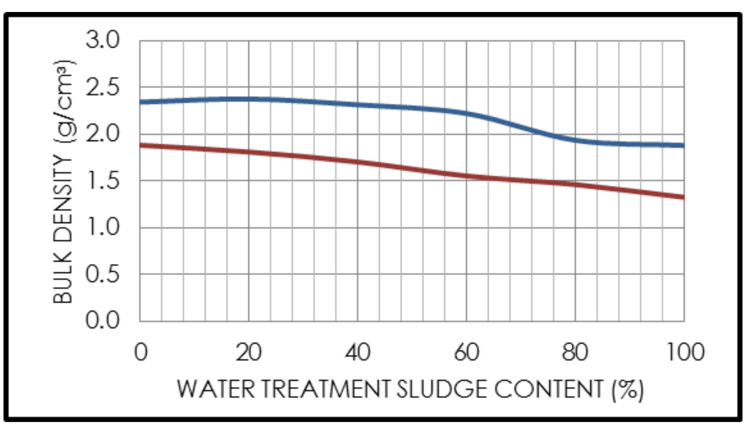


Figure 10 The density test result

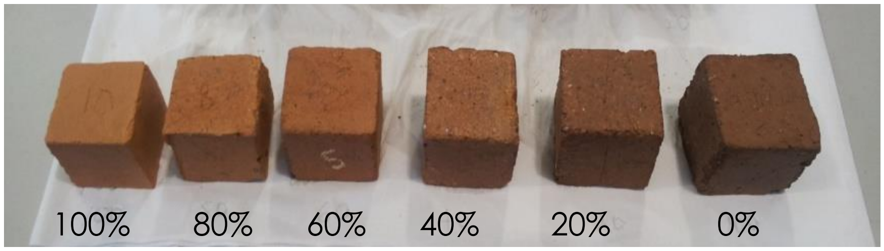


Figure 11 The brick samples with 0 to 100% WTS composition

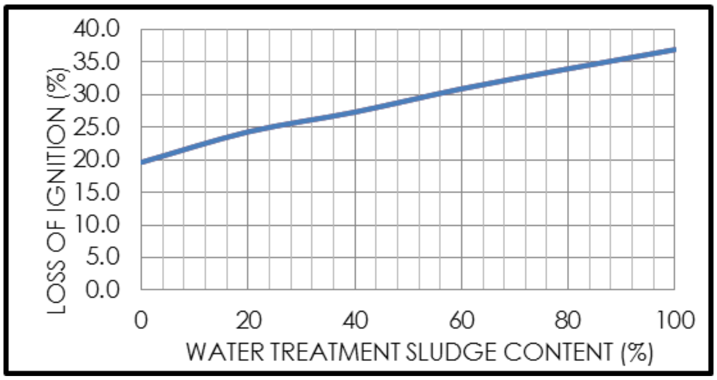


Figure 12 The Loss on Ignition test result

4.0 CONCLUSION

This research study examined the characteristics performance of fired clay mixed with varying amounts of WTS. These following conclusions are presented:

1. By taking into consideration all analysis has been done in this research, the application of the brick produced was summarized in Table 6.

Table 6 Application of WTS - clay bricks corresponding to MS 7.6:1972

WTS-Clay Brick WTS Content (%)	MS 7.6:1972 : Brick categories
0	• Load bearing class 1 • Non load bearing partitions • Load bearing 1- and 2- storey dwelling houses • Load bearing Internal walls
20	• Non load bearing partitions
40	• Non load bearing partitions
60	• Load bearing class 1 • Non load bearing partitions • Load bearing 1- and 2- storey dwelling houses • Load bearing Internal walls
80	• Load bearing class 1 • Non load bearing partitions • Load bearing 1- and 2- storey dwelling houses • Load bearing Internal walls
100	• Load bearing class 1 • Load bearing class 2
	• Non load bearing partitions • Load bearing 1- and 2- storey dwelling houses • Load bearing Internal walls

2. Clay-WTS combination produces a lightweight bricks, which have become an important trend for green buildings. This is because lightweight bricks reduce the building weight. The numbers of inner pores in lightweight bricks are much greater than in traditional bricks. Lightweight bricks have a relatively low thermal conductivity property that can be applied to reducing the building's energy use.

3. The proportion of WTS in the mixture is the key factor that affects the quality of the brick. The chemical, mechanical and chemical properties of the bricks produced generally complied with MS 7.6:1972.

