PHYSICAL AND TOXICOLOGICAL PROPERTIES OF WATER TREATMENT RESIDUE INCORPORATED CLAY BRICKS

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FACULTY OF ENGINEERING
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Abstract

Water Treatment Residue (WTR) disposal is a major issue in most parts of the world as well as in Malaysia due to its huge quantity. It is estimated that WTR weighs at 2 % of the total treated water quantity. In 2014, Malaysia produces 16,000 million L/d (MLD) of drinking water. Only 30 % of the Malaysia Water Treatment Plant operates with sludge treatment and treated effluent discharge to water course. The characteristic of the WTR depends on the quality of river water (water source) and the type of coagulants used. Common chemical coagulants used in Malaysia are alum ($AlSO_4$) and poly-aluminum chloride (PAC). These chemical coagulants generates residue which containing aluminium which is classified as scheduled wastes (SW 204) under Environmental Quality Act 1974, Environmental Quality (Schedule Wastes) Regulation 2005. This research study focused to reuse a portion of WTR as raw material which can be used as plasticizer with laterite earth for clay bricks manufacturing process. The research project investigated physical and mechanical properties of WTR Bricks such as compressive strength, efflorescence effects, bulk density, water absorption, weight reduction according to BS/EN Standard, loss of ignition, toxicity and ecotoxic analysis. The results indicates best combination for laboratory size brick of 40% WTR – 60% Laterite and commercial size bricks 30% WTR – 70% Laterite.”.

Keywords: water treatment residue, clay bricks, green bricks, alum sludge, reuse alum sludge

SIFAT-SIFAT FIZIKAL DAN TOKSIKOLOGI BAGI BATU BATA YANG MENGANDUNGI RESIDU RAWATAN AIR BATU

Abstrak

Pelupusan residu rawatan air merupakan isu utama di sebahagian besar dunia dan Malaysia disebabkan kuantitinya yang amat banyak. Residu rawatan air dianggarkan mempunyai keberatan sebanyak 2% daripada jumlah kuantiti air terawat. Pada tahun 2014, Malaysia menghasilkan 16,000 juta L / sehari (JLS) air minuman. Hanya 30% Loji Rawatan Air Malaysia beroperasi dengan sistem rawatan enapcemar dan pembuangan efluen terawat ke aliran air. Ciri-ciri sisa air bergantung pada kualiti air sungai (sumber air) dan jenis bahan kimia koagulasi yang digunakan. Bahan kimia untuk koagulasi yang digunakan di Malaysia ialah tawas (AlSO4) dan poli-aluminium klorida (PAC). Bahan koagulasi kimia ini menghasilkan sisa yang mengandungi aluminium yang diklasifikasikan sebagai sisa terjadual di bawah Akta Kualiti Alam Sekeliling 1974, Peraturan Kualiti Alam Sekeliling (Buangan Terjadual) 2005. Kajian penyelidikan ini berfokus dalam menggunakan semula sebahagian residu rawatan air sebagai bahan mentah yang dapat digunakan sebagai bahan pemplastik dengan tanah laterit untuk proses pembuatan batu bata tanah liat. Projek penyelidikan mengkaji ciri-ciri fizikal dan mekanikal Batu Bata WTR seperti kekuatan mampatan, kesan efloresen, ketumpatan pukal, penyerapan air, penurunan berat mengikut Standard BS / EN, kehilangan pencucuhan, ketoksikan dan analisis ekotoksik. Hasil kajian ini menunjukkan gabungan 40% sisa air - 60% laterit yang bersaiz makmal dan 30 WTR dan 70% laterit untuk batu bata bersaiz komersial adalah lebih baik berbanding dengan batu bata pembuatan tempatan.

Kata kunci: sisa air, batu bata tanah liat, bata hijau, slaj alum, pengunaan semula

Sludge alum,

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LIST OF SYMBOLS AND ABBREVIATIONS

For examples:

WTP	:	Water Treatment Plant
WTR	:	Water Treatment Residue
EQA	:	Environmental Quality Act 1974
$Al(SO_4)_2$	:	Aluminum Sulphate
H_2SO_4	:	Sulphuric Acid
SiO_2	:	Silicone Oxide
Fe_2O_3	:	Ferric Oxide
AI_2O_3	:	Aluminum Oxide
CaO	:	Calcium Oxide
MgO	:	Magnesium Oxide
SO_3	:	Sulphur Oxide
Na_2O	:	Natrium Oxide
K_2O	:	Kalium Oxide
CI	:	Chlorine
MnO	:	Manganese Oxide
LOI	:	Loss of Ignition

ICP-OES	:	Inductively Coupled Plasma Optical Emission spectroscopy
BS EN	:	British Standard / European Standard
MS	:	Malaysian Standard
SW 846	:	Solid Waste 846 (Test Method)
TCLP	:	Toxicity Characteristic Leaching Procedure.

CHAPTER 1:INTRODUCTION

1.1 Overview

Water is an essential need for human daily needs and consumptions. Production of potable water is to ensure clean and safe water for consumption of human being. Contaminants are removed from raw water through series of treatment to produce potable water. Aluminum sulphate (alum) is widely used for treatment of raw water. The alum coagulates impurities which is removed through sedimentation and filtration processes.

In Malaysia, water treatment process generates by-products known as water treatment residue which is classified as scheduled wastes with code SW204. This implies that water treatment residue requires special handling and disposal method which is heavily regulation by law. It was estimated that two (2) percent volume of sludge is generated of every cubic meter of water produced (Yoshiko Goto, 2013). Hence, water treatment residue is generated in huge quantities which cause disposal issues among water treatment plant operators. Apart from disposal related issues, the increasing environmental awareness among general public has resulted in ever increasing pressure on water production industry to develop and implement safer disposal techniques. Moreover, researchers have linked aluminum's contributory influence to occurrence of Alzheimer's, children mental retardation, and the common effects of heavy metals accumulation, (Prakhar & Arup, 1998).

1.2 Problem statement

Even though posing very minimal health risks, water treatment residue is classified as schedule waste SW204 despites efforts of declassification of water treatment residue from schedule waste. From literature review and current practice reveal that abundance water treatment residuals generated daily with lacking of treatment facilities. Upgrading water treatment plants with water treatment residual facility will involve billions of ringgits. This type of upgrading will directly impact production cost of every cubic meter of water. Therefore, an economical method to treat these water treatments residual and an efficient conversion as a value added of these water treatment residues are required. The research focuses and develops a method to treat the water treatment residue and to convert water treatment residue to clay bricks.

1.3 Aims and objectives

The current research mainly focuses on developing a feasible formulation to maximise incorporation of WTR into clay bricks to convert water treatment residue into a value-added product. In order to achieve this main target, the following are specific objectives covered in this work:

- ✓ To develop an optimal formulation for incorporating WTR into clay bricks
- ✓ To develop an optimal firing temperature ramp (samples using fresh clay bricks from clay brick manufacturing)
- ✓ To conduct analyses on WTR clay bricks for the best composition from formulation. (as per General Brick Specification as per Malaysia Standard MS 76: 1972 / British Standard BS 3921: 1985).
- ✓ To conduct toxicity studies on WTR clay bricks.

1.4 Thesis structure

This thesis will be presented in 5 Chapters.

Chapter 1: Introduction

In this chapter, the process of potable water treatment is introduced. The explanation highlights the generation of water treatment residue which is classified as scheduled wastes. Problem statement for this study was discussed in this chapter. Details for aim and objectives were pointed for this study.

Chapter 2: Literature review

Chapter 2 on literature review explains how water treatment residue is generated, classification of water treatment residue, Malaysian water operator compliance for water treatment residue and physical and chemical of the water treatment residue are discussed. Comparison of the studies reuse of water treatment residue was discussed.

Chapter 3: Material and Methods

This chapter is on the preparation of raw material, characterisation of raw materials and final product characterisation for this study are discussed in details.

Chapter 4: Results and discussion

Chapter 4 is on the research findings and its interpretations are discussed and detailed according to research methodology.

Chapter 5: Conclusion

In this chapter the conclusion for this research work is discussed and listed. The conclusion is based on the aim and objective of this research work.

Chapter 6: Recommendations

The recommendations for the future research works on this field of studies are listed discussed in chapter 6.

CHAPTER 2:LITERATURE REVIEW

For more than a century, the primary goal of a water treatment plant (WTP) has remained the same: produce water that is biologically and chemically safe, noncorrosive, and non-scaling and is appealing to consumers. In pursuit of that goal, water suppliers produce residuals as a result of the treatment process. Aluminum sulphate with trade name of alum widely used all over the world for water treatment process due to its availability and economical reasons (Sales & de Souza, 2009). Treatment process produces water treatment residue (alum sludge) by removing impurities such as suspended solids, heavy metals, and organic matters.

2.1 Water Treatment Process

Water treatment is a process that improves quality of water by removing impurities. The production of portable water varies depending on the type of raw water. Raw water refers to natural water source found in the environment, such as rainwater, ground water, lakes, rivers and sea water. Types of available water treatment processes are conventional water process, dissolve air flotation treatment process, and desalination/distillation water treatment process. Water treatment processes depends on the water sources and raw water quality. For example, seawater treatment for drinking water goes through distillation or desalination process while river water goes through coagulation, flocculation and chlorination.

River water treatment process involves removal of contaminants from raw water to produce drinkable or potable water for human consumption. The contaminants removed during the treatment process are suspended solid, bacteria, algae, viruses, fungi, and minerals such as manganese, iron, and aluminium. This contaminant is removed via physical processes, chemical processes and biological processes. Physical processes for water treatment are screening, settling and filtration. Chemical processes are such as disinfection, coagulation and flocculation. Biological processes are slow sand filtration and oxidization.

Conventional water treatment for potable drinking standard primarily involves pre-screening, clarification and disinfection. The treatment of raw water (surface water) begins with intake screens to prevent debris (dead plants, large solids and etc.) and fish from entering the water treatment plant which can damage pumps and other component. Clarification process involves chemical treatment and physical treatment. Chemical treatment such as coagulation and flocculation are used to bind together suspended and dissolved solid into larger, heavier mass off solids called floc. The most common chemicals (coagulants) used in coagulation and flocculation is aluminum sulphate (alum). Other chemicals, such as ferric sulpate, ferric chloride, poly aluminum chloride (PAC) or sodium aluminate, may also be used depending on water quality and water treatment design. Coagulation and flocculation involves two stages: rapid mixing after adding coagulant and slow mixing. Rapid mixing is to disperse the coagulants evenly throughout the raw water ensuring chemical reaction is widespread. After the rapid mixing a gentle agitation continues to promote particle collisions and enhance the growth of floc. The next stage in water treatment process is sedimentation. Sedimentation is uses gravity to settle heavier floc from water. Sedimentation also sometimes incorporated with incline plate to promote faster settling of the floc. Then the clarified water is channel to filtration to remove smaller floc that carries over from sedimentation stage. Filtration is a physical process that removes these floc and other impurities from water by percolating it downward through layer sand. Suspended particles become trapped within the filter media, which also remove harmful protozoa and natural colour. After water passes through sand filtration the clear water disinfected and adjust the pH according potable water standard. Disinfection stage is to destroy pathogenic bacteria and is essential to prevent the spread of waterborne disease (Nathanson, 2014). Water treatment residue (settled and filtrated floc) forms or generated at coagulation process and accumulated at sedimentation and filtration stage.

2.2 Water Treatment Residue (Alum Sludge)

Alum is an mixed aluminum salt with composition of $M\text{-}Al(SO_4)_2\text{-}12H_2O$ where M is either potassium ion ($K\text{-}Al(SO_4)_2\text{-}12H_2O$) or ammonium ion ($NH_4\text{-}Al(SO_4)_2\text{-}12H_2O$) (G. J. Bugbee & Frink, 1985).

$$2\ Al(OH)_3 + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O \quad \text{R1}$$

Gelatinous precipitation of aluminum hydroxide is formed when alum is hydrolysing in the raw water. The hydrolysis is forming aluminum ion (Al^{3+}) which reacted with water to form Hydrogen ions (H^+) as follows:

$$Al(OH)_3 + 3H^+ = A1^{3+} + 3H_20 \quad \text{R2}$$

Therefore, the aluminum sulphate forms aluminum hydroxide ($Al(OH)_3$) and Sulphuric Acid (H_2SO_4). This process wills targets turbidity and natural organic substances from raw water. The mechanism of the removal of turbidity can be achieved by charge neutralization and aluminum hydroxide ($Al(OH)_3$) precipitation. Positive charge of hydroxo polymer of aluminum will adsorb negative charged particles and promotes for aggregation to occur at flocculation process. While at precipitation involves formation gelatinous aluminum hydroxide which collides and aggregate with the turbidity. Raw water which contains various types of particles will conglomerate into larger flocs and settled at sedimentation tank or filtered via sand filtration beds (B. G. J. Bugbee et al., 1985; Dassanayake et al., 2015; Snodgrass et al., 1984; Trinh & Kang, 2011).

