# Development of Sustainable LSP-Bricks Using Local Industrial Wastes

*Ani Maslina Saleh[1], Mohamad Nidzam Rahmat[2] and Norsalisma Ismail[3]*
*[1,2,3]Faculty of Architecture, Planning and Surveying, UiTM Shah Alam, MALAYSIA*
*E-mail: drnidzam04@gmail.com*

## ABSTRACT

Received: 30/11/2020
Reviewed: 24/12/2020
Accepted: 24/01/2021

*Uncontrolled infrastructure development may produce excessive carbon emission and scarcity of natural resources. The reuse of waste materials in general promotes material ecology and the cradle-to-cradle concept. The utilisation of industrial waste in the development of advanced materials promoting the extensive research on sustainable building components. The main objective of this research is to investigate the potential of utilising local industrial waste, Solid Waste Fly Ash (SwFA) and Paint Sludge (PS) as target material in replacing laterite soil that is non-renewable natural resources. Standard industrial size bricks were fabricated consist the combination of Laterite Clay, SwFA and PS (LSP) at 50:25:25 ratios. The results for engineering and environmental properties were within the acceptable of engineering standards and performances. This test result suggests potential used of SwFA and Paint Sludge as substitute to clay for unfired brick. This will certainly contribute to the recycling of SwFA and industrial sludge (Paint Sludge and possibly others) and hence to minimise the impact of these by-product to the environment if send to landfill. The manufacture of unfired bricks can exploit locally available waste materials and can be used in certain applications of low load bearing situation. This research also suggests innovation and enhanced waste management and contribution towards the concept of green building components.*

***Keywords:*** *Industrial waste, eco-bricks, durability, thermal, acoustic*

## INTRODUCTION

Currently most of the country across the world realized to improve the conventional way of development into more sustainable approach without damaging the world we live in. Building contributes to total environmental burden due to use of raw materials (30%), energy (42%), water (25%) land (12%), atmospheric pollution emission (40%), water effluents (20%), solid waste (25%) and other releases (Sangwan, 2018). This percentage clearly support the notion that the construction industry imposes considerable loading on environment and impact severely on practically every environmental issue affecting sustainability. For instance, the laterite clay bricks one of building components required laterite soils which is non-renewable materials. In addition, the traditional process producing bricks consumed high firing energy and high carbon emission to the environment. The challenge for the construction industry is to re-engineer its entire process in order to significantly reduce its impact on the environment.

Recycling waste for green bricks production seems to be feasible solution controlling the environmental pollution but also cheaper option for development of green building. The awareness of community concerning the up to date ‘sustainability issue’ in Malaysia is growing as the numbers of researches on sustainable and eco-bricks are increasing. According to Chau et al., (2014). Malaysian construction industry has the right path towards more sustainable development. Precisely the application of sustainable construction materials and products encompassed of overall environmental sustainability effort and vital criteria in promoting the use of environment-friendly materials obtained from sustainable sources and recycling. Hence recycling the wastes in bricks production is possible solution to reduce environmental pollution but also economical option to design green building components which also contribute marks to GBI score points and leads to escalating in market for green building materials especially in Malaysia itself.

## LITERATURE REVIEW

Producing a sustainable construction component could prevent and control the pollution and environmental degradation which also one of the key areas in Malaysia's Green Strategies (Department of Environment, DOE 2010). The production of conventional building components for example, clay bricks involve high energy consumption through intensive firing and high carbon dioxide emission. This will also lead to higher material cost to the end user. For this reason, to achieve sustainable construction, there has been a growing interest in reducing energy consumption in the manufacture of building components and construction materials in general. The development of unfired clay building components for example, enables the reduction in manufacturing, energy costs as well as a reduction in carbon dioxide ($CO_2$) emission. Zhang (2013) reported that production of 1kg Ordinary Portland Cement (OPC) consumes approximately 1.5kWh of energy and discharges approximately 1kg of $CO_2$ to the air. The cement production is one of the world's highest $CO_2$ emitting processes and responsible for around 5-8% of carbon generated worldwide (Kajaste and Hurme, 2016). Nevertheless the use of traditional binder cement and lime increase the carbon footprint, as an average cement industry presents an embodied energy of 0.95 kg CO2 per kg of cement produced (Abdallqader, 2016). On the other hand, using industrial waste and/or by-product materials as raw materials to replace the amount of clay used to make unfired bricks or to enhance the performance, is an effective way of recycling waste materials. It reduces the use of natural resources, reduces energy consumption and hence produces a new cost-effective product. Therefore, this research is programmed to use waste or by-product material and targeted to reduce cost in the production of building materials through unfired brick production. The use of waste materials, perhaps, is one of the ways of integrating sustainable approaches in the construction industry.

