Sewage Sludge Incorporating Into Fired Clay Brick: Indoor Air Quality Testing

Aeslina Abdul Kadir, AmirulAmran, NurulSalhana Abdul Salim, MohdIkhmalHaqeem Hassan, Nurul Nabila Huda Hashar

Abstract*—*Sewage industry have generated huge amount of sewage sludge. It is found that the amount of sewage sludge generated by Malaysia sewerage companies has reached 5.3 million m^3 per year. Sewage sludge (SS) are usually disposed into a landfill or incineration but due to the huge amount of sludge produced and limited availability of lad, it has become an environmental hazard. Thus, this research was conducted to utilize sludge that resulted from the wastewater treatment plant into fired clay brick as well as contributed to other alternative disposal method for the sludge. This research focuses on the investigation of indoor air quality of fired clay brick incorporating with SS. The SS was collected from IWK located at Senggarang and Perwira whilst clay soil was collected at Yong Peng, Johor. The characteristics of SS and clay soil were analyzed using X-ray fluorescence (XRF). From the results, it showed that SS was high with silicon oxide (SiO_2) and zinc (Zn) that makes it compatible to replace clay soil as raw materials. Next, two types of sewage sludge brick (SSB) which are Senggarang brick (SB) and Perwira brick (PB) were incorporated with 0%, 1%, 5%, 10% and 20% of SS respectively. Then, the compressive strength test was conducted in accordance with the British Standard BS 3921: 1985. Based on the result, it shows that 5% of SS replacements as clay soil into fired clay brick have achieved the optimum strength. As for the indoor air quality (IAQ) test were done in walk-in stability chamber (WiSC) and the gas emission was compared with the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ) through Department of Occupational Safety and Health Malaysia (DOSH, 2010). From the result, IAQ brick for SB and PB showed that up to 5% in fired clay brick were complied with the standard which below the acceptable limit that has provided for wall, column and cube formed. Thus, as a conclusion this method provided an alternative disposal method for the SS whilst producing a new low-cost building material with no negative effect to human as well as benefit to the environment.

Keywords : Sewage sludge, Indoor Air Quality, Fired Clay Brick.

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Aeslina Abdul Kadir, Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, University of Tun Hussein Onn, Malaysia.
(Email: aeslina.ak@gmail.com)

AmirulAmran, Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, University of Tun Hussein Onn, Malaysia.
(Email: amirulamran93@gmail.com)

NurulSalhana Abdul Salim, Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, University of Tun Hussein Onn, Malaysia.
(Email: nurulsalhana@gmail.com)

MohdIkhmalHaqeem Hassan, Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, University of Tun Hussein Onn, Malaysia.
(Email: mohd.ikhmal.haqeem@gmail.com)

Nurul Nabila Huda Hashar, Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, University of Tun Hussein Onn, Malaysia.
(Email: nurulnabilahudahashar@gmail.com)

I. INTRODUCTION

Sewage sludge (SS) is based on the wastewater treatment in sewage treatment plants (STP). SS is generated by various sources such as residential, institutional, commercial, and industrial development. This treatment produces fresh sludge where decomposed by anaerobic bacteria and resulting in a condition of liquidity for a few days before turning into semi-solid slurry. Sludge generated every year due to the rapid growth of population and development due to urbanization life [1].

In general, the sewage treatment is a process to remove contaminants from wastewater. The treatment includes physical, chemical, biological processes and environmentally safe of treated wastewater. There are three stages of treatment which are pre-treatment, primary treatment, and secondary treatment. During the pre-treatment stage, large solids and sand are filtered through the grit screen. Next, the wastewater will be further treated using primary treatment in which the wastewater will undergo the sedimentation process through the action of gravity. The sedimentation process will allow all the solid to settle oil and grease to float. Then, the settleable and floatable solid will be removed and the wastewater will be further treated in secondary treatment through one or more biological process. Based on the rapid development within the country, it can be deduced thatthe volume of sludge will be increase alongside with amount of wastewater generated [2]. The SS is an organic matter that includes of carbohydrate, fat, oil, grease, proteins and surfactants while inorganic consists of chloride, phosphorus, pH and Sulphur [3]. Clay brick also have moderate insulating properties that can decrease the temperature of the building during summer [6]. The time and firing temperature depends on the raw materials used but if the brick is under fired, the brick produce was weakened due to the poor bonding between the clay particles [4]. Fired bricks are one of the longest-lasting and strongest building materials [5].