Departmental of Environmental (DOE) Malaysia classified water treatment residual as schedule waste SW204. According to Environmental Quality (Scheduled Wastes) Regulations, 2005 requires hazardous wastes to be properly packaged, labeled and stored. Waste generators are responsible to ensure that the scheduled wastes generated and stored temporarily in their premises pending further treatment or disposal, are managed according to the above stated Regulations. Amongst the vital elements for proper management of scheduled wastes are the selection of suitable location for storage, design of storage area, selection of storage containers and the use of appropriate labelling based on hazardous characteristics, as well as good practices in managing or handling the scheduled wastes containers. These elements are crucial as to prevent leakages or spillages of scheduled wastes which could pose immediate danger to the workers and lead to contamination to its surrounding environment (Jabatan Alam Sekitar, 2012).

Complex federal, state, and local guidelines govern the management, transport, disposal, and recycling of these residuals generated by treatment facilities (Anderson et al., 2003). In Malaysia, common type of sludge treatment facility is sludge lagoon as shown in Table 2.1 (Yoshiko Goto, 2013).

Table 2.1: Design Capacity, Production and Sludge Treatment Facility at Water Treatment Plants in Malaysia

No.	State	No. WTP	Water Treatment Plant (MLD)		Sludge Treatment Facility, %
			Design	Production	
1	Perlis	5	289	218	25
2	Kedah	36	1300	1326	35
3	Penang	9	1497	988	33
4	Perak	46	1789	1215	9
5	Selangor	34	4606	4563	65
6	N. Sembilan	22	793	736	22
7	Melaka	8	556	487	50
8	Johor	44	1986	1508	26
9	Pahang	80	1300	1065	No data
10	Terengganu	13	906	638	27
11	Kelantan	32	480	430	3
12	WP Labuan	6	104	64	100
13	Sabah	67	1286	1132	No data
14	Sarawak	85	1529	1165	No data
Total		487	18421	15535	≈ 30

Disposal options for residuals are subject to many regulations that significantly influence disposal cost. Residual disposal into surface waters must comply with the Environmental Quality Act 1974 under regulation Environmental Quality (Industrial Effluent) Regulation 2009. Residuals discharged into publicly owned treatment works are also regulated under the Environmental Quality (Schedules Wastes) Regulation 2005. These discharges are subjected to Special Management Approval under regulation 7 Environmental Quality (Scheduled Wastes) Regulation 2005 and other limitations generally imposed by the publicly owned treatment works through a permit, a local ordinance, or both and Jabatan Alam Sekitar.

2.3 Physical and engineering properties of water treatment residual

Studies have shown the diversity of physical and chemical properties of WTP residuals. The properties of WTP residual are influenced by (Aldeeb et al., 2003; Babatunde & Zhao, 2007):

- Raw water source and its contaminants (river water, ground water and spring water: contaminations such as organic and non-organic materials),
- Process of the water treatment systems, (type of coagulants, dosage of coagulants, treatment systems such as conventional, dissolve air floatation, Ultrafiltration.)
- Dewatering and drying.

The characteristics of WTP residuals vary from plant, quality of water, treatment process and processing method for dewatering (Aldeeb et al., 2003). WTP residuals are commonly disposed by discharging to lower water stream and landfills. Examples of engineering properties include dry unit weight, particle size distribution, specific resistance, plasticity, compaction, and shear strength. Researchers have investigated the engineering properties of WTP residuals. Table 2.1 summaries their findings in terms of the range of values and experimental conditions. Characterisation study for physical and engineering parameter for various types of WTP residuals was conducted and reported. This study focuses on reuse the residuals with blend of natural resources to convert to clay brick (water treatment residue bricks). Aldeeb et al. (2003) reported a comprehensive compilation for physical and engineering properties until year 2003. A continuation of the compilation until 2020 is reported in this work. Knowledge of the physical and engineering properties of WTP residuals is important to ensure optimum processing, disposal, and reuse.

Research works have reported significant variability on engineering properties of WTP residuals. The range of residual soil properties under different operating conditions of the plant and experimental procedure are well established. Blending residuals with soils enhances the engineering properties of the residuals; although, the blending performance of residuals from different plants must be investigated on a case-by-case basis. Extensive information on WTP residual physical properties and the required physical properties for landfill applications is available in other references (Cornwell et al., 1992; USEPA, 1996; Vandermeyden & Cornwell, 1998; Wang et al., 1992).

Table 2.2: Physical and Engineering Properties of Water Treatment Residuals Reported in the Literature

Parameter	Value	Remarks	Reference
Unit weight (density)	1,170 kg/m^3 (73.041b/cu.ft); 20% total solids; 1.440-1,560 kg/m^3 (89.90-97.39 lb/cu.ft) 1.005g/cm^3 1.013g/cm^3 1.002g/cm^3	Dry unit weight Alum Sludge (low density) Alum Sludge (high density) Conditioned alum	(Neubauer, 1968) (Knocke & Wakeland, 1983)
Specific gravity of dry solids	2.05-2.71	Total of 16 alum residual samples were tested.	(Schenkelberg, 1995)
	1.87-2.71	Total of 10 samples from different WTPs were tested.	(Xia, 1994)
	2.02 and 2.33	Two alum-coagulated residual samples were tested.	(Raghu et al., 1997)
	2.21-2.52	After blending with natural soil that had specific gravity of 2.58	(Raghu et al., 1997)
Particle size distribution	0.002-0.039 mm (7.9 x 10-5 to 1.5 x 10-3 in.)	Alum-coagulated residuals from 16 WTPs	(Schenkelberg, 1995)
Thickness	3–10 mm	a platy aggregate with a thickness of with homogeneous water content	(Park et al., 2009)
Average particle size, D_{50}			
Modified uniformity coefficient, of D_{20}/D_{70}	2.33-34.60	A modified uniformity coefficient used instead of traditional uniformity coefficient (D_{60}/D_{10}) because D_{10} value could not be reached.	(Schenkelberg, 1995)
Percent of fines below 0.075 mm	93% and 98%	Two alum-coagulated residuals were tested after blending with topsoil having 86% fines; the percentage fines varied from 56.7 to 90.7%.	(Raghu et al., 1997)

Parameter	Value	Remarks	Reference
Specific resistance	0.1 x 1010 to 0.44 x 1010 s^2/g (0.98 x 1013 to 4.32 x 1013 m/kg)	Two alum-coagulated residual samples were tested. Filterability (specific resistance) of alum residuals could be improved using polyelectrolyte conditioners.	(Gates & McDermott, 1968)
	0.33 x 1010 to 25.40 x 1010 s^2/g (3.24 x 1013 to 24.92 x 1013 m/kg)	Total of 16 alum residual samples were tested. Specific gravity and grain size distribution are the most important parameters affecting specific resistance.	(Schenkelberg, 1995)
Plasticity			
Plasticity index	Very low	Lime/alum/polyamine-coagulated residuals	(Raghu et al., 1987)
	286% and 311%	Alum-coagulated residuals of two WTPs	(Wang et al., 1992)
	61%	Ferric-coagulated residuals	(Wang et al., 1992)
	118%	The value decreased with aging.	Raghu et al (1995)
	4.0-322.1%	Ten samples from different WTPs were tested. Not all samples showed plastic behavior.	(Xia, 1994)
	Non-plastic to 93%	Two alum residuals were tested. After blending with topsoil, values ranged from non-plastic to 18%, depending on the solid content.	(Raghu et al., 1987)
Calcium carbonate equivalence (CCE)	100 to 200 g/kg	Neutralizing power relative to pure calcium carbonate	(Elliott & Dempsey, 1991)
Total Nitrogen	4.4 -10 g/kg		
Liquid limit	423% and 550%	Alum-coagulated residuals of two WTPs	(Wang et al., 1992)

Parameter	Value	Remarks	Reference
	108%	Ferric-coagulated residuals	(Wang et al., 1992)
	330%	The value decreased with aging.	(Raghu, 1995)
	35.5-617.4%	Ten samples from different WTPs were tested.	(Xia, 1994)
	206-50%	Two alum residuals were tested. After blending with topsoil, values ranged from 42 to 73%, depending on the solids content.	(Raghu et al., 1997)
Proctor compaction test			
Modified test	65% optimum water content 51 lb/cu ft (8.2 kN/m3) maximum dry unit weight	Lime/alum/polyamine-coagulated residuals. One-hump moisture-density curve	(Raghu et al., 1987)
Standard test	17% optimum water content 105lb/cu.ft (16.8 kN/m3) maximum dry unit weight	Lime/alum/polyamine-coagulated residuals. One-hump moisture-density curve	(Raghu et al., 1987)
	45% optimum water content 72 lb/cu.ft (11.5kN/m3) maximum dry unit weight	Ferric-coagulated residuals showing one hump moisture density curve.	(Wang et al., 1992)
	No maximum dry unit weight	Two alum residuals were tested.	(Wang et al., 1992)
	41.7% optimum water content 5.0 lb/cu ft (0.8 kN/m3) maximum dry unit weight	Alum residuals were tested from dry to wet, one-hump moisture density curve.	(Raghu et al., 1987)
	36.8% optimum water content 4.7 lb/cu.ft (0.7 kN/m3) maximum dry unit weight	Alum residuals were tested from wet to dry, showing increasing pattern moisture density curve.	(Raghu et al., 1987)

Parameter	Value	Remarks	Reference
	27-61% optimum water content 9.5-14.6 kN/m3 maximum dry unit weight	Two alum residuals were blended with topsoil at different ratios.	(Raghu et al., 1987)
	50.1-83.0% optimum water content 5.40–14.64 kN/m3 maximum dry unit weight	Ten samples from different WTPs were tested from dry to wet. When tested from wet to dry,some samples had increasing pattern moisture density curve.	(Xia, 1994)
Direct shear strength	4.14 and 4.83 kPa (0.60 and 0.70 psi) cohesion factor 19.3-19.0° internal friction angle	Two alum residuals; admixing a bulking agent such as slaked lime, fly ash, or soil enhances the shear strength of the alum residuals.	(Wang et al., 1992)
	8.27 kPa (1.20 psi) cohesion factor 17.so internal friction angle	Ferric residuals	(Wang et al., 1992)
	2.4-106.8 kPa (0.35-15.49 psi) cohesion factor 3-450 internal friction angle	Ten samples from different WTPs were tested.	(Wang et al., 1992)
Unconfined compression strength	32-214 kNfm2	Blended alum residuals with topsoil at different ratios	(Raghu et al., 1987)
	70.0-316.9 kPa (1.02-45.96 psi)	Ten samples from different WTPs were tested. Some of these samples did not show maximum compressive strength.	(Xia, 1994)

2.4 Recycling and Reuse of Water Treatment Residue

Water treatment residue can potentially be utilized as useful materials through various method of process which may involve blending with other materials. Makris & O'Connor, 2007 reported that sludge recycling and re-utilization was environmental-friendly and economically feasible. Lower volume of WTR being introduced into streams would result in cheaper costs for potable water treatment.

Many studies have also pointed out the usage of sludge. The potential beneficial use of sludge include land application (Agyin-Birikorang et al., 2009; Ippolito et al., 2011; Novak & Watts, 2005; Oladeji et al., 2008; Raghu et al., 1987; Walsh et al., 2008), bricks and ceramic manufacturing (Ahmad et al., 2016; Elangovan & Subramanian, 2011; Hegazy et al., 2012; Hsieh & Raghu, 2008; C. Huang et al., 2001; Ling et al., 2017; Raghu, 1995; Ramadan et al., 2008; Safiuddin et al., 2010; Sarabia-Guarín et al., 2020; C.-H. Weng et al., 2003; Wilson, 2007; Wolff et al., 2015), land reclamation (Babatunde & Zhao, 2007; Dayton & Basta, 1997; Hsieh & Raghu, 2008), and cement production (Hsieh & Raghu, 2008; C. H. Huang & Wang, 2013; Tay et al., 2000). Water Research Foundation (WRF) has explored the potentials options for converting sludge to some useful purpose and marketing of sludge for reuse (WRF, 2020) for land application, cement and brick manufacturing, turf farming, composting and top soil and potting soil production. The Netherlands recycle 99.8% of the sludges generated from the potable water production process through a jointly established union to manage sludge recycling and explore potential uses of WTR. Recycled WTR produced in the Netherlands are widely used for brick making, materials for road barriers, road foundation, land elevation and ballast material in construction of industrial parks (Vewin, 2020).