## Sustainable brick production

Clay bricks are very sturdy, fire resistant, and require minimum maintenance. Good claybricks building depend on the strength, and fire resistance properties, durability, beauty and performance with mortar Sadik et. al., (2013). Brick masonry has good thermal mass effect which makes useful components for fuel-saving, natural heating and cooling strategies during the solar heating and night-time cooling. Brick houses have moderate insulating properties, which make the brick houses cooler in summer and warmer in winter, compared to houses built with other construction materials (El Fgaier et. al., 2016). The manufacturing processes of fired bricks contribute to the emission of carbon dioxide ($CO_2$) which increasing the greenhouse gases to the atmosphere. This impact became critical and should be reduced, as it contributed to global warming and natural disasters. High-energyconsumption during the production will also contribute to high cost building materials which led to increasing of total construction cost generally. New research should be carried out to find alternative strategies to integrate sustainable process and technology in the production of construction materials/components. Henceforth it has become a need in producing sustainable construction materials globally. Zhang (2013), pointed that firing consumed a significant energy of 2.0 kWh per brick, and emitted a large quantity of greenhouse gasses about 0.41kg of $CO_2$. Another issue in brick industry was a shortage of clay that non-renewable sources in many parts of the world. Therefore unfired brick mostly has lower embodied energy and is easier to recycle and dispose as compared to fired brick. Unfired brick is considered as natural product, with the utilisation of waste material either from Industrial by-products or agriculture by-product in replacing the natural raw materials in the production of sustainable or green construction components is the new era of research nowadays (Zhang et. al., 2018; Al-Fakih et. al., 2019; Pitarch et. al, 2021). Further promoting sustainable development research, it is also in line with government green policy and supporting government campaign of reduce, reuse, and recycle. The use of waste from other industries will also contribute for low cost building materials. Pappu et. al., (2007) classified 5 categories of solid waste have been explored as construction materials that are agro waste (organic nature), industrial waste (inorganic), mining/mineral waste, non-hazardous wastes and hazardous waste were used to produce bricks, blocks, wood substitute product as well as ceramic products. Brick production utilising recycle wastes is a breakthrough for sustainable green materials which the best solution to avoid all generated waste dumped into the landfill. The awareness of society today in the direction of sustainability in Malaysia encourage more researches on the sustainable and eco-friendly construction materials. The construction industry has the important roles to implement sustainability practices to ensure a better life for everyone now and for future generations, by reduce dependency on non-renewable construction materials through the use of environmental friendly materials. The latest development of eco-friendly materials especially green bricks is excellent concepts to convert waste into innovated building materials.

## MATERIALS AND METHODOLOGY

Three main target materials used in this research are Laterite Clay (LC) collected from the surrounding area in Shah Alam, Solid Waste Fly Ash (SwFA) collected from incinerator in Pahang and Paint Sludge (PS) were by-product from Jotun-paint manufacturer in Shah Alam. All these target materials were air dried and crushed into smaller particles. X-Ray Fluorescence (XRF) test identify the oxide composition of all target materials as presented in Table 1 and Figure 1.