II. MATERIALS AND METHOD

A. Raw materials preparation

Clay soil was collected in Yong Peng, Johor. Meanwhile, sewage sludge (SS) were obtained from Indah Water Konsortium (IWK) which located at Senggarang and Perwira. Firstly, the clay soil and SS were dried in oven for 24 hours at 105^{o}C to ensure that the excess moisture present in the clay soil and SS was eliminated to the minimum. Then, both of raw materials were grinded and crushed in order to made the sieve process are easier. The passing sieve of 3.35-micron were used to manufactured a clay brick. Fig 1a and Fig 1b showed the raw materials after sieving process.

(a)

(b)

Fig 1: Grinded of (a) clay soil and (b) SS

B. Characteristic of raw materials

The chemical composition and heavy metal concentration of clay soil and SS was determined by using X-Ray fluorescence (XRF).

C. Brick manufacturing

There were a few types of brick that was manufactured which is control brick (CB), Senggarang brick (SB) and Perwira brick (PB). Table 1 shows the ratio mixture of CB, SB and PB. The mixing process was conduct manually by hand to ensure that the raw materials are homogenizes. After the homogenized process, the mixture was put into the brick mould (215 mm x 102 mm x 65 mm) and compacted by automated brick making machine. The compressed brick was then dried for 24 hours in an oven at 105°C. Then, the manufacturing brick were firing in a furnace at heating rates of 1°C/min until the furnace temperature reached 1050°C.

Table 1: Ratio mixture of CB, SB and PB

Mixture	Percentage (%)	Clay (g)	SS (g)	Water (ml)
Control brick (CB)	0	2800	0	476
Senggarang brick (SB)	5	2660	140	510
Perwira brick (PB)	5	2660	140	507

Since decades ago, there are numerous intentions from many national and institutional scientific organization as well as environment community on the effects of Indoor Air Quality to the building occupants. The most important element is the Indoor Air Quality for all building should be able to maintain the health and comfort of building occupants. The current research trend on the IAQ has shown that there are an increase of pollutants year by year within the building. In order to protect the comfort and health of the occupants, there are various enforcement of standards and regulations related to IAQ in many countries. Apart from that, there are also the introduction of policies for non-industrial building and monitoring plans in a few countries. The estimation from one study has proved that most people spend about 90% of their lifetime in both private and public indoor environments, such as house, office, classroom as well as vehicles. This is the main reason to the significant impact caused by IAQ on community's health and their life quality. There are also some cases in which the body exposure to indoor air pollution is greater than outdoor pollution. Poor indoor air quality can be dangerous especially to vulnerable groups such as children, young adults or patients suffered from various diseases [7]. IAQ testing was conducted in the Walk in Stability Chamber (WiSC) which is separated from air and gas from outside source. WiSC was designed with thethermal insulated properties so that it can be used with the controlled temperature and humidity to enable the study on thermal comfort, heat stress and IAQ Figure 2 to Figure 4 showed the sample of fired clay brick that has been built with a dimension of 1 m x 1 m x 1 m cube (Fig. 2), 0.2 m x 0.1 m x 1.5 m wall (Fig. 3) and 0.5 m x 0.5 m x 1.5 m column (Fig. 4). Two properties which are air temperature and relative humidity were determined according to [8]. From the testing, the following gases have taken to been measured: carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compound (TVOC), ozone (O_2) and particulate matter (PM_{10}). Lastly, after 8 hours, the data was collected and the results were compared with the standards Industry Code of Practice on Indoor Air Quality [8].

Fig 2: Cube

Fig 3: Wall

Fig 4: Column

III. RESULT AND DISCUSSION

The results of X-Ray fluorescence (XRF) analysis, compressive strength and indoor air quality (IAQ) were discussed thoroughly.