In Malaysia, sludge recycling and reuse is a new area which is yet to be explored. WTR recycling and beneficial uses have been extensively promoted as an environment-friendly disposing method by researchers (Makris & O'Connor, 2007). Several studies were conducted on the possible uses on WTR in Malaysia. Wahid et al. (2008) reported that WTR possess the plasticity characteristic which can be beneficial when incorporated pottery products. Meanwhile, Hassan (2006), Ling et al. (2017), Syed Zin (2007), and Wahid et al., (2008) also presented findings on the potential of WTR use in ceramics. Thoo (2011) explored the conversion of WTR into pallets for power generation, material for brick making and pottery.

There have been recent reported works that discusses the physical–mechanical properties and the micro-structure of clay bricks when incorporated with the sludge of water treatment plants (SWTP) to replace clay with much success (Heniegal et al., 2020). Researchers (Gencel et al., 2021) have gone further to investigate the engineering performance of no-clay bricks having WTS, glass, and marble wastes to promote better management of WTS. Clay material has also been replaced by sludge from a groundwater treatment plant and fly ash from a thermal power plant for brick making (Trang et al., 2021).

2.5 Characteristics of WTR incorporated clay bricks

C. H. Weng et al., (2003) reported that bricks with 10% sludge and 24% moisture content are considered good quality. Goldbold et al. (2003) successfully manufactured bricks which ratio 80:20 (clay: ferric sludge from WTPs). Horth (1994) reported the addition of 5–10% of ferric sludge to clay producing good results with only a slight reduction in mechanical strength. C. Huang et al. (2001), has discovered that dam sediment mixed with 0–20% sintered WTR meets first or second level brick criteria according to the Chinese national standards. Other researchers reported that 50% and 5% addition of iron-based WTP sludge resulted in a negligible impact on the fired properties of the brick (Anderson et al., 2003; Ramadan et al., 2008). Carvalho & Antas (2005) and (Babatunde & Zhao, 2007) similarly reported that the addition of sludge to bricks in low quantities (1, 1.04, and 5%) reduced mechanical properties and increased water absorption. The authors reported possibilities of incorporating water treatment residue into bricks without negatively affecting properties of bricks. In conclusion, the quantity of WTR that should be added as a partial substitute for clay in brick manufacturing depends on the characteristics of the clay used in the process. The composition of the WTR depends largely on the composition of raw water source. There have been recent studies have reported the characteristics of conventional clay bricks (Iftikhar et al., 2020)

Standard	**Brick Description**	**Bulk Density (kg/m^3)**	**Water Absorption (%)**	**Compressive Strength (MPa)**
Chinese National Standard	1st Class Brick	1800–2000	15 (Max.)	15
	2nd Class Brick	1800–2000	19 (Max.)	9.8
ASTM	Severe Weathering	--------	--------	20.7
	Moderate Weathering	--------	--------	17.2
	Negligible Weathering	--------	--------	10.3
Indian Standard	1st class	--------	15 (Max.)	5–10 (load bearing)
	2nd Class	--------	20 (Max.)	3–5 (non-load bearing)
Brazilian Standard	--------	--------	--------	1.5 (Min.)

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In this study, the WTR generated from a 1228 MLD WTP (Water source: Sg Muda River) was used in various proportions as a partial substitute in brick manufacturing. The experiments were conducted using market size model bricks and 5 cm x 5 cm x 5 cm sample bricks. This work presents the results of the analyses of the physical and mechanical properties of the WTR-clay bricks and investigates the commercial significance.

2.6 Toxicological characteristics of conventional and WTR bricks

There have been studies focused on determining the toxicological characteristics of WTR bricks. Studies generally sparked from the fact that WTR can potentially be toxic to aquatic life (Sotero-Santos et al., 2005). Valorisation of toxic components was a potential to produce green bricks because metal concentrations met the requirements for the potential mobility and toxicity of contaminants for WTR and sludge clay bricks (Ettoumi et al., 2021). For this reason, the approach of employing WTR is more attractive and in support for increasing sludge reutilisation for WTR.

2.7 Summary

From the previous research works, an approach on the composition selection and temperature was adopted for the current study. Temperature settings were selected based on successful attempts from research works reported. These parameters affect the characteristic of the bricks produced. Temperature increment has largely influenced on the water absorption and compressive strength. While composition of the raw materials influences the compressive strength and brittleness of the bricks.

CHAPTER 3:MATERIALS AND METHOD

3.1 Raw material

In this study, two raw materials were used. The materials are water treatment residue (WTR) collected from water treatment plant and laterite bought from laterite supplier. The raw material were characterised for particle size distribution, chemical composition and moisture content.

Water treatment residue was collected from washing of sedimentation tank from water treatment plant. The concentration of the water treatment residue in wash water sedimentation tank is below 1%. The sludge was dewatered through drying beds to achieve a concentration of suspended solids in sludge not less than 50%. Drying bed as shown in Figure 3.1 was used to achieve desired moisture content of the water treatment residue. Harvested dried sludge is shown in Figure 3.2 is milled using rotary mill and sieved at mesh size of 10 mesh for mixing process. Chemical composition of WTR is summarized in Table 3.1 by x-ray fluorescence spectroscopy (XRF) at analysis laboratory. Harvested WTR in Figure 3.2 also used for wet mixing at moisture content of 50%.

Table 3.1: Chemical composition of water treatment residue

Parameter	WTR (%)
SiO_2	43.84
Fe_2O_3	7.05
AI_2O_3	28.16
CaO	0.17
MgO	0.37
SO_3	N.D.(< 0.1)
Na_2O	0.06
K_2O	1.27
CI	0.0919
MnO	0.018
LOI	28

From Table 3.1, it is obvious that the major chemical compositions of the sludge were silica, aluminum, and iron oxides, which are extremely similar to the major chemical compositions of the brick clay (Hegazy et al., 2012).

Figure 3.1: Water treatment residue pump from effluent discharge for drying.

Figure 3.2: Wet sludge collected from drying bed

Figure 3.3: Milled and sieved dried WTR

Laterite earth as shown in Figure 3.4 was collected from a brick producer for the research project. Laterites are soil types rich in iron and aluminium, formed in hot and wet tropical areas. Nearly all laterites are rusty-red because of iron oxides. They develop by intensive and long-lasting weathering of the underlying parent rock. Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. Laterite composition is shown in Table 3.2 (Saeed et al., 2015). Laterite was milled and sieved to mesh size of 10 and below to have homogeneous mixing. Figure 3.5 3.5 shows the mill used in the research work at a speed of 100 rpm for 30 – 60 minutes. Figure 3.6 is milled and sieved laterite for mixing process.

Figure 3.4: Laterite (red earth) taken from local brick manufacturer.

Table 3.2: Chemical composition of laterite

Parameter	Laterite
SiO_2	21.55
Fe_2O_3	24.31
AI_2O_3	29.4
CO_2	3.65
MgO	-
SO_3	3.98
Na_2O	0.07
K_2O	0.11
CI	-
MnO	-
LOI	-

Figure 3.5: Rotary mill used for this study

Figure 3.6: Milled and sieved laterite

3.2 WTR and laterite mixing ratio

Conventional brick making composition was adapted for this study. Composition to prepare for this research project was adopted from local clay brick producer. Clay bricks here produce using clay and laterite earth. Optimal percentage of water treatment residues for the research project was determined by making series batch of bricks with ratio of water treatment residue 0 – 100 percent. However, water treatment residue bricks with percentage more than 80 were discarded due to fragility and high rate of shrinking.

Objective 2: Mixing Ratios

Purpose of stage 1 is to obtain optimum ratio of water treatment and laterite soil. Initially 10% - 100 % sludge was decided to be added, however, the brick making process faced difficulties during the firing up. The bricks were found to be prone to breakage and shrinkage. 10%, 90%, and 100% WTR ratios were neglected as the final products were likely to be damaged. Seven ratios of water treatment residue with laterite as following Table 3.3 were experimented.

Table 3.3: Composition of WTR and Laterite

Sample Series	Percentage ,%	
	WTR	Laterite
1	80	20
2	70	30
3	60	40
4	50	50
5	40	60
6	30	70
7	20	80

Total of seven (7) series of mixing ratio is prepared to find best percentage of water treatment residue. The sizes of the bricks were prepared according to market standard with a dimension of 10 cm width × 25 cm length × 8 cm height (10×25×8). A few sample size of 5 cm width x 5 cm length x 5 cm height adapted from work reported by (Ramadan et al., 2008) was prepared to be used for characterization works. Several mixing method and preparation techniques were attempted. Two types mixing were carried out in process making bricks which is dry and wet mixing. The mixing methods used are listed below.

a) Dry Mixing

- Dried Water Treatment Residue (WTR) and Laterite (L) were ground and sieved at using wire mesh. Wire mesh size that used is 10.
- Strained WTR and laterite is dry mixed at desired ratio. (Moisture content of WTR and Laterite used at mixing about 8 ~ 10 %)

- Water added to well mixed WTR-Laterite at desired weight percentage of well mixed WTR-L (%wt).
- Partially mixed WTR-L with water well mixed using extruder mixing until homogenous of mixing obtained as show Figure 3.7 and Figure 3.8.

Figure 3.7: Hand mixing

Figure 3.8: Extrusion mixing

b) Wet Mixing

- Wet WTR collected from WTR drying beds at percentage of moisture content of 45% - 50 %. (WTR at this moisture content chosen to cater mixing with laterite without adding any additional water)
- Laterite is grinded and strained.
- Laterite mixed with wet WTR at desired weight percentage (20%wt, 30%wt, etc.)

The best sample preparation technique was found using wet sludge instead dry sludge mixing because dry sludge mixing could not achieved desired homogeneity. Extrusion mixing was used to ensure homogeneous mixing.

Bricks were moulded using metal mould and pounding method. Then extrusion mixing and pounding mould was used similar to industrial brick manufacturer. Three temperatures adopted and samples were made accordingly. The fresh moulded bricks were dried using fresh air for six to seven days for slow drying and oven dried at 100°C for 24 hours (Elangovan & Subramanian, 2011; Ramadan et al., 2008). Initial drying is important for volumetric shrinkage without cracking. It is also helps to prevent warp and crack from variation in moisture during firing.

Figure 3.9: WTR obtain from effluent discharge and dried to 50%

Figure 3.9 is showing sludge to be harvest at 50% moisture content which explained in raw material. Figure 3.10 is mould used for commercial sized bricks (10x25x8) and Figure 3.11 is mould used in lab scale bricks (5x5x5).

Figure 3.10: Brick mould (10×25×8) cm

Figure 3.11: Brick mould (5×5×5) cm

3.3 Bricks firing temperature

Firing temperature was adapted from conventional brick firing method. Based from the studies on conventional firing method founds that minimum of 12 hours of firing at temperature 1000°C – 1200°C. Series of experiment conducted to obtain firing temperature and duration.

Objective 1: Temperature Setting

Temperature setting is very important stage in making bricks. Firing bricks need an optimum temperature to prevent bricks deformation. A study has been conducted at initial stage of making bricks to obtain the optimum temperature. In this experiment bricks tested on firing temperature from 900 – 1050 degree Celsius, duration of firing from 9 hours to 12 hours and series of firing with ramping temperature setting. For this experiment, fresh bricks from conventional brick making factory was used.

Three temperature settings with ramping setting and 12 hours of duration was concluded from the experiment. Table 3.4 below exhibit the findings for the objective. The temperature ramps were developed based on laboratory scale firing of bricks. For each firing, the furnace was able to accommodate 4 bricks at a time. The furnace used is shown in Figure 3.12.