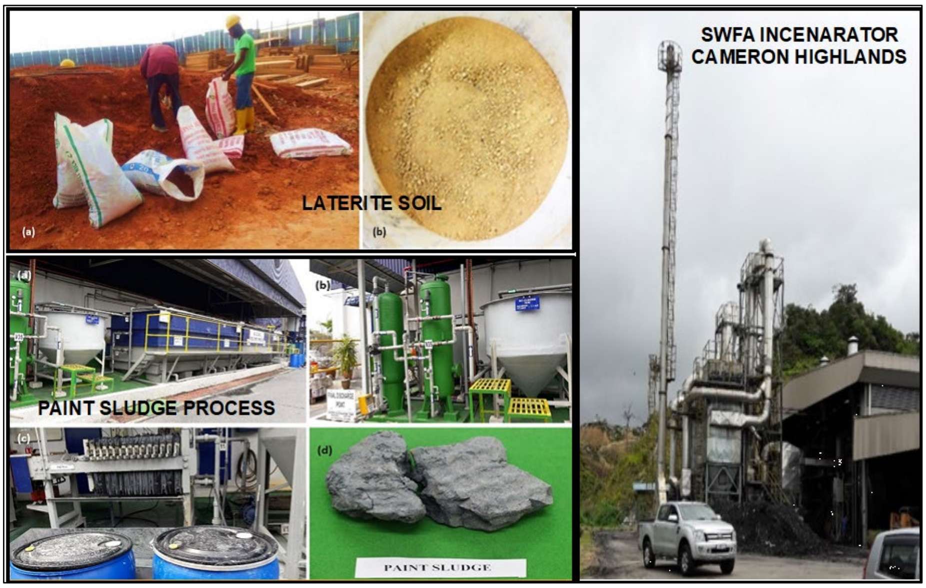


**Figure 1.** Target Material, Laterite Soil, Paint Sludge and Solid Waste Fly Ash

**Table 1**: Chemical Composition for all Target Materials

| OXIDE | WT (%) | SwFA | LC | PS |
|---|---|---|---|---|
| Silicon Dioxide | $SiO_2$ | 5.845 | 26.518 | - |
| Aluminium Oxide | $Al_2O_3$ | 4.721 | 33.267 | 23.378 |
| Calcium Oxide | $CaO$ | 7.412 | 0.033 | 19.032 |
| Magnesium Oxide | $MgO$ | 3.603 | 1.137 | 5.674 |
| Ferric Oxide | $Fe_2O_3$ | 9.937 | 21.569 | 17.459 |
| Titanium Oxide | $TiO_2$ | 0.343 | 0.793 | 15.197 |
| Sulphur Trioxide | $SO_3$ | 1.238 | 0.058 | 0.862 |
| Diphophorus Penta Oxide | $P_2O_5$ | 1.084 | 0.030 | - |
| Sodium Oxide | $Na_2O$ | 4.785 | 0.218 | - |
| Potassium Oxide | $K_2O$ | 0.711 | 0.698 | - |
| Chromium Oxide | $Cr_2O_3$ | 2.205 | - | 6.222 |
| Nickel Oxide | $NiO$ | - | - | 0.702 |
| Zirconium dioxide | $ZrO_2$ | - | - | 0.160 |
| Silver Oxide | $Ag_2O$ | - | - | 0.010 |
| Cadmium oxide | $CdO$ | - | - | 0.033 |
| Strontium peroxide | $SrO$ | - | - | 0.046 |
| Chlorine | $Cl$ | - | - | 0.036 |

Ordinary Portland Cement (PC) and Hydrated Lime (HL) were used as a traditional stabiliser and also blended stabiliser with Ground Granulated Blast Furnace Slag (GGBS) which also by-product from the iron manufacturing industry. Thirty percent (30%) dosage of stabiliser were applied for all bricks system. PC and HL stabiliser system equally blend with GGBS at 50:50 ratio. The moisture content of the mix was pre-determined using Proctor compaction test. Series of bricks with dimension 225mm x 102.5mm x 65mm was fabricated in a laboratory scale according to the formula: T + S + W = 2500 g. Where T as Target materials; S as Stabiliser; W as moisture content in percentage which in this experiment 20% of moisture content was used. The mix design composition of the investigation is presented in Table 2.

Extensive laboratory experimentation and testing to explore the fundamental information in development of sustainable bricks. All bricks were pressed at Materials Laboratory Faculty of Architecture, Planning and Surveying (FSPU), UiTM Shah Alam according to the industrial standard brick size (Figure 2). All the engineering properties test were conducted according to BS EN 772-1:2011. The acoustic tests were done in a reverberant room at Acoustic Laboratory FSPU. Two types of acoustic test, sound transmission loss and sound insulation that conducted at room temperature (30ºC±2). The acoustic test was carried out according to BS EN ISO 140-3(1990) to identify sound transmission class (STC). Laboratory measurement of airborne sound insulation of the building elements/components. Building Acoustic Software Type dB Bati 32-bit version 4.532 were used for the acoustic test.


