SWPS ECO Bricks: Development of Sustainable Brick Utilising Solid Waste Fly Ash and Paint Sludge

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Abstract. 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 of the combination of Laterite Clay, SwFA and PS (SWPS) 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.

1. 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 [1]. This percentage clearly support the notion that the construction industry imposes considerable loading on environment and impact severely on practically every environmental issues affecting sustainability. For instance, the laterite clay bricks one of building components required laterite soils which is non-renewable materials. In addition, with the materials utilized the process producing the fired bricks also consumed high 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 inexpensive 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, Abd Rahim, & Mohamed [2] 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 of 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.

2. Materials and Methodology

Three main target materials used in this research; 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 paint manufacturer in Shah Alam. All these target materials were air dried and crushed into smaller particles. X-Ray Fluorescence (XRF) test initially completed to identify the oxide composition of all target materials as presented in Table 1.

Table 1. Chemical Composition for all Target Materials.

| OXIDE                  | WT (%) | SwFA     | LC         | PS         |
|------------------------|--------|----------|------------|------------|
| Silicon Dioxide        | 5.845  | 26.518   | -          | -          |
| Aluminium Oxide        | 4.721  | 33.267   | 23.378     |            |
| Calcium Oxide          | 7.412  | 0.033    | 19.032     |            |
| Magnesium Oxide        | 3.603  | 1.137    | 5.674      |            |
| Ferric Oxide           | 9.937  | 21.569   | 17.459     |            |
| Titanium Oxide         | 0.343  | 0.793    | 15.197     |            |
| Sulphur Trioxide       | 1.238  | 0.058    | 0.862      |            |
| Diphosphorus Penta Oxide | 1.084 | 0.030    | -          |            |
| Sodium Oxide           | 4.785  | 0.218    | -          |            |
| Potassium Oxide        | 0.711  | 0.698    | -          |            |
| Chromium Oxide         | 2.205  | -        | 6.222      |            |
| Nickel Oxide           | -      | -        | 0.702      |            |
| Zirconium dioxide      | -      | -        | 0.160      |            |
| Silver Oxide           | -      | -        | 0.010      |            |
| Cadmium oxide          | -      | -        | 0.033      |            |
| Strontium peroxide     | -      | -        | 0.046      |            |
| Chlorine               | -      | -        | 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:

\[ T + S + W = 2500 \text{ g} \] \quad \text{Equation (1)}

Where T as Target materials; S as Stabiliser; W as moisture content in percentage which in this experiment 20% of moisture content was used.

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, UiTM Shah Alam according to the industrial standard brick size.
All the engineering properties test were conducted according to BS EN 772-1:2011 [3]. All the acoustic tests were done in a reverberant room at Acoustic Laboratory Faculty of Architecture, Planning and Surveying, Shah Alam. Two types of acoustic test were performed which, 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. The standard applies to the acoustic test facilities complete with structural isolation between source room and receiving room. The intention of this test to investigate the specimens performance at the isolating sound.

3. Result and Discussion

3.1 Compressive Strength

Figure 1 indicates the pattern of compressive strength for HL stabiliser system (see Figure 1(a)) and PC stabiliser system (see Figure 1 (b)) for SWPS bricks system. SWPS with HL stabiliser systems showed that blended stabiliser HL-GGBS gave better performance in compressive strength compared to SWPS bricks stabilised with HL only. SWPS bricks with HL only at 7 days curing period did not reach 5,000 kN/m² the strength only attained at 4,043 kN/m², but the strength increased when reached 28 days curing period which logged at 6,479 kN/m². The compressive strength at 60 days curing period had slightly increased to 6,547 kN/m² and the strength marginally developed at 180 days and 365 days the compressive strength reached 10,674 kN/m² and the final monitored curing period the strength attained at 16,577 kN/m². SWPS bricks with blended stabiliser HL-GGBS increased the compressive strength value which at 7 days curing period the value recorded at 8,661 kN/m² that was more than required strength at 5,000 kN/m². When reached 28 days curing period the compressive strength continuously increased to 13,638 kN/m² the values gradually improved when reached 60 days curing period to 15,202 kN/m². The compressive strength at 180 days achieved at 16,707 kN/m² and continuously increased at the 365 days final curing period observation recorded at 25,630 kN/m².

![Figure 1](image1.png)

**Figure 1.** Compressive strength of SWPS bricks with (a) HL stabiliser system and (b) PC stabiliser system.

Figure 1(b) indicates the comparative of compressive strength pattern for SWPS bricks with PC stabiliser system. SWPS bricks with stabiliser of PC and PC-GGBS also exceed the minimum requirement in compressive strength. Compressive strength for SWPS bricks stabilised with PC only for at 7 days curing period the compressive strength logged at 11,163kN/m², 12,450 kN/m² 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 15,947 kN/m$^2$ when reached the final curing period at 365 days the compressive strength reached 27,035 kN/m$^2$. SWPS with blended stabiliser PC-GGBS indicated steadily increased of compressive strength. At 7 days curing period the strength recorded at 7595 kN/m$^2$ slightly lower than SWPS with PC 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$^2$.

3.2 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 1. Average STC for SWPS with HL:GGBS at 38db and average STC for SWPS with PC:GGBS at 32db.

![Figure 2. Transmission loss vs frequencies for SWPS Brick stabilised with (a) HL:GGBS and (b) PC:GGBS.](image-url)

Figure 2 above 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 3 below 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 are better in terms of conducting sound.
4. 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/m² 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 [4] or to its continued formation, without necessarily developing a crystalline structure, but blocking pores and providing strength as it develops [5]. 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 CO₂ 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 [6] prove that decrease in density improved the sound insulation performance and some stabilisers and fibres increased the durability. [6] 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), [7] 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 waste 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 [8]. 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 [9]–[14]. 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.

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