Table 3.4: Optimal ramping temperature and duration

Step	Temperature (°C)			Burning Time
	Brick A	Brick B	Brick C	
1	100	100	100	30
2	300	300	300	30
3	500	500	500	60
4	700	800	800	90
5	950	1000	1050	510

Figure 3.12: Furnace used in this studies Daihan FHP 27

3.4 Bricks characterisation

Water treatment residue bricks were tested according to standards shown in Table 3.5. According to this method the characteristic that measured are compressive strength, water absorption, loss of ignition, density, efflorescence, initial rate of water absorption, moisture movement, proximate analysis, toxicology characteristic leaching procedure and compositional analysis.

3.4.1 Compressive Strength

The compressive strength was analysis using BS EN 772-1:2000 - Clause 5.3.4 and MS 76: 1972 Clause 39. These standards are adopted because they are commonly used as reference by industries to assess clay bricks. Compressive strength, (N/mm^2) = Maximum load at failure (N) / Average area of bed faces (mm^2)

$$Compressive\ Strength, (N/mm^2) = \frac{maximum\ load\ at\ failure\ (N)}{average\ area\ of\ bed\ faces\ (mm^2)} \quad [1]$$

3.4.2 Water Absorption

The water absorption was analysed using BS EN 771-1:2003, Annex C : Determining Water Absorption Clause - 5.3. and MS 76 : 1976 clause 40. The bricks soaked for twenty four hours and the difference in weight was measured. For each bricks, the water absorption, W_a, expressed as a percentage of the dry mass, is calculated using the following equation [2].

$$W_a = \left(\frac{m_2 - m_1}{m_1}\right) \times 100 \quad [2]$$

3.4.3 Loss on Ignition

Loss on ignition (LOI) is to analysis content of organic material in WTR (Ramadan et al., 2008). The analysis test is done by burning WTR of temperature range 400°C – 500°C for four hours. First, crucible is dried for an hour at temperature of 105°C. The crucible is cooled using desiccator and weighed (W_c). Samples of WTR added into crucible and dried overnight at 105°C. The crucible with sample is cooled using desiccator and reweighed (W_s). The crucible with sample placed onto furnace at 400°C – 500°C. The crucible place removed from furnace and let it cool by placing on asbestos sheet. The crucible cooled using desiccator and weighed (W_a)

$$Loss\ on\ Ignition = \frac{(W_s - W_a)}{(W_s - W_c)} \times 100\% \quad [3]$$

3.4.4 Density Result

The analysis of density was done using BS EN 772-13:2000 - Clause 5.3.3.

3.4.5 Efflorescence

Method of Test : MS 76: 1972 - Clause 42

Samples for each firing temperature and mixing ratio were subjected to efflorescence test. The test conducted to analyse soluble salt. Figure 3.13 is setup for efflorescence test method. A flask containing distilled water shall be inverted and its mouth placed in contact with the exposed face of the specimen. A quantity of distilled water capable of saturating the specimen shall be used. If the distilled water is completely absorbed within 24 hours a further quantity of distilled water shall be used. After a few days, when the water has been absorbed and the specimen appears to be dry, a similar quantity of distilled water shall be used and a further drying period allowed. The specimens shall then be examined for efflorescence.

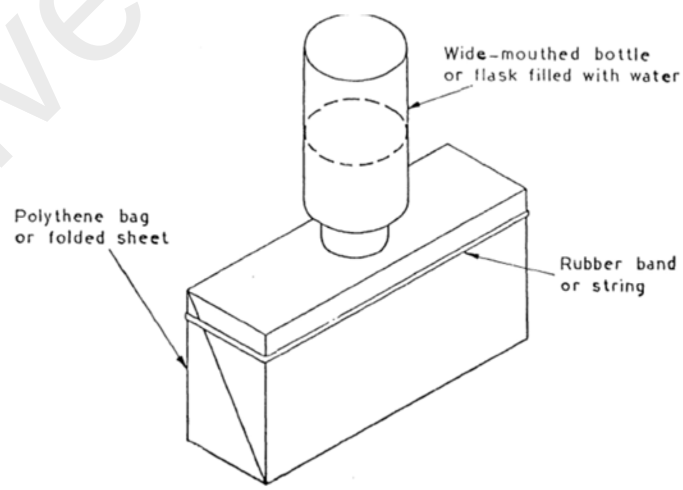

Figure 3.13: Setup for Efflorescence Test.

3.4.6 Initial Rate of Water Absorption

Method of Test : BS EN 772-11:2000 - Clause 5.3.8

3.4.7 Moisture Movement

Method of Test : BS EN 772-14:2000 - Clause 5.3.10

3.4.8 Proximate Analysis

a. Moisture according to BS:EN 12880:2000

b. Ash according to BS:EN 12879:2000

c. Total organic matter (by calculation)

3.4.9 Toxicity Characteristic Leaching Procedure (TCLP)

i. Toxicity Characteristic Leaching Procedure (TCLP) analysis according to SW846 Method 1311.

ii. TCLP Inorganic As, Ba, Ag, Cd, Cr, Pb and Se according to SW 846 6010C using ICP-OES; Hg according to SW 846 7473

iii. TCLP Organic according to method EPA 82608 and 8270C

3.4.10 Compositional Analysis

i. Analysis of Heavy Metals namely Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Sb, Se, Tl, V, Zn and Pb according to SW 846 6010C using ICP-OES
ii. Mercury Analysis according to SW 846 Method 7473
iii. Chromium Hexavalent according to SW 846 3060A
iv. Cyanide analysis according to APHA 4500-CN C&E Colorimetric Method
v. Chloride Sulphate and Nitrate analysis according to APHA 4110-B using on Chromatography

Summary of the testings' are presented in the Table 3.5 and Table 3.6.

Table 3.5 : Summary of the testings' part 1

No	Testing	Methods	
		BS EN	MS 76: 1972
1	Compressive Strength	772-1:2000 Clause 5.3.4	
2	Water Absorption	771-1:2003 Annex C Clause 5.3.7	
3	Loss on Ignition (LOI)		
4	Density	772-13:2000 Clause 5.3.3	
5	Efflorescence		Clause 42
6	Initial Rate of Water Absorption	772-11:2000 Clause 5.3.8	
7	Moisture Movement	772-14:2000 Clause 5.3.10	
8	Proximate Analysis		
	a. Moisture	12880:2000	
	b. Ash	12879:2000	
	c. Total organic matter (by calculation)	calculation	

Table 3.6: Summary of the testings' part 2

No.	Testing	Methods		
		SW	EPA	APHA
1	Toxicity Characteristic Leaching Procedure (TCLP)			
	a. TCLP	846 Method 1311		
	b. TCLP Inorganic (using ICP-OES)			
	i) As, Ba, Ag, Cd, Cr, Pb and Se	846 6010C		
	ii) Hg	846 7473		
	c) TCLP Organic		82608 & 8270C	
2	Compositional Analysis			
	a. Analysis of Heavy Metals using ICP-OES			
	i) Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Sb, Se, Tl, V, Zn & Pb	846 6010C		
	ii) Mercury	846 Method 7473		
	iii) Chromium Hexavalent	846 3060A		
	b) Cyanide analysis using C&E Colorimetric Method			4500-CN
	c) Chloride Sulphate & Nitrate analysis using chromatography		4110-B	

3.4.11 Scanning Electron Microscopy (SEM)

The SEM is used to examine the internal microstructure of the fired bricks. The test was conducted using Scanning Electron Microscope Phenom 1 and Phenom 2. Samples from compressive strength analysis was kept to be use for examine bricks with lowest, medium and highest compressive strength. The sample is placed in appropriate sample holder and the holders being adjust before placing the sample in to SEM Phenom. The magnification result is obtained and the picture saved for comparison.

3.5 Microorganism Toxicity Characterisation

3.5.1 Daphnia Magne acute immobilisation test.

This test conducted according to OECD Guidelines for the Testing of Chemicals (Sotero-Santos et al., 2005). This guideline describes an acute toxicity test to assess effects of chemicals towards daphnids. Existing test methods were used to the extent possible (1) (2) (3). The main differences in comparison with the earlier version are the extension of the test duration to 48 hours, the provision for more information on recommended culture and test media, and the introduction of a limit test at 100 mg/l of test substance (Baird et al., 1989).

3.5.2 Freshwater Algae inhibition

This test conducted according to OECD Guidelines for the Testing of Chemicals. Growth Inhibition Test, the need to extend the Guideline to include additional species and update it to meet the requirements for hazard assessment and classification of chemicals has been identified. The purpose of this test is to determine the effects of a substance on the growth of freshwater microalgae and/or cyanobacteria. Exponentially growing test organisms are exposed to the test substance in batch cultures over a period of normally 72 hours. In spite of the relatively brief test duration, effects over several generations can be assessed (OECD, 2006).

3.5.3 Fish Acute Toxicity Test

The fish are exposed to the test substance preferably for a period of 96 hours. Mortalities are recorded at 24, 48, 72 and 96 hours and the concentrations which kill 50 per cent of the fish (LC50) are determined where possible. One or more species may be used, the choice being at the discretion of the testing laboratory. At least seven fishes must be used at each test concentration and in the controls. The test substance should be administered to, at least, five concentrations in a geometric series with a factor preferably not exceeding 2.2. The limit test corresponds to one dose level of 100 mg/L. This study includes the observations of fish at least after 24, 48, 72 and 96 hours (OECD, 2019).

CHAPTER 4: RESULTS AND DISCUSSION

Using WTR as raw material in construction industry can be considered to be an economical and environmentally sound option because of its abundance source generated by water treatment plants. Furthermore, repurposing of WTR will offset the legally required costs of disposal for WTR. Additionally, this is advantageous for clay brick manufacturers due to reduction in cost of obtaining raw material. Reusing WTR as raw material for clay bricks also provides advantage in environmental impacts because the WTR will no longer be sent for disposal to landfills and scheduled waste. The characteristics of the clay bricks produced in this study is presented in this section.

4.1 Raw materials analysis

This section discusses the characteristics of water treatment residue (WTR) and clay brick raw material (obtained from clay brick manufacturing company). The findings from this section shall be the basis for determining the suitability of incorporating WTR as raw material in blend for making clay bricks.

4.1.1 Composition Analysis of water treatment residue and laterite clay

Table 4.1 shows the composition of the clay for Batch 1, Batch 2 and Clay Brick Raw Material. The results show that the chemical compositions and soil particle distribution are similar for water treatment residue and clay brick raw material. This suggests that based on the properties of the water treatment residue, the suitability of using WTR as raw material for making clay bricks. This result is also reported by other researchers (Elangovan & Subramanian, 2011; Ramadan et al., 2008). Furthermore, the abundance of WTR from water treatment plants supports the feasibility of using WTR as a raw material. The significant parameter for clay properties are silicon oxide and aluminum oxide (Botero et al., 2020).

Table 4.1: Properties of WTR and clay brick raw material

Parameter	WTR (Batch 1)	WTR (Batch 2)	Industry Clay Brick Raw Material
SiO_2	58.40	63.2800	75.9067
Fe_2O_3	5.465	5.5167	4.1567
AI_2O3	17.44	13.6200	7.9033
CaO	0.074	0.0620	0.3087
MgO	0.308	0.2833	0.2333
SO_3	N.D(<0.1)	0.0000	0.0000
Na_2O	0.04	0.0333	0.0300
K_2O	1.013	0.8100	0.6667
CI	0.039	0.0506	0.0365
MnO	0.029	0.0293	0.0029
L.O.I.	26.8	31.6	14.0
Soil Particle Size Distribution:			
Clay (<0.002 mm)	22.1	24.1	18.6
Silt (0.02 - 0.002 mm)	15.5	18.5	27.3
Fine sand (0.2 - 0.02 mm)	18	20	33.8
Coarse sand (2 - 0.2 mm)	20.3	22.6	14.5

4.1.2 Soil Particle size distribution

Characterisation of WTR important parameters shows that WTR has same mineralogy composition with clay used for clay brick production. The result obtained for soil particle distribution as following

Table 4.2 Soil Particle Distribution

Soil Particle Distribution	Sample 1	Sample 2
Coarse Sand	70	77
Fine Sand	10	9
Silt	2	1
Clay	0.4	0.2
Sample 1: Sample of bricks raw material from Clay Brick Factory *Sample 2: Water treatment residue from Sg Dua Water Treatment Plant, Pulau Pinang*		

From the results presented in Table 4.2, it is shown that the WTR Sg Dua Water Treatment Plant exhibits similar soil particle composition as clay bricks. Therefore, this research focused on the reuse of sludge by mixed with laterite soil in brick making through pounding process.