**Figure 2.** Fabrication of LSP Bricks Materials were throughly mixed and pressed.

**Table 2:** Mix Design Composition

| Target Material | Code name | Stabiliser | Ratio | Dosage (%) |
|---|---|---|---|---|
| LATERITE SOIL: SwFA: PAINT SLUDGE | LSP | HL | 100 | |
| | | OPC | 100 | 30 |
| (50:25:25) | | HL:GGBS | 50:50 | |
| | | OPC:GGBS | 50:50 | |

## RESULT AND DISCUSSION

Results from the experimental work done using the fabricated eco-bricks are presented and discussed below.

## Compressive Strength of LSP Bricks system (50:25:25 ratio)

Figure 3 indicates the pattern of compressive strength for HL stabiliser system (Fig 3(a)) and OPC stabiliser system (Fig 3(b) for LSP bricks system. LSP brick with HL stabiliser systems showed that blended stabiliser HL-GGBS gave better performance in compressive strength compared to LSP bricks stabilised with HL only. LSP bricks with HL only at 7 days curing period did not reach 5,000 kN/m$^2$ the strength, which only attained 4,043 kN/m$^2$, but the strength increased when reached 28 days curing period which logged at 6,479 kN/m$^2$. The compressive strength at 60 days curing period had slightly increased to 6,547 kN/m$^2$ and the strength marginally developed at 180 days and 365 days the compressive strength reached 10,674 kN/m$^2$ and the final monitored curing period the strength attained at 16,577 kN/m$^2$. LSP bricks with blended stabiliser HL-GGBS increased the compressive strength value which at 7 days curing period the value recorded at 8,661 kN/m$^2$, above required strength of 5,000 kN/m$^2$. When reached 28 days curing period the compressive strength continuously increased to 13,638 kN/m$^2$ the values gradually improved when reached 60 days curing period to 15,202 kN/m$^2$. The compressive strength at 180 days achieved at 16,707 kN/m$^2$ and continuously increased at the 365 days final curing period observation recorded at 25,630 kN/m$^2$.

Fig 3(b) indicates the comparative of compressive strength pattern for LSP bricks with OPC stabiliser system. LSP bricks with stabiliser of OPC and OPC-GGBS also exceed the minimum requirement in compressive strength. Compressive strength for LSP bricks stabilised with OPC only for at 7 days curing period the compressive strength logged at 11,163kN/m$^2$, 12,450 kN/m$^2$ were recorded at 28 days, the value continued to increase at 13,690 kN/m$^2$ when reached 60 days. Curing period at 180 days the compressive strength constantly rose to 15,947kN/m$^2$ when reached the final curing period at 365 days the compressive strength reached 27,035 kN/m$^2$. LSP with blended stabiliser OPC-GGBS indicated steadily increased of compressive strength. At 7 days curing period the strength recorded at 7595 kN/m$^2$ slightly lower than LSP with OPC stabiliser. The strength progressively improved to 28 days to 60 days and 180 days which attained at 12,538 kN/m$^2$ to 13,736 kN/m$^2$ and 15,497 kN/m$^2$ respectively. The final observation of curing period the strength reached 21,507 kN/m$^2$.