A. Properties of raw materials

Table 2(a) and 2(b) showed the chemical composition and heavy metal concentration of clay soil and sewage sludge (SS). From the results, it shows that the highest percentage of chemical composition for clay soil, Senggarang and Perwira sludge is silicon dioxide (SiO_2) with percentage 49.30%, 14.30% and 16.30% respectively. Followed by aluminium oxide (Al_2O_3) with 18.40%, 6.66%, 4.79% and ferric oxide (Fe_2O_3) with 6.78%, 9.85% and 9.35% for clay soil, Senggarang sludge and Perwira sludge respectively. The lowest percentage of chemical composition is manganese oxide (MnO) with 0.04% for soil, 0.6% for Senggarang sludge and 0.5% for Perwira sludge. On other hands, the highest percentage of heavy metals concentration for clay soil and sewage sludge from Senggarang and Perwira is zinc (Zn) with 260 ppm, 1126 ppm and 983 ppm respectively. Thus, Zn is a suitable element for replacement material with clay soil. The lowest percentage of heavy metals concentration for clay soil was cobalt (Co) with 6 ppm and same percentage for Senggarang and Perwira sludge which is 8 ppm.

Table 2(a): Chemical composition of clay soil and sludge

Element	Chemical composition		
	Clay soil	Senggarang sludge	Perwira Sludge
SiO_2	49.30	14.30	16.30
Al_2O_3	18.40	6.66	4.79
Na_2O	ND	0.23	ND
K_2O	3.09	0.71	1.07
Fe_2O_3	6.78	9.85	9.35
CaO	ND	6.55	2.40
MgO	0.80	1.15	0.85
P_2O_5	ND	5.58	6.68
TiO_2	0.94	0.50	0.52
MnO	0.4	0.6	0.5
SO_3	ND	9.20	4.61

Table 2(b): Heavy metals concentration of clay soil and sludge

Element	Heavy metals concentration		
	Clay soil	Senggarang sludge	Perwira sludge
Sc	19	6	7
V	150	41	44
Cr	100	130	126
Co	6	8	8
Ni	15	28	30
Zn	260	1126	983
Pb	30	55	52
As	8	12	9
Rb	97	22	29
Y	37	18	25
Nb	16	9	6

B. Compressive strength

The compressive strength test was tested to get the optimum percentage of the materials incorporated into fired clay brick. This test was followed according to BS 3921:1985. The results are shown in Table 3. Based on the result, the optimum percentage was up to 5%. This is due to value of strength for Senggarang and Perwira brick in the range for the characteristic of clay brick between 7N/mm^2 and 100N/mm^2.

Table 3: Compressive strength results

Mixture Proportion (%)	Compressive Strength (MPa)	
	Senggarang Brick (SB)	Perwira Brick (PB)
Control	27.1	27.1
1	23	22.3
5	15	11.3
10	9.3	6.8
20	1.4	1.5

C. Indoor air quality gas emissions

Total volatile organic compound

Total volatile organic compound (TVOC) is defined as the amount of volatile organic compounds that were obtained from indoor air. Basically, it measures gas that released from particular substances such liquid or solid. Besides, TVOC have a short-term and long term adverse effect to human health for example occupant had been complaint about the bad indoor of air quality. The impact may include irritation of membranes, eyes, nose and throat. According to industry code of practice on indoor air quality (ICOP-IAQ), (DOSH, 2010), the limitation for TVOC is 3 ppm.

Table 4: TVOC emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	0.30	0.40	0.10
Column	0.50	0.30	0.20
Cube	0.40	0.50	0.10

* Empty Room (ER) as a reference for a comparison for the types of bricks = 0.46 ppm
** Acceptable limits for TVOC is 3 ppm

Fig 5 below illustrated data in Table 4. The graph (Fig 5) shows of TVOC against types of bricks in the pattern of wall, column and cube. Based on data in Table 4, PB showed the lowest of emissions in the form of wall at 0.10 ppm, column at 0.20 ppm and cube at 0.10 ppm. Meanwhile, for SB, it received majority highest emissions of TVOC in the form of wall (0.40), column (0.30) and cube (0.50) in unit ppm whilst CB has the highest emissions rather than SB and PB at column parameter with 0.50 ppm. According to limitation for ER, the TVOC level for CB, SB and PB appeared to be minimum in every pattern except for CB column and SB cube form. As a conclusion, the amount of TVOC for CB, SB and PB is still below the limit as stated in Table 4.