4.1.3 Loss on Ignition (LOI) of Water Treatment Residue

Loss on Ignition is a test used in inorganic analytical chemistry, particularly in the analysis of minerals. It consists of strongly heating ("igniting") a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change. Average loss on ignition for the WTR is 15.0 percent. This result is an average of 4 samples of WTR. This indicates the total volatile organic content of the WTR that used for making clay bricks.

Table 4.3: Loss of ignition for water treatment residue

Loss of ignition (LOI) by temperature, °C	Percentage, %
350	5.9
450	9.3
600	15.0

Average loss on ignition of WTR is 15 percent for 600°C. Therefore, increasing of the WTR content in WTR bricks making will reduce the brick weight. The weight reduction also will be related with WTR content which is a comparatively light weight element. Table 4.3 shows the loss of ignition for sample with increment of the temperature.

4.1.4 Gaseous Emission

The samples of laterite and water treatment residue were tested for gaseous emission measurement to detect potential gaseous that will be emitted during high temperature firing. The results obtained for both samples shows zero percentage of sulphur detected from the samples. There is a potential of nitrogen oxides and carbon oxides, however it is observed the percentage is very low where for nitrogen below 0.5 percent and for the carbon below 5 percent. Table 4.4 exhibits the results from brick samples for gaseous emission.

Table 4.4: Results of Gaseous emission from samples

Sample	Results			
	Carbon, C %	Hydrogen, H %	Nitrogen, N %	Sulphur, S %
Laterite	1.0	0	0.29	0
WTR	3.3	0.29	0.35	0

4.2 Optimal ramping temperature sequence

In this work, the optimal ramping temperature sequence was developed to avoid cracking and other physical deformities due to improper curing time and temperature. Fresh molded bricks are taken from local manufacturer to determine the temperature sequencing and settings. Table 4.5 shows figures of burned bricks with various temperature settings which are used to determine burning temperature sequence and setting. The optimal temperatures were programmed into the furnace and used in all subsequent firing of bricks for this entire work. It is also notice that ramping temperature (rate of change in temperature over time) settings has improved final burned bricks quality.

Table 4.5: Results of various temperatures ramping on clay bricks

No.	Images	Description	Explanation
1.		Dry for 24hrs at Temperature 100°C Burn at 900°C for 8 hours	Crack lines and side cracked, orange color
2.		Dry for 5days at room temperature Burn at 900°C for 8 hours	Complete cracked, orange color
3.		Dry for 24hrs at Temperature 100°C Preheat at temperature 300°C for 1 hours Burn at 900°C for 7 hours	Complete cracked, orange color
4.		Dry at temperature 50°C for 8 hrs, 70°C for 8hrs and 100°C for 8hours Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Mostly cracked out, pale color
5.		Dry at temperature 50°C for 12 hrs and 70°C for 12hrs Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Mostly cracked out, pale color

No.	Images	Description	Explanation
6.		Dry for 24hrs at Temperature 100°C. Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Pale and orange mix and no cracks.
7.		Dry for 24hrs at Temperature 70°C. Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Pale and orange mix
8.		Dry for 24hrs at Temperature 50°C Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Orange on top and at bottom (pale color)
9.		Preheat 300°C for 3hrs – dried bricks. Burning Temperature setting 100°C – 30minutes 300°C – 60 minutes 500°C – 60 minutes 700°C – 60 minutes 950°C – 270minutes	Orange at top and bottom is pale color
10.		Dried Bricks Burning Temperature setting 100°C – 30minutes 500°C – 60 minutes 950°C – 390minutes	Pale color and one of the brick break into few 3 pieces another in good condition.

The final temperature setting is as shown in Table 4.6 which resulted in the best quality of brick in terms of color and properties. No cracks were observed on bricks fired with these settings.

Table 4.6: Final temperature setting for burning bricks

Step	Temperature (°C)			Burning Time
	Setting A	Setting B	Setting C	
1	100	100	100	30
2	300	300	300	30
3	500	500	500	60
4	700	800	800	90
5	950	1000	1050	510

4.3 Characterisation of lab size sample fired bricks

4.3.1 Compressive Strength of the WTR Bricks

The compressive strength of a brick represents it strength and capability to withstand load. The WTR bricks should exhibit similar or superior compressive strength characteristics for it to be considered as comparable to conventional clay bricks. From Table 4.7 and Figure 4.1, it can be seen that the compressive strength for the 40% WTR mixture shows the highest compressive strength compared to the other compositions tested. Load bearing internal walls shall be not less than 2.8N/mm^2 (Standards Malaysia, 1972).

Table 4.7: Compressive strength of the WTR bricks

Percentage of WTR, (%)	Compressive Strength, N/mm^2		
	950˚C	1000˚C	1050˚C
20	6.01	6.35	6.66
30	8.58	8.91	9.74
40	9.14	10.13	11.98
50	6.97	7.46	8.04
60	5.13	5.35	6.32
	Compressive Strength, N/mm^2		
Commercial Bricks	4.3 to 6.9		

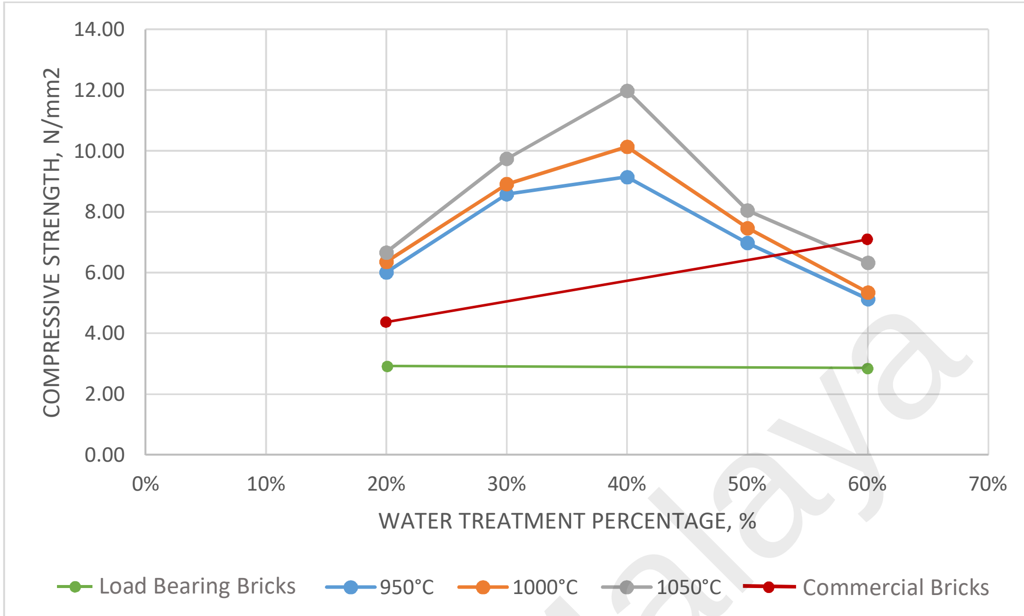

Figure 4.1: Average compressive strength WTR bricks vs water treatment residue percentage comparing with commercial bricks and loading bearing bricks standard.

4.3.2 Water Absorption

Durability of the bricks was measured by water absorption of the bricks. It indicates the sustainability of the brick against humid environments. Increased rate of moisture absorbency indicates the bricks having more pores. The more moisture the bricks absorb shows the lowering of strength of the bricks. The percentage of water absorption reduces with increasing of firing temperature due to the decreased number of pores. When the bricks undergo firing at higher temperatures, the aluminum starts to melt and a compact and solid bricks will be formed with higher density. Although high number pores of lower fired brick have advantages in its insulation properties, however the strength and weight are reduced. At this point the structural strength of the structural also reduces which defeat the purpose of clay brick structures. Meanwhile the water absorption increases as the WTR content increases, this due to content of organic constituent increase resulting at higher percentages of WTR content. Water absorption of bricks (10 samples for every WTR composition) by percentages is presented as Table 4.8. Trending chart for the water absorption is shown in Figure 4.2.

Table 4.8: Water absorption for different WTR composition

Temperature, °C	Water Absorption / WTR Composition, %				
	20%	**30%**	**40%**	**50%**	**60%**
950	18.28	17.94	24.64	27.74	31.28
1000	15.86	15.28	20.72	21.53	24.65
1050	15.18	15.98	17.88	18.20	19.51

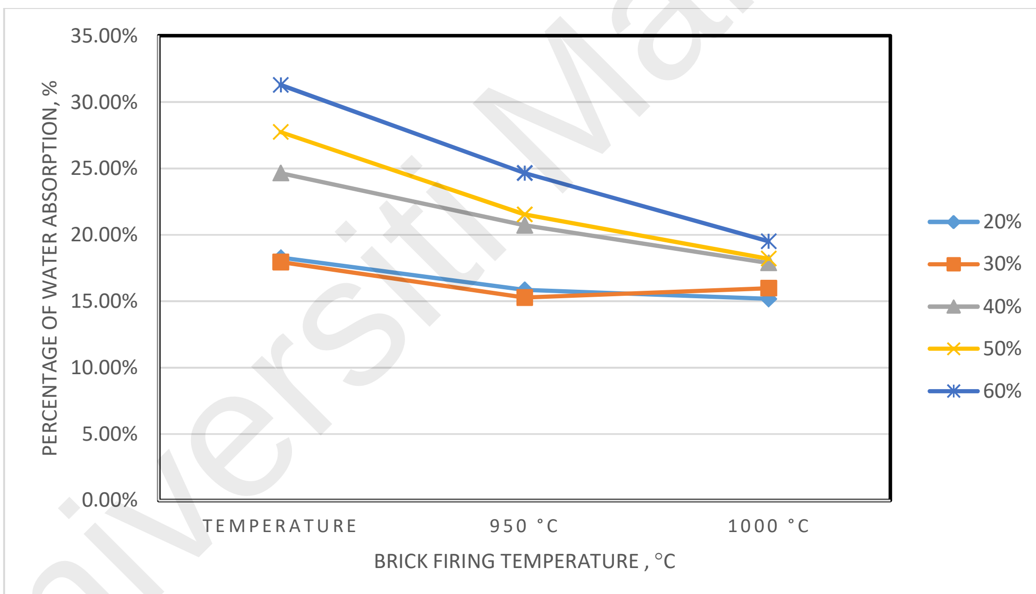

Figure 4.2: Water absorption versus WTR percentage

4.3.3 Loss on Ignition of Fired WTR Bricks

Loss on ignition describes the process of measuring the weight change of a sample after it has been heated to high temperature causing some of its content to burn or to volatilize. The loss on ignition of the product indicates the extent to which the pyro processing was incomplete. The trend shows that incorporation of higher WTR percentage into the clay brick formulation relatively increases the loss of ignition. This suggests that WTR contains relatively more volatile constituents compared to clay. Consequently, there will be a limit to the acceptable WTR percentages incorporable into clay bricks. Higher percentages of WTR will potentially create more pores that can cause reduction of strength and solidity of the clay bricks. The percentage of weight reduction in the weight of the clay bricks are shown in Table 4.9. Trending chart for the loss of ignition is shown in Figure 4.3.