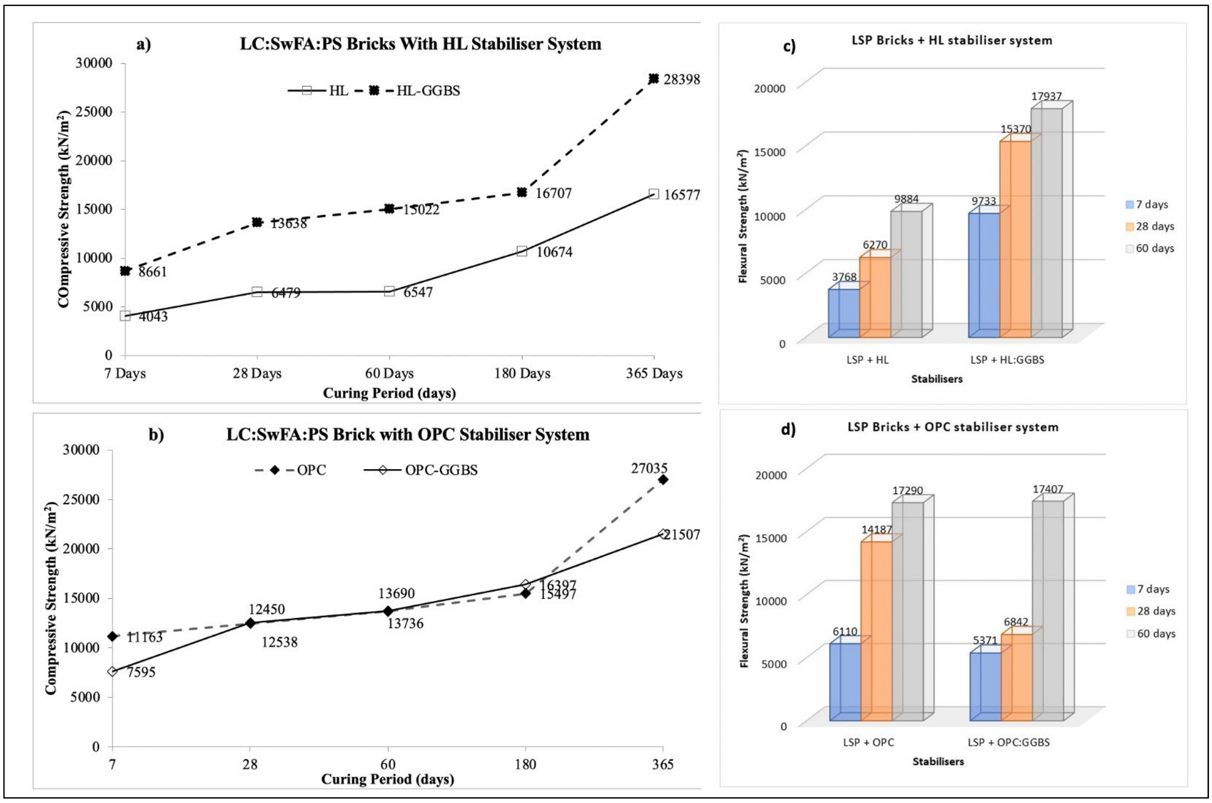


**Figure 3**. (a and b) Compressive strength vs Curing period and (c and d) Flexural strength vs stabilisers of LSP Bricks

## Flexural Strength of LSP Brick System

Figure 3 (c) and (d) shows the flexural strength value for LSP brick stabilised with HL and OPC stabiliser system. This LSP brick system recorded the highest flexural strength of all other brick system investigated. Both stabiliser system also showed incredibly increased of flexural strength value with the increased of curing period like all previous brick system discussed. When HL on its own to stabilised LSP bricks, flexural values gain 3,768kN/m$^2$ at an early stage of curing, 7 days before climbing to 6,270kN/m$^2$ and 9,884kN/m$^2$ at 28 and 60 days respectively. On the other hand when LSP bricks were stabilised with HL:GGBS stabiliser, the flexural strength were enhanced greatly. At 7 days curing the flexural strength was recorded at 9,733kN/m$^2$ and continue to increase to 15,370kN/m$^2$ at 28 days and the finally to 17,937kN/m$^2$ at 60 days. Figure 3 (d) illustrates the flexural strength for LSP bricks using OPC stabiliser system. Very high strength value were recorded at prolonged curing period of 60 days which was 17,290kN/m$^2$. This condition indicated that prolonged pozzolanic reaction occur in the brick system. When LSP bricks were stabilised with OPC:GGBS stabiliser, the flexural strength were low the early curing of 7 and 28 days which are 5,371kN/m$^2$ and 6,842kN/m$^2$ respectively. At 60 days of curing, the flexural strength value was greatly attained at 17,407kN/m$^2$ which occurred from the never ending pozzolanic reaction as the OPC and GGBS contained higher cementitious materials of C-S-H and C-A-H that improved the brick's strength.

## Acoustic Properties

Only SWPS bricks specimens using blended binder HL:GGBS (50:50) and PC:GGBS (50:50) at 30% dosage were tested for acoustic properties. The sound transmission loss and sound absorption tests were conducted after the brick specimens cured for 28 days. A wall of $1m^2$ consists of 78 identical bricks was built for the test. Three reading were taken, and the average result was recorded and presented in the Figure 4. Average STC for SWPS with HL:GGBS at 38db and average STC for SWPS with PC:GGBS at 32db. Figure 5 shows the graphs of sound transmission loss vs frequencies for both SWPS bricks systems. Transmission loss lines are between STC 30 and STC 40 for SWPS bricks stabilised with HLGGBS and at parallel level as STC 30 for SWPS bricks stabilised with PC:GGBS but below STC 40. At low frequency level below 400 Hz, transmission loss is at peak at 44 Hz, and then reduced and levelled out at higher frequencies. Figure 5 represent schematic drawing on the condition of sound transmission loss for SWPS bricks stabilised with blended binders of HL:GGBS and PC:GGBS. The average value of sound transmission loss for SWPS bricks stabilised with HL:GGBS are higher than are SWPS bricks stabilised with PC:GGBS which are 38 dB and 32 dB respectively. Therefore, this brick mix composition is better in terms of conducting sound.