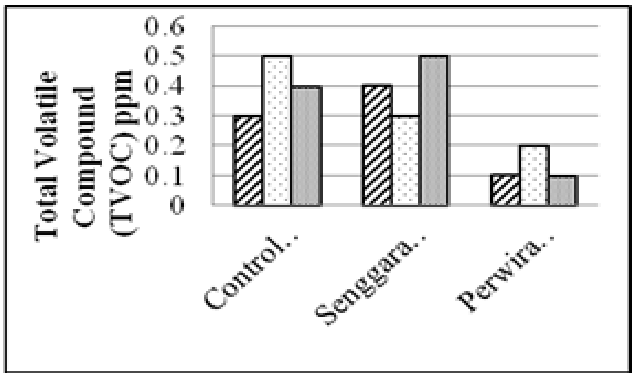

Fig 5: Graph emission of TVOC

Carbon dioxide

This gas is a greenhouse gases (GHG) that produced by human activities, in terms of the quantity released and the total impact on global warming. Besides that, carbon dioxide (CO_2) is a nonflammable, colorless, and odorless in gaseous and liquid form. Based on the limitation from (ICOP-IAQ), the CO_2 is about 1000 ppm.

Table 5: CO_2 emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	504	323	318
Column	621	350	300
Cube	598	340	325

* Empty Room (ER) as a reference for a comparison for the types of bricks = 590 ppm
** Acceptable limits for CO_2 is 1000 ppm

Fig 6 presents on carbon dioxide (CO_2) for CB, SB and PB. The mixture proportion is between 0% and 5% from sewage sludge (SS). From the result, CB (0%) showed the highest percentage of CO_2 in the form of wall, column and cube at 504 ppm, 621 ppm and 598 ppm respectively. Meanwhile, for SB (5%) and PB (5%) showed lower results in each form where PB column is at 300 ppm while the SB wall is at 323 ppm. According to empty room (ER) measurement, it shows the highest reading of CO2 emissions compared to CB, SB and PB. As a conclusion, even the ER still higher than CB, SB and PB but it still below the acceptable limit provided which is below 1000 ppm.

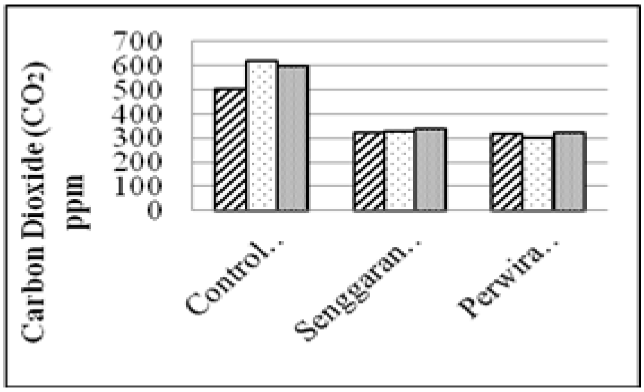

Fig 6: Graph emissions of CO_2

Carbon monoxide

Carbon monoxide (CO) can cause a risk to health problem if not controlled and easily detected as a poisonous, colorless, odorless, and tasteless gas. Nevertheless, the limitation of CO is 10 ppm according to ICOP-IAQ. Table 6 produced the result of CO for CB, SB and PB.

Table 6: CO emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	0.93	0.08	0.09
Column	0.54	0.11	0.10
Cube	0.50	0.18	0.20

* Empty Room (ER) as a reference for a comparison for the types of bricks = 0.30ppm
** Acceptable limits for CO is 10ppm

Fig 7 shows the graph of CO emissions from different types of fired clay bricks with different types of arrangement. According to the result obtained, CB has achieved the highest emissions, 0.93 ppm (wall), 0.54 ppm (column) and 0.50 ppm (cube). The SB wall and PB column showed the lowest CO emission based on the data recorded. Nevertheless, all the data of CB, SB and PB are still satisfy and comply with the standard which means CO did not exceed 10 ppm.