Table 4.9: Loss on Ignition of Fired WTR Bricks at different WTR percentage

	Loss on Ignition / Percentage of WTR				
Temperature, °C	20%	30%	40%	50%	60%
950	3.20%	4.80%	6.40%	8.08%	9.44%
1000	3.33%	4.91%	6.38%	8.74%	9.97%
1050	3.65%	5.28%	6.41%	8.43%	9.77%

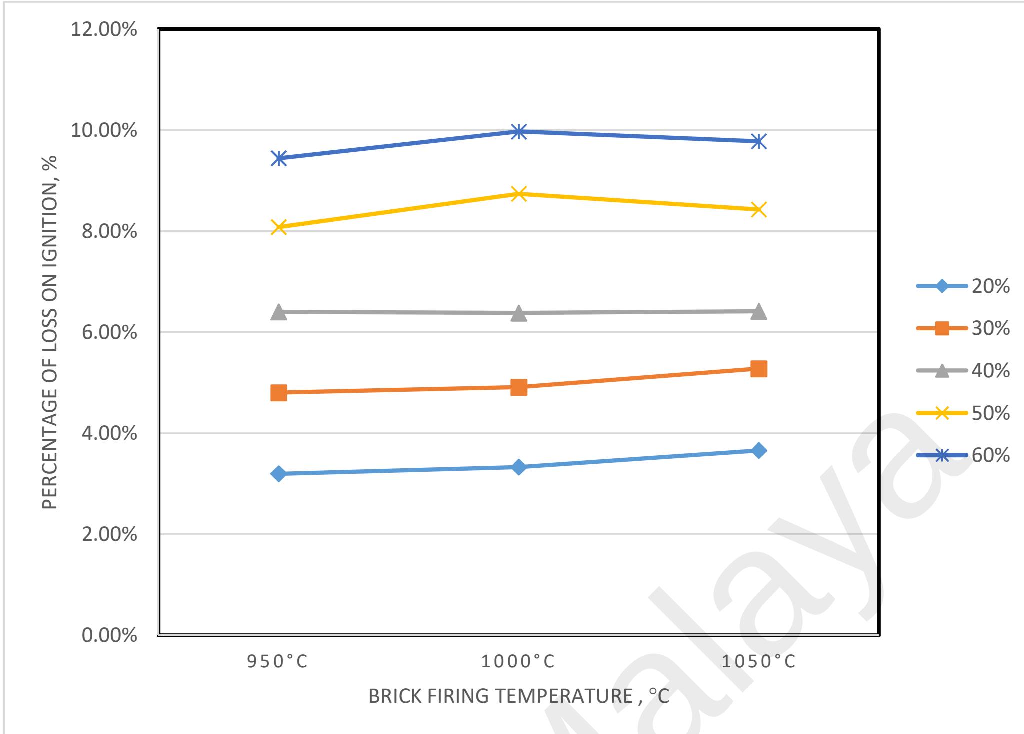

Figure 4.3: Loss on Ignition of Fired WTR Bricks at different WTR percentage

4.3.4 Efflorescence

Efflorescence is defined as the migration of a salt to the surface of a porous material where it forms a coating. The process involves the dissolving of an internally held salt a solvent which may be water or any other solvent. The solvent with the salt held in solution migrates to the surface. When the solvent then evaporates the coating of salt will be left behind.

From the observation of results there is no efflorescence effects were observed on the surface of brick samples. Therefore, no salt deposition from moisture causes any efflorescence effect. This might be due to the minerals in the bricks has completed bonds as an effect of high temperature curing.

4.4 Characterisation of Industrial size sample fired bricks

4.4.1 Compressive Strength

The load tends to reduce size, as opposed to loads which will tend to elongate. In other words, compressive strength resists being pushed together, whereas tensile strength resists tension being pulled apart. The strength of materials, tensile strength, compressive strength, and shear strength can be analysed independently.

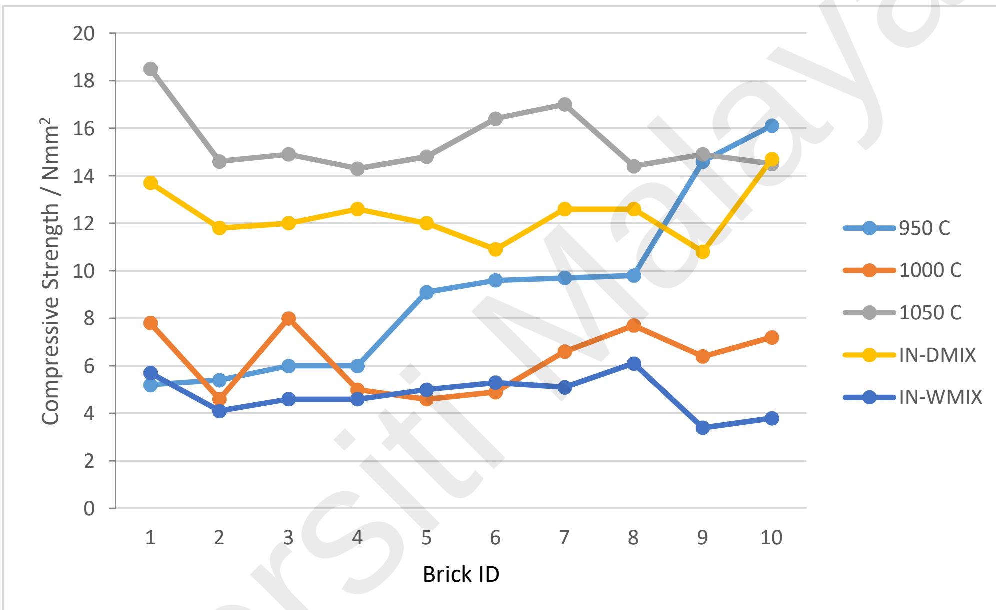

Figure 4.4: Compressive strength of bricks

Five (5) type of clay bricks with 30 wt% WTR content. The five type of WTR bricks are as follows:

i) Dry mix bricks burned at lab furnace 950°C

ii) Dry mix bricks burned at lab furnace 1000°C

iii) Dry mix bricks burned at lab furnace 1050°C

iv) Dry mix bricks burned at industrial clay brick manufacturer

v) Wet mix bricks burned at industrial clay brick manufacturer

From the results obtained and Figure 4.4, it could be reported that the bricks produced by the dry mix method exhibited relatively better compressive strength. This can be result of superior densification in absence of water. The firing temperature also affected the compressive strength of the bricks, where the 950°C temperature yielded bricks with uneven compressive strength as found in 10 of the tested bricks. Overall, the 1050°C yielded bricks with good compressive strength. The bricks that were fired by industrial burning exhibited lower compressive strength. However, this may be due to the loosening of particles which reduced compactness caused by vibrations during transportation from the laboratory facility to the manufacturing premise. The reduced compactness of unfired bricks may have caused inefficient burning of the bricks.

4.4.2 Water Absorption

The water absorption tests were conducted on bricks to determine their durability properties (Hegazy et al., 2012). Durability properties can be explained by the degree of burning, quality and behaviour exhibited by bricks by weathering. The dryness and porosity of bricks provides it with the ability to absorb and release moisture inherently from the environment, mortar or concrete. Dry bricks will absorb moisture when laid, thus making mortar weak and poor. The bond between bricks and mortar will be weakened due to insufficient amount of water for the reaction of cement in the mortar – thus reducing the strength of the structure (Forth et al., 2000). Furthermore, excessive absorption of water reduces brick strength and therefore makes poor durability of built structure. Porous bricks also allow absorption of rainwater which causes rising dampness in walls. As such, water absorption properties of bricks are a significant parameter providing useful indicative properties of bricks.

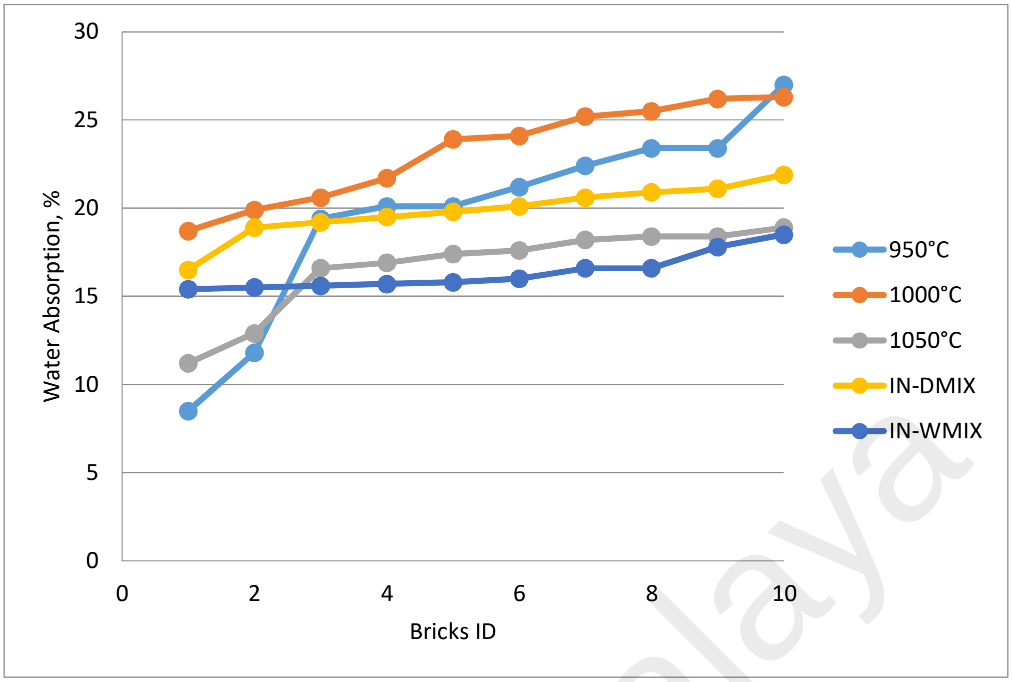

Figure 4.5: Water absorption for clay bricks

The water absorption observed from Figure 4.5 for bricks burned at 1050°C were exhibiting more stability compared to other burning pattern. Relatively, the water absorption for the bricks burned at 1050°C was better. Higher temperatures resulted in bricks in higher density. The lower water absorption properties indicates better resistance during freezing which is beneficial to temperate countries where temperatures can drop to sub-zero levels in winter. Conversely, these bricks will provide good resistance as higher pores give more heat resistance.

4.4.3 Density Result

Brick density is an important parameter because it will determine the weight of the brickwork. Characteristics like cores, cells and frogs can decrease brick density and therefore decrease material cost.

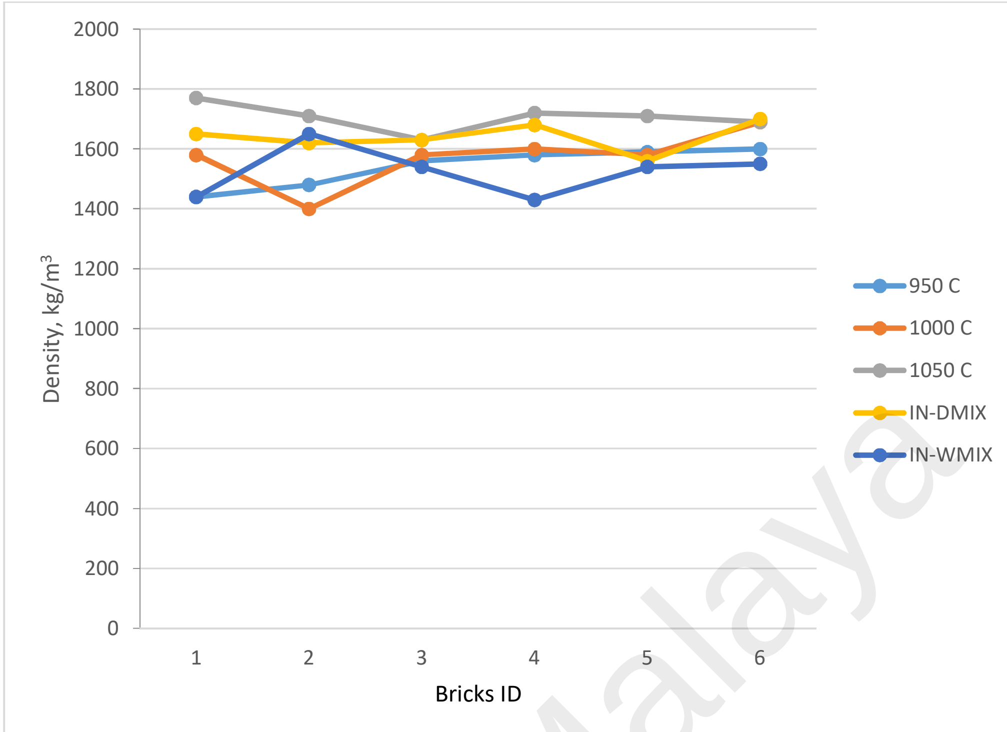

Figure 4.6: Density of Brick versus firing temperature

Brick samples that were fired at 1050°C exhibited highest densities compared to other firing patterns / type of burned brick as observed in Figure 4.6 . The higher temperature allowed for more efficiency of bonding and the solidification process. The reductions of brick volume after firing were observed and the volume reduction of bricks fired at 1050°C reduced the most. Reduction in volume of fired bricks increases its density.

4.4.4 Efflorescence

Efflorescence is defined as the migration of a salt to the surface of a porous material where it forms a coating. The process involves the dissolving of an internally held salt a solvent which may be water or any other solvent. The solvent with the salt held in solution migrates to the surface. When the solvent then evaporates the coating of salt will be left behind. The bricks using water treatment residue were not showing any effect of efflorescence. This indicates these bricks are free of any unwanted salt which can cause salt deposition.