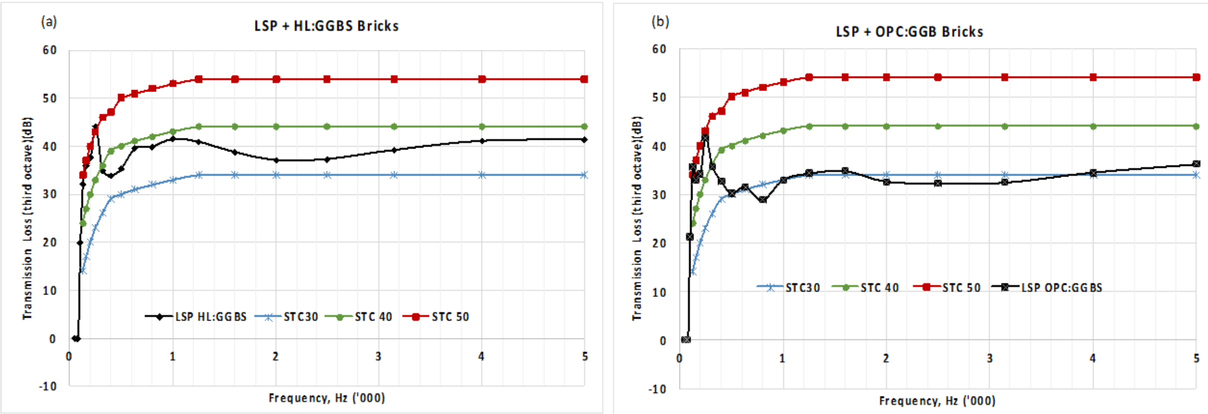


**Figure 4**: Transmission loss vs frequencies for LSP Brick stabilised with (a) HL:GGBS and (b) PC:GGBS

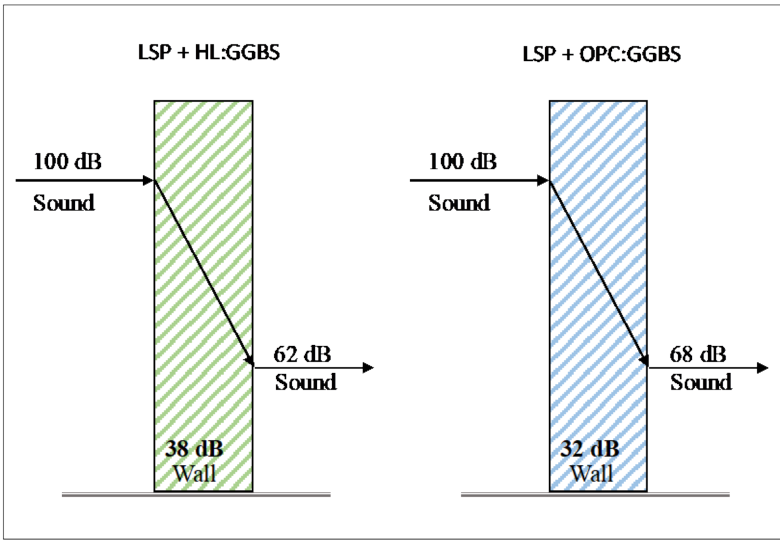


**Figure 5**: Schematic drawing of sound transmission loss of LSP Brick-wall

## Thermal Conductivity of LSP Brick System

Figure 6 shows the thermal conductivity values of bricks made of the combination of Laterite Soil: SWFA: Paint Sludge at 50:25:25 ratio. The overall thermal values are below 0.45 W/m.K for all stabilizer used. In this system, when blended binders were used to stabilized bricks, recorded marginally higher thermal values than when hydrated lime and PC were used on its own as stabilizer. The highest thermal conductivity value marked by LSP+HL:GGBS brick which is 0.451 W/m.K., and the lowest thermal values for the system is LSP+OPC which is 0.272 W/m.K.