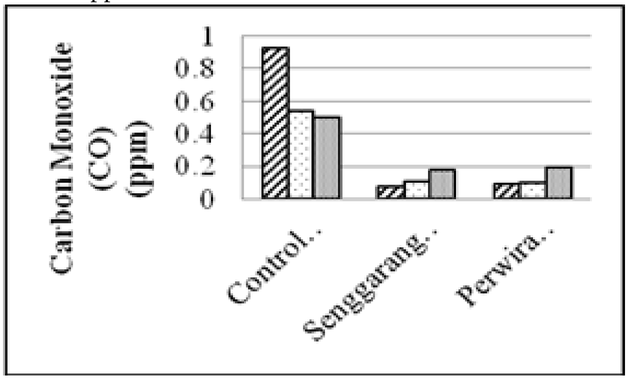

Fig 7: Graph emissions of CO

Ozone

(O_3) or formerly known as ozone is colorless gas that can affect the amount of health problems include coughing, breathing process and lung damage. According to DOSH (2010), the permissible limit stated for O_3 is 0.050 ppm.

Table 7: O_3 emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	0.01	0.008	0.007
Column	0.01	0.006	0.005
Cube	0.01	0.007	0.006

*** Empty Room (ER) as a reference for a comparison for the types of bricks = 0.010 ppm**
**** Acceptable limits for O_3 is 0.050 ppm**

Fig 8 below shows O_3 emissions results as shown in Table 7. Based on the graph, CB has the highest O_3 emissions with constant value of 0.01 ppm compared to SB and PB. The lowest value obtained by PB column where at 0.005 ppm. Thus, it showed that all samples are complied with standard which not exceed the limitation stated in industry code of practice of indoor air quality (ICOP-IAQ).

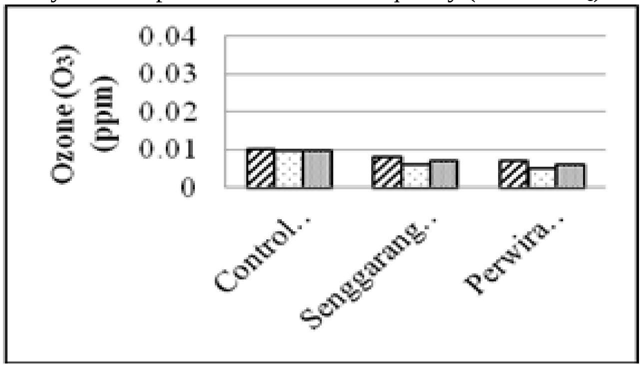

Fig 8: Graph emissions of O_3

Formaldehyde

Formaldehyde (HCHO) is one of Volatile Organic Compounds (VOCs). Nevertheless, it was the gas that composed by hydrocarbons and oxidation. The effect of HCHO likely irritating to eyes, nose and respiratory system.

Table 8: HCHO emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	0.01	0.011	0.009
Column	0.01	0.009	0.007
Cube	0.01	0.006	0.005

*** Empty Room (ER) as a reference for a comparison for the types of bricks = 0.000 ppm**
**** Acceptable limits for HCHO is 0.1 ppm**

Fig 9 illustrated the result in Table 8. The highest value was obtained in wall parameter for SB wall (0.011 ppm) followed by CB wall (0.010 ppm) and PB wall (0.009 ppm). The CB gives constant value while SB and PB slightly decrease within form of arrangement by wall, column and cube. By referring to acceptable limit of HCHO, the data presented are complies with standard required. .

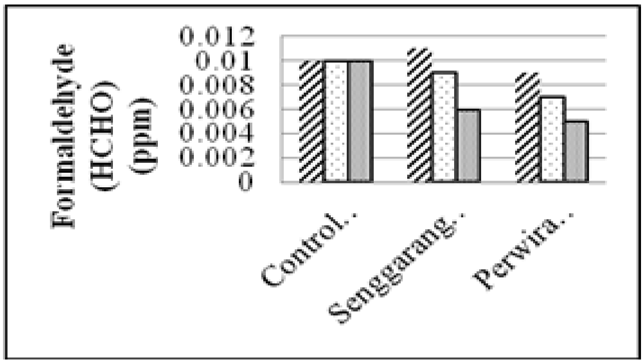

Fig 9: Graph emissions of HCHO

Particulate matter

Particulate matter (PM10) or referred to particle pollution is defined as a complex mixture of solid or liquid that suspended to air. Thus, this particle is in variety size, shape and composition which affect the respiratory system for example lungs through inhale process. Based on the ICOP-IAQ standard, the permissible limits for PM10 are 0.150 mg/m3.