4. For future work, leaching test, as described in Method 1311 Toxicity Characteristic Leaching Procedure (TCLP) will be performed and analyze using inductive coupled plasma optical emission spectroscopy (ICP-OES) and Atomic Absorption Spectrophotometer (AAS) to investigate the leach ability of metals from clay-WTS.

Acknowledgement

The authors acknowledge the Ministry of Higher Education Malaysia for providing the financial fund through this Exploratory Research Grant Scheme, ERGS/1/2013/STWN01/UPNM/02/02. The support of Konsortium ABASS Sdn Bhd Water Treatment Plant, Malaysia is gratefully acknowledged.

References

[1] Malaysian Water Association (MWA) 2013. *Malaysia Water Industry Guide 2013*. MWA,.Kuala Lumpur.

[2] Department of Environment, Malaysia (DOE) 2013."Schedule Wastes Inventory." *Malaysia Environmental Quality Report 2011*. 137-149. DOE, Kuala Lumpur.

[3] Sengupta, P., Saikia, N., &Borthakur, P. C. 2002. Bricks from Petroleum Effluent Treatment Plant Sludge : Properties and Environmental Characteristics. *Journal of Environmental Engineering*.128: 1090–1094.

[4] Liew, A. G., Idris, A., Wong, C. H. K., Samad, A. A., Noor, M. J. M. M., &Baki, A. M. 2004. Reusability of sewage sludge in clay bricks. *Waste Management & Research : The Journal of the International Solid Wastes and Public Cleansing Association. ISWA*. *22*: 226–233.

[5] Huang C, Pan JR, Sun KD, Liaw CT. 2001. Reuse of treatment plant sludge and dam sediments in brick making. *Journal of Environmental Engineering*. 127: 922-927.

[6] Balasubramanian, J., Sabumon, P. C., Lazar, J. U., &Ilangovan, R. 2006. Reuse of textile effluent treatment plant sludge in building materials. *Waste Management*. *26*: 22–28.

[7] Kadir, A. A., &Mohajerani, A. 2008. Physico-mechanical properties and leachate analysis of clay fired bricks incorporated with cigarette butts, *2008*(Icenv).

[8] Chiang, K. Y., Chou, P. H., Hua, C. R., Chien, K. L., &Cheeseman, C. (2009). Lightweight bricks manufactured from water treatment sludge and rice husks. *Journal of Hazardous Materials*. 171: 76–82.

[9] Ismail, M., Ismail, M. A., Lau, S. K., Muhammad, B., & Majid, Z. 2012. Fabrication of Bricks From Paper Sludge And Palm Oil Fuel Ash, *Concrete Research Letters*. 60–66.

[10] Hegazy, B. E. E., Fouad, H. A., &Hassanain, A. M. 2012. Incorporation of water sludge , silica fume , and rice husk ash in brick making. Advances in Environmental Research. 1(1): 83–96.

[11] Salleh, S., Shaaban, G., Mahmud, H. B., Kang, J., Looi, K. T., & Materials, A. 2014. Production of Bricks from Shipyard Repair and Maintenance Hazardous Waste. *International Journal of Environmental Science and Development*. *5*(1): 52–55.

[12] Fratta. D, Aguettant J., Smith L.R. 2007 Introduction to soil mechanics laboratory testing, CRC Press, Taylor & Francis Group.

[13] Malaysian Standard, Department of Standard Malaysia 2010. MS 7.6:1972 .1972. General specification of bricks.

[14] Mahbub, K., Fukushi, K., Turikuzzaman, K., &Moniruzzaman, S. M. (2013). Effects of using arsenic – iron sludge wastes in brick making. *Waste Management*. 1-6.

[15] Mohammed, H., Hamid, R., Rozaimah, S., Abdullah, S., Tan, N., & Raihan, M. 2013. Physical and Mechanical Properties of High Performance Concrete with Alum Sludge as Partial Cement Replacement. *Jurnal Teknologi*. 2: 105–112.

[16] Ramadan, M. O., Fouad, H. A., &Hassanain, A. M. 2008. Reuse of Water Treatment Plant Sludge in Brick Manufacturing. *Journal of Applied Sciences Research*. *4*(10): 1223–1229.

[17] Sulthana, B. S., &Gandhimathi, B. R. 2013. Utilization of textile effluent wastewater treatment plant sludge as brick material. *Journal Material Cycle Waste Management*. 15: 564-570

[18] Victoria, A. N. 2013. Characterization and performance evaluation of water works sludge as bricks material. *International Journal of Engineering and Applied Sciences*. *3*(3): 69–79.