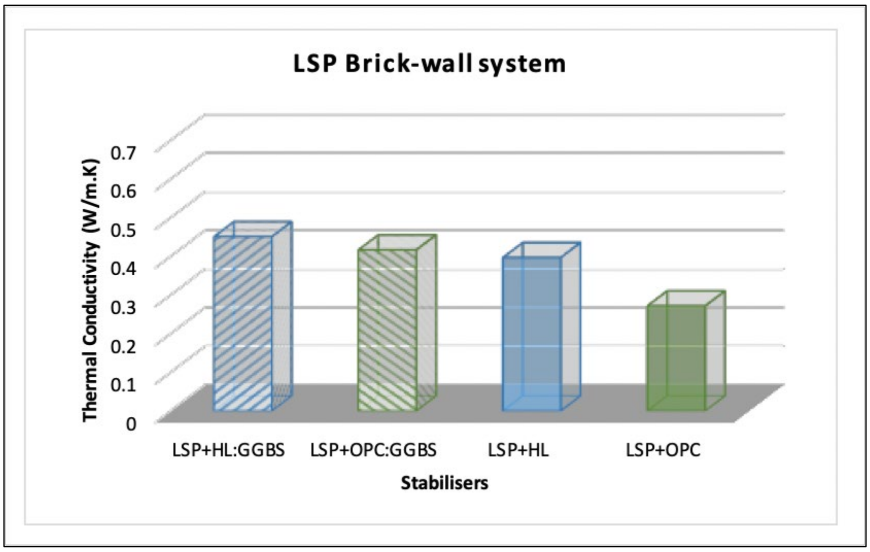


**Figure 6:** Thermal conductivity vs stabilisers of LSP Bricks

## CONCLUSION

Utilising locally available waste materials as target materials for development of unfired bricks give promising idea of cradle-to-cradle sustainable construction components regeneration. In this study approved that most of the SWPS bricks able to reach minimum requirement at 5,000kN/m$^2$ even at the early strength development except SWPS stabilised with HL. Hence the compressive strength for all bricks were developed steadily until the end of curing period duration at 365 days. Long curing period (weeks and months) are required for the newly formed minerals binding to provide notable ongoing benefit of strength increment. This is due to increased pozzolanic reaction between lime and clay fractions. It is recognised that the principal cementitious product of pozzolanic reactions is calcium-alumino-silicate-hydrate (C-A-S-H) gel. The strength development of lime-clay material may be attributed to either the gradual crystallisation of C-A-S-H gel or to its continued formation, without necessarily developing a crystalline structure, but blocking pores and providing strength as it develops (Akula and Little, 2020). The use of GGBS is an added advantage since GGBS has less environmental burdens relative to the lime or PC. Its manufacture involves only a fraction of the energy used and not as much of $CO_2$ emissions compared to either PC or lime. In terms of the applicability of GGBS-based stabilisers for construction or stabilisation, the performance of the stabilised material has recently been well established. However, in terms of building components, the current research is among the pioneering endeavours to utilise GGBS in building applications besides in concrete.

Designing materials with acceptable acoustical properties is one of factor to address sustainable environment in construction industry. Controlling noise pollution either from external or internal through materials with good acoustical properties improve the building environmental performance. In this research elements of acoustic properties the sound transmission loss was measured which to identify the bricks sound transmission class (STC). In this acoustical properties test only SWPS bricks stabilised with HL:GGBS and stabilised with PC:GGBS were tested. SWPS bricks stabilised with HL:GGBS are higher than SWPS brick stabilised with PC:GGBS the sound transmission loss result which are 38 dB and 32 dB respectively. There both types of bricks are better in terms of conducting sound. A study done by (Binici et. al., 2009; Fiala et. al., 2020) prove that decrease in density improved the sound insulation performance and some stabilisers and fibres increased the durability. Binici et. al., (2009) also reported that larger pores improved the acoustic properties.