4.4.5 Initial Rate of Water Absorption

The optimum brick to mortar bond for a particular brick type is dependent on the compatibility of the absorptive properties of brick and the water retentive characteristics of the mortar. This makes the absorptive properties of bricks an important parameter in determining the optimum structural strength of brickwork.

The brick suction properties are measured by the standard initial rate of absorption (IRA) test which measures the bricks ability to draw water from wet mortar. IRA is determined by the mass of water absorbed as a function of gross area. (Morgan, 1977)

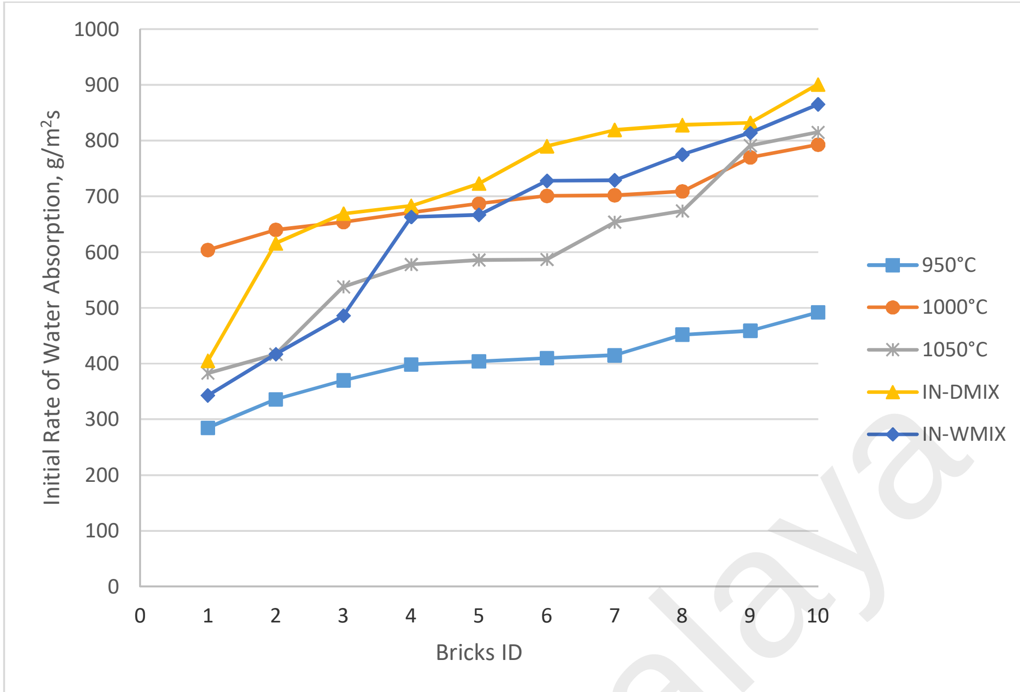

Figure 4.7: Initial rate of absorption versus firing temperature

Observing from Figure 4.7 the bricks fired at 950°C exhibited the lowest IRA on average. The ability of a brick to absorb water from mortar is measured by IRA. Bricks having low suction require leaner mortar for optimal bonding to be achieved. This is typically done by increasing the composition of washed sand in the mortar mix. Brick with high suction require mortar with higher water retention which can be achieved by shortening the bed joint or wet bricks to reduce their suction. Conversely, brick wetting can lead to efflorescence to the brickwork. The developed WTR bricks have no prepetition of salts for efflorescence effect to manifest. Therefore, the IRA is important for the construction process to ensure that mortar with high water retention is used for optimal boding in the brickwork.

4.4.6 Moisture Movement

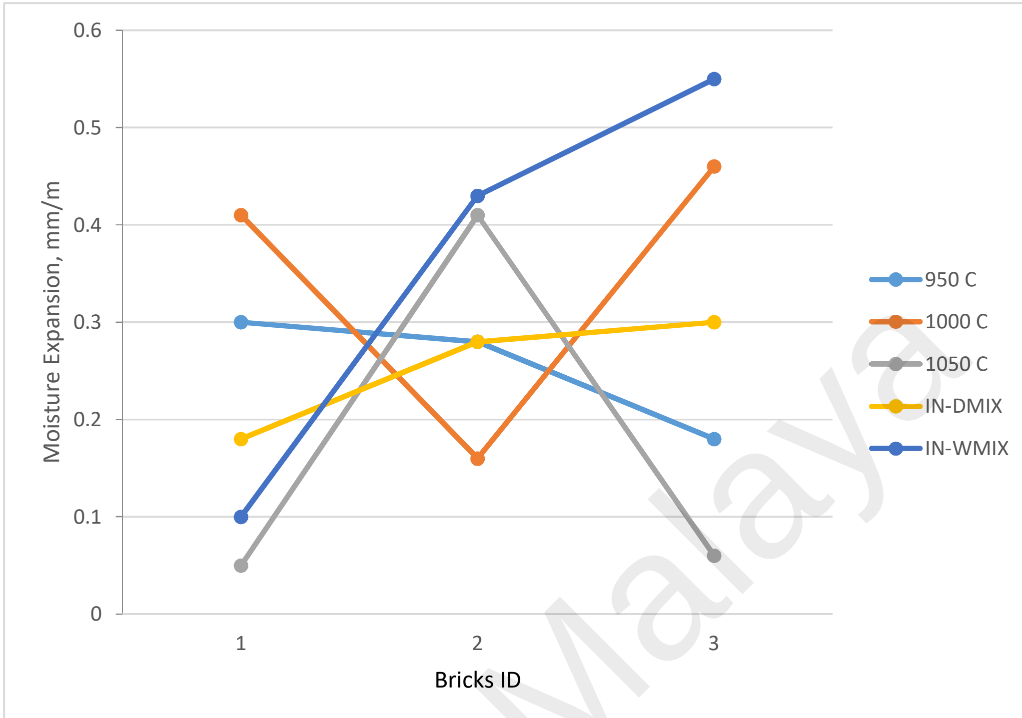

Figure 4.8: Moisture movement-moisture expansion versus firing temperature

Changes in moisture content can cause dimensional changes in masonry materials and all types of building materials, except for metal. These changes in dimension can be permanent and irreversible. For example, clay brick can exhibit long term moisture expansion which is at ultimate value after the unit have been cooled. Moisture expansion rate is dependent on time, type of clay and firing degrees. The British Standard provided guidance of movements caused by moisture variations and stipulates typical movement range between 0.02% to 0.07%.

Moisture from the ambient atmosphere can cause long term expansion. Both internal and external walls absorb moisture. However, external walls absorb moistures at higher rates.

Masonry and building materials also demonstrate reversible shrinkage with varying moisture content throughout all stages in their lifespan.

Moisture in cement mortar, cement render and wall tiling fixatives can cause walls constructed from fired clay or calcium silicate to expand. However, this expansion movement is not permanent and reversible after the loss of moisture. Such masonry walls also exhibit permanent movements. Calcium silicate walls tend to undergo long term shrinkage while clay bricks tend to undergo long term expansion.

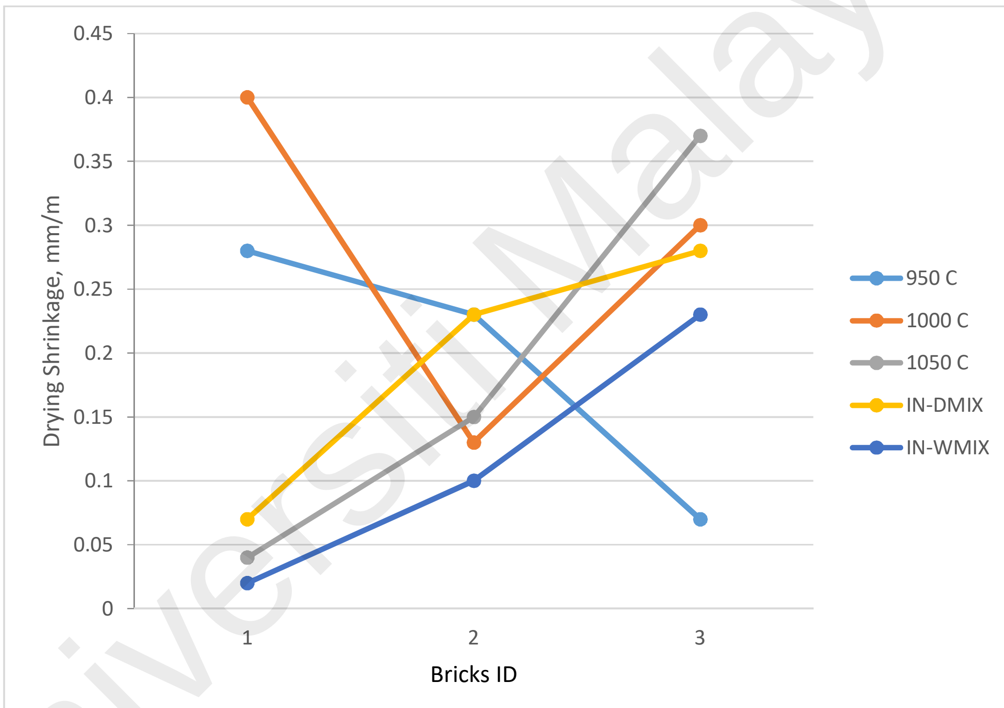

Figure 4.9: Moisture movement-drying shrinkage versus firing temperature

Figure 4.9 shows the moisture movement-drying shrinkage for the bricks. The moisture movement (moisture expansion and moisture shrinkage) for the bricks is lower than 0.05%.

4.5 Proximate Analysis

A proximate analysis comprises the mass percentages of moisture, ash, volatile matter, and fixed carbon, which are obtained from a series of three standardized tests BS EN 12880. Table 4.10 shows results of proximate analysis for the WTR bricks.

Table 4.10: Proximate analysis for the bricks.

Parameter	Dry Basis (%)
Moisture	-
Ash	98.8
Total Organic Matter	1.2

4.6 Toxicity Characteristic Leaching Procedure (TCLP) Analysis

TCLP or Toxicity Characteristic Leaching Procedure is a chemical analysis process used to determine whether there are hazardous elements present in a waste. The test involves a simulation of leaching through a landfill and can provide a rating that can prove if the waste is dangerous to the environment or not. The bricks were tested for TCLP analysis and the results are presented in following table Table 4.11. The results show all the parameters are below the standard requirement for TCLP.

Table 4.11: TCLP Analysis for bricks.

Parameters	**unit**	**LOR**	**STD**	**Results**
Antimony	mg/kg	10	500	2.1
Arsenic	mg/kg	5	500	< 25.9
Barium	mg/kg	5	10000	116
Beryllium	mg/kg	1	75	< 0.1
Cadmium	mg/kg	1	100	3.8
Chromium	mg/kg	1	2500	49
Chromium IV	mg/kg	10	500	1.1
Cobalt	mg/kg	1	8000	15
Copper	mg/kg	1	2500	22
Lead	mg/kg	1	1000	77
Mercury	mg/kg	1	20	0.01
Molybdenum	mg/kg	1	3500	< 0.6
Nickel	mg/kg	1	2000	51

Parameters	unit	LOR	STD	Results
Selenium	mg/kg	10	100	< 7.5
Silver	mg/kg	1	500	< 0.4
Thallium	mg/kg	1	700	< 0.3
Vanadium	mg/kg	1	2400	121
Zinc	mg/kg	1	5000	< 76
Aluminum	mg/kg	1	N/A	202
Pentachlorophenol	mg/kg	1	17	<1.0
2,4-Dichloropenoxy Acetic Acid	mg/kg	1	100	N/A
2,4,5-Trichloropenxypropionic Acid (silvex)	mg/kg	1	10	< 1.0
Trichloroethylene	mg/kg	0.5	2040	< 0.5
Aldrin	mg/kg	0.5	1.4	< 0.5
Chlordane	mg/kg	0.5	2.5	< 0.5
DDT, DDE, DDD	mg/kg	0.5	1	< 0.5
Deldrin	mg/kg	0.5	8	< 0.5
Endrin	mg/kg	0.1	0.2	<0.1
Heptechlor	mg/kg	0.5	4.7	< 0.5
Kepone	mg/kg	0.5	21	< 0.5
Lindane	mg/kg	0.5	4	< 0.5
Methoxychlor	mg/kg	0.5	100	< 0.5
Mirex	mg/kg	0.5	21	< 0.5
PCBs	mg/kg	0.5	50	< 0.5
Toxaphene	mg/kg	0.5	5	< 0.5

LOR : Limit of Reporting
STD : Standard (Threshold limit)

4.7 Compositional Analysis

Compositional analysis is analysis of heavy metal for the samples. The bricks was test for this analysis which the results are complying with standard requirements. The result is presented in Table 4.12.