Table 9: PM_{10} emissions results

Parameter	CB (0%)	SB (5%)	PB (5%)
Wall	0.109	0.213	0.230
Column	0.087	0.174	0.190
Cube	0.095	0.208	0.210

*** Empty Room (ER) as a reference for a comparison for the types of bricks = 0.195 mg/m^3**
**** Acceptable limits for PM_{10} is 0.15 mg/m^3**

The graph for PM10 against types of fired clay bricks. This parameter was measured in milligram per meter cube (mg/m3). Empty room (ER) result were greater than limitation provided with 0.195 mg/m³, however the SB and PB also indicate the same pattern as the value hit to peak which higher than acceptable limits. It increased in range of 0.150 mg/m³ to 0.230 mg/m³. From the result obtained, CB shows the lowest emission and complies with standard provided for wall at 0.109 mg/m3, column at 0.087 mg/m3 and cube at 0.095 mg/m3 respectively. In conclusion, the incorporated of sewage sludge with fired clay brick are unsafe to be used as an indoor brick in term of particulate matter (PM10) because the value of SB and PB were higher which ER also demonstrated higher value than acceptable limits provided.

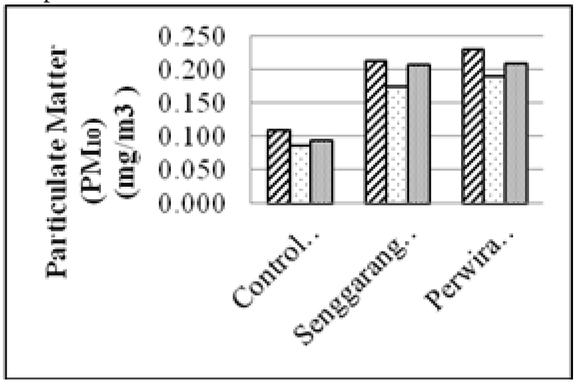

Fig 10: Graph emissions of PM_{10}

IV. CONCLUSION

In conclusion, by incorporated sewage sludge (SS) into fired clay brick is a good decision due to the obtained result. This is because the value of silicon oxide and zinc is higher and suitable to be replaced with clay soil respectively along with the benefits to establish fertilization and generally good in biomass process. Apart from that, the optimum percentage of SS also important due to avoid less strength of bricks. The higher the percentage of SS, the lower the strength obtained. Furthermore, based on the indoor air quality result stated for control brick (CB), Senggarang brick (SB) and Perwira brick (PB), it showed that the parameter for total volatile organic compound (TVOC), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3) and formaldehyde (HCHO) was below the acceptable limit required. So, its means that, the fired clay brick that incorporated with sewage sludge is safe to be used in term of building materials. In other hands, particulate matter (PM_{10}) for SB and PB was over than acceptable limit as the condition of empty room (ER) are the same. Thus, in terms of used for indoor building materials was not safe in future development. The result of indoor air quality also showed a good result which is the value is less from the standard of limitation from the industry code of practice of indoor air quality. Thus, it proved that by using sewage sludge into fired clay brick is a good low-cost alternative materials and suitable to use as indoor buildings material.

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VII. AUTHORS PROFILE

Aeslina Abdul Kadir Associate Professor at Faculty of Civil and Enviromental Engineering, UniversitiTun Hussein Onn Malaysia with 16 years of teaching experience. Various projects and publications in solid waste management, waste recycling and sustainable building material.

AmirulAmran Bachelor of Civil Engineering at UniversitiTun Hussein Onn Malaysia (UTHM).

NurulSalhana Abdul Salim Currently a Doctorate of Philosophy in Civil Engineering student at UTHM. Previously, she completed her Master and Bachelor Degree in Civil Engineering at UTHM. She has various publications in waste management, waste recycling and sustainable building material.

MohdIkhmalHaqeem Hassan Bachelor of civil engineering (hons) UTHM 2013. Master of Civil Engineering (2016). Now pursuing doctor of philosophy in civil engineering at UniversitiTun Hussein Onn Malaysia (UTHM). Born at BatuPahat Johor.

Nurul Nabila Huda Hashar Graduated with Diploma in Civil Eng at Polytechnic Sultan Azlan Shah (PSAS) in 2014 and Bachelor of Civil Engineering at UniversitiTun Hussein Onn Malaysia (UTHM) in 2019. Now pursuing Master by Research in Civil Engineering at UTHM.