At the end of incineration and paint production for each target materials SWFA from incinerator and PS from paint production process will end up in sanitary landfill. Department of Environment, DOE (2010), reported that amount of sludge containing heavy metal that has been disposed by the industry is 92,314 tonnes and fly ash is 9,077 tonnes been disposed to the sanitary landfill. Escalation number of solid wastes in Malaysia is due to rapid development and population. Malaysian generates more waste due to the latest figure solid waste production was 33,000 tonnes in 2012 and increase to 38,000 tonnes of waste per day in 2016 (Alias et. al., 2018). Minimising dependency of sanitary landfill and limitation of current sanitary landfill it is vitally need to convert waste into more value-added products. Recently its crucial to improve the construction practices in order to minimise the industry disadvantageous effects on the natural environment. It has been observed that the construction professionals and researchers have endeavours more in reducing environmental impact of construction, green buildings, designing for recycling and eco-labelling of building materials (Kadir et. al., 2011; Raut et. al., 2011; Muntahor 2011; Zhang 2013; Monteiro and Vieira 2014; Al-Fakih et. al., 2019). Furthermore, building performance is now a major concern of professionals in building industry, and environmental building performance assessment has becoming one of vital issues in sustainable construction.

## ACKNOWLEDGEMENT

Authors would like to thank Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Shah Alam for providing facilities and support for this research. This research work was financially supported by Universiti Teknologi MARA Internal Grant no: 600-IRMI 5/3 LESTARI (009/2018).

## REFERENCES

Abdalqader AF, Jin F, Al-Tabbaa A, (2016), *"Development of greener alkali-activated cement: utilisation of sodium carbonate for activating slag and fly ash mixtures"*. Journal of Cleaner Production Vo; 113 pp 66-75. https://doi.org/10.1016/j.jclepro.2015.12.010.

Al-Fakih A, Mohamed BS, Liew MS, Nikbakht E. (2019), *"Incorporation of waste materials in the manufacture of masonry bricks: An update review"*. Journal and Building Engineering Vol 21, pp 37-54.

Alias FS, Manaf AL, Ariffin M, Abdullah SH (2018), *"Solid waste minimisation in Malaysia"*. Pertanika J. Sch. Res. Rev. Vol 4 No 3 pp 26-41.

Binici H, Aksogan O, Bakbak D, Kaplan H, Isik B, (2009), *"Sound insulation of fibre reinforced mud brickwalls"*, Construction and Building Material, Vol 23 No 2 pp 1035-1041.

BS EN771-1 (2011), *"BSI Standard Publication Specification for masonry units Part 1: Clay Masonry Units"*. United Kingdom.

Chau SY, Abd Rahim MHI, Mohamed SH (2014), *"An Insight of Sustainable Housing In Malaysia"*. IGRASS Vol 1 pp 1-5.

Department of Environment (2010), *"Environmental Requirements: A Giude For Investors"*, Ministry of Natural Resources and Environment. Oct pp 1-78.

Fiala L, Konrad P, Fort J, Keppert M, Cerný R., (2020) *"Application of ceramic waste in brick blocks with enhanced acoustic properties"*. Elsevier Journal of Clean Production. Vol 261 https://doi.org/10.1016/j.jclepro.2020.121185

Kadir AA, Mohajerani A. (2011), *"Bricks: An excellent building material for recycling wastes – A review"*. Environmental Management Engineering Vol 731,733 pp 108-115.

Kajaste, R., Hurme, M., (2016). *"Cement industry greenhouse gas emissions - Management optionsand abatement cost".* Elsevier Journal of Clean Production. Vol 112, pp 4041-4052. https://doi.org/10.1016/j.jclepro.2015.07.055

Monteiro SN, Vieira CMF (2014), "*On the production of fired clay bricks from waste materials: A critical update".* Construction Building Material Vol 68, pp 599-610.

Muntahor AS, (2011), *"Engineering characteristics of the compressed-stabilised earth brick".* Construction Building Material Vol 25, No 11, pp 4215-4220.

Pitarch A.M., Reig L, Tomas A.E., Forcada G., Soriano L., Borrachera M.V., Paya J., Monzo J.M., (2020), *"Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in eco-friendly Portland Blended cements".* Elsevier of Journal Cleaner Production Vol 279 p 1-12. https://doi.org/10.1016/j.jclepro.2020.123713

Raut SP, Ralegaonkar RV, Mandavgane SA (2011), *"Development of sustainable construction material using industrial and agricultural solid waste: A review".* Construction Building Material Vol 25, pp 4037-4042.

Sangwan V, (2018), *"Impact of construction works on environment and climate change"*, Pharma Innovation Journal, Vol 7 No 7 pp 180-183

Zhang L, (2013), *"Production of bricks from waste materials – A review".* Construction Building Material Vol 47, pp 643-655.