Table 4.12: Compositional Analysis Results.

Parameters/site	unit	LOR	STD	Results
Arsenic	mg/L	0.05	5	<0.015
Barium	mg/L	0.1	100	0.004
Benzene	mg/L	0.005	0.5	< 0.005
Cadmium	mg/L	0.01	N/A	0.001
Aluminium	mg/L	0.01	N/A	0.67
Carbon Tetrachloride	mg/L	0.005	0.5	< 0.005
Chlordane	mg/L	0.005	0.03	< 0.005
Chlorobenzene	mg/L	0.005	100	< 0.005
Chloroform	mg/L	0.02	6	< 0.02
Chromium	mg/L	0.01	5	0.002
o-Cresol	mg/L	0.05	200	<0.05
m-Cresol	mg/L	0.05	200	<0.05
p-Cresol	mg/L	0.05	200	<0.05
Cresol	mg/L	0.05	200	<0.05
2,4,D	mg/L	0.05	10	<0.05
1,4-Dichlorobenzene	mg/L	0.05	7.5	<0.05
1,2-Dichloroethane	mg/L	0.005	0.5	<0.005
1,1-Dichloroethylene	mg/L	0.005	0.7	<0.005
2-4-Dinitrotoluene	mg/L	0.05	0.13	<0.05
Endrin	mg/L	0.005	0.02	<0.005
Heptachlor (and its epoxide)	mg/L	0.005	0.008	<0.005
Hexachlorobenzene	mg/L	0.05	0.13	<0.05
Hexachlorobutadiene	mg/L	0.05	0.5	<0.05
Hexachloroethane	mg/L	0.05	3	<0.05
Copper	mg/L	0.01	25	<0.01
Lead	mg/L	0.05	5	0.04
Lindane	mg/L	0.05	0.4	<0.05
Mercury	mg/L	0.001	0.2	0.008
Methoxychlor	mg/L	0.05	10	<0.05
Methyl ethyl ketone	mg/L	0.05	200	<0.05
Nitrobenzene	mg/L	0.05	2	<0.05
Pentachlorophenol	mg/L	0.05	100	<0.05
Phyridine	mg/L	0.05	5	<0.05
Selenium	mg/L	0.1	1	0.3
Silver	mg/L	0.01	5	< 0.0002
Tetrachloroethylene	mg/L	0.005	0.7	<0.005
Toxaphene	mg/L	0.05	0.5	<0.05
Trichloroethylene	mg/L	0.005	0.5	<0.005
2,4,5-Trichlorophenol	mg/L	0.05	400	<0.05
2,4,6-Trichlorophenol	mg/L	0.05	2	<0.05
2,4,5-TP (Silvex)	mg/L	0.05	1	<0.05
Vinyl Chloride	mg/L	0.05	0.2	<0.05

4.8 Cyanide, Sulphite, Nitrate and Chloride analysis

The bricks was analyzed for cyanide which was conducted according to APHA 4500-CN C&E Colorimetric Method and Chloride Sulphate and Nitrate analysis according to APHA 4110-B using on Chromatography. The results those shown in Table 4.13 are very low in the concentration of the parameters. However there are no standard limits for this parameter.

Table 4.13: Cynide, Chloride, Suphate and Nitrate Analysis

Parameter	Dry Basis (mg/kg)
Cyanide	0.06
Chloride	9.0
Sulphate	34.4
Nitrate	13.0

4.9 Microorganism Toxicity Characterisation

4.9.1 Result Summary for Daphnia Magne acute immobilisation test

The 48-hour static acute immobilization test using daphnia magna was conducted on the eluate of crushed bricks. The concentration of the eluate was based on total dissolved solid (TDS) content after the water-leaching procedure. The TDS in the eluate based on dry solid fraction of the bricks was 45mg/L. The test species showed no immobility in the 100% eluate at 24- and 48-hours exposure. This 100% eluate represents 0.0045% of soluble substances in the crushed bricks that was extracted in 1L water.

4.9.2 Freshwater Algae Inhibition

The 72-hour growth inhibition test using *Pseudokirchneriella subcapitata* ATCC 22662 was conducted on a sample of crushed bricks. The test results were obtained from a definitive test with series of eluate concentrations of 100%, 31.25%, 9.77%, 3.05% and 0.95 prepared from 100g of dried sample in 1 litre water. The algae were exposed for a period of 72 hours. Algae cell counts were recorded at 24, 48, and 72 hours. The growth inhibition results indicate that the half maximal effective concentration (EC_{50}) value at 72-hour exposure of algae, *Pseudokirchneriella subcapitata* ATCC 22662 was 6.4mb/l of TDS extracted from crushed bricks in water. The value is acceptable based on the inhibition test.

4.9.3 Fish acute toxicity Test on Bricks

The acute fish toxicity test on brick sample using is common carp, *Cyprinus carpio*. The test was conducted according to OECD Guideline for testing chemicals 203 Fish, Acute Toxicity Test (1992) and ETRC Standard Operation Procedures manual.

The result was obtained from a definitive test or confirmation test on 100% concentration of aqueous eluate extracted from 100g dry mass of "Brick" in 1L water. The test fish was exposed for a period of 96 hours. Observed Abnormal Response toxicity was recorded at 3, 6, 24, 48, 72 and 96 hours. It is confirmed that no toxicity response in terms of fish mortality was observed during the exposure.

Therefore, the LC_{50} (lethal concentration required to kill 50% of the population) value at 96-hour exposure of fish to the 100% eluate concertation of brick sample could not be ascertained as the eluate sample was practically non-toxic to the fish species studied.

4.10 Morphology [Scanning Electron Microscopic (SEM)]

The SEM image is presented for sample of bricks with lowest compressive strength, medium range compressive strength and highest range of compressive strength.

i. Brick sample T1 (5 x 5 x 5) – composition of 60 percent of WTR and 40 percent of laterite at firing temperature of 950°C tested at 5.13 N/mm^2 (lowest compressive strength)

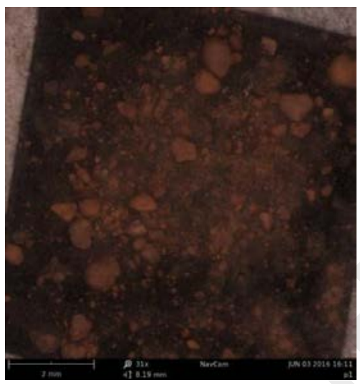

Figure 4.10: SEM 31X

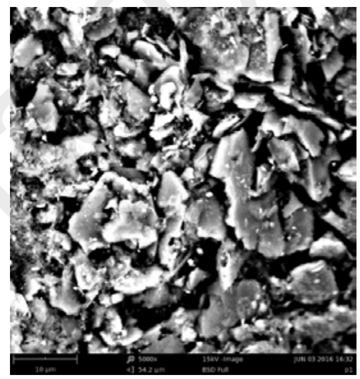

Figure 4.12: SEM 5000X

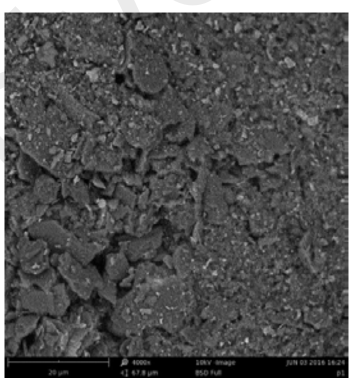

Figure 4.11: SEM 4000X

ii. Brick sample Q2 (5 x 5 x 5) – composition of 20 percent of WTR and 80 percent of laterite at firing temperature of 1000°C tested at 8.91 N/mm^2 (lowest compressive strength)

Figure 4.13: SEM 28X

Figure 4.15: SEM 5000X

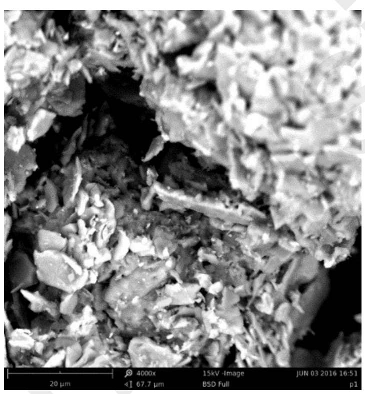

Figure 4.14: SEM 4000X

iii. Brick sample R3 (5 x 5 x 5) – composition of 40 percent of WTR and 60 percent of laterite at firing temperature of 1050°C tested at 11.98 N/mm2 (lowest compressive strength)

Figure 4.16: SEM 24 X

Figure 4.17: SEM 4000X

Figure 4.18: SEM 3000X

CHAPTER 5: CONCLUSION

An evaluation for the water treatment residue combining with laterite as conventional clay brick production shows a potential for clay-based products such as clay bricks. The WTR can substitute for clay portion of making clay bricks. As observed, WTR bricks did not show a decline in any of the characteristic tested on the bricks. It is also observed the compressive strength for WTR bricks is better comparing to market clay bricks due to better densification. This study on the composition of clay bricks using replacing clay with water treatment residue was from the range of 10 percent to 90 percent. However due to the condition and structure of the clay bricks after firing temperature it is performed for 20wt% to 60wt% of WTR. For clay bricks sample size (5 x 5 x 5)cm and 30wt% of WTR for market size sample bricks (10 x 24 x 8) as the profile shows highest compressive strength. The optimum composition is varying on the size of the bricks with higher compressive strength at composition 30wt% to 40wt%. It is also observed for bricks patterns getting higher brittleness as the composition more than 40wt% and those bricks with lower than 30wt% breaks easily as the binding component is insufficient for the bricks.

As for the firing temperature, it is observed that higher firing temperature giving better compressive strength. In this study, three type of firing temperature 950°C, 1000°C and 1050°C was tested for the bricks performances and bricks with 1050°C firing temperature have given highest performance in quality and appearances.

There is no significant impact from the leachate analysis, microorganism (Daphne), algae and fish acute testes from the fired WTR bricks. The WTR and laterite also monitored to observed for any significant emission and ensure the waste is safe for manufacturing processes. The gaseous emission and toxicity study exhibit results that comply with Malaysian Standard. This verifies the temperature sintering technology binds the metals in water treatment residue and proves safe consumer product.

In conclusion, the water treatment residue from water treatment plant can be converted to clay bricks. It is also recommended the use of WTR at a range of 30wt% to 40wt% which will give an optimal compressive strength and structure. Moreover, it is noticed that higher percentage of the WTR causes for more cracks and brittle bricks. The properties of the WTR Bricks have improved compressive strength than the market clay bricks and serves as a solution for disposal of water treatment residue. These WTR bricks will solve problem for water treatment operator for compliance Malaysian Environmental Quality Act 1974. At present water treatment residue is classified as SW 204 at Environmental Quality (Scheduled Wastes) Regulation 2005. Based on the overall performances, the WTR Bricks can be used as building material for many purposes.

5.1 Recommendations for Future Works

The possible applications of the waste added samples are listed in Table 5.1 and 5.2. The WTR Bricks can be used for type of Load Bearing class 1 & 2.

Table 5.1: Application of waste added samples as per MS 76:1972

Type	Class	Strength (MPa)	Absorption (%)	Appropriate application
Engineering	A	≥ 69.0	≤ 4.5	-
	B	≥ 48.5	≤ 7.0	-
Load Bearing	15	≥ 103.0	No specific requirement	-
	10	≥ 69.0		-
	7	≥ 48.5		-
	5	≥ 34.5		-
	4	≥ 27.5		-
	3	≥ 20.5		-
	2	≥ 14.0		-
	1	≥ 7.0		WTR Bricks
Damp Proof	DPC	As required	4.5	All WTR Bricks

Table 5.2: Application of waste added samples as per ATSM Classification

Bricks/Tiles	Building Bricks	Sewer Bricks	Manhole Bricks	Load Bearing clay wall tile	Industrial floor bricks
Min. Strength (MPa)	17.2	26.-55	15-21	3.4-9.6	5.2-13.8
Max. water absorption (%)	17	6-15	17-25	17-25	1-12
Complying samples	-	-	-	WTR Bricks	WTR Bricks

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