Journal of the Civil Engineering Forum, January 2023, 9(1):101-108
DOI 10.22146/jcef.5309
Available Online at: http://journal.ugm.ac.id/v3/JCEF/issue/archive

Experimental Study of Sand-Cement Brick with Expanded Polystyrene Beads and Silica Fume as Partial Replacement Materials

Yong Tat Lim*, Chun Hou Chong, Jen Hua Ling, Mazizah Ezdiani Binti Mohamad, How Teck Sia, Wen Kam Leong
School of Engineering and Technology, University of Technology Sarawak, Sarawak, MALAYSIA
*Corresponding author: limyongtat@uts.edu.my

SUBMITTED 11 August 2022 **REVISED** 11 September 2022 **ACCEPTED** 27 September 2022

ABSTRACT The construction industry is growing fast alongside the economy and population. In the construction industry, brick is one of the major building materials, and this material is in high demand for construction purposes. Admittedly, the continuous growth in population will eventually lead to a shortage of raw materials, such as sand and ordinary Portland cement in the long run. This issue can be resolved by utilizing waste materials, such as Expanded Polystyrene (EPS) beads and Silica Fume (SF), to replace sand and cement in the production of bricks, respectively. In this study, 120 specimens were produced with EPS beads replacing 10% to 15% of sand and SF replacing 10% to 20% of cement. The cement-to-sand and water-to-cement ratios were 1:2.5 and 1:0.5 respectively. Furthermore, the performance of the bricks was analyzed to determine their compressive strength, density, water absorption, and strength-to-weight ratio (s-w ratio). EPS beads were found to reduce the compressive strength and density, while SF strengthened the mix, hence compensating for the performance loss caused by the beads. From the results, the sand-cement brick with 15% EPS beads and 10% SF met all the requirements of the industry in the aspect of compressive strength, density, and water absorption. Also, less sand and cement were required to achieve comparable performance with the control brick. It reduces the weight of bricks by approximately 27.78% without affecting their effectiveness. Therefore, the application of this sand-cement brick could reduce the imposed load on the structure thus more cost-effective building can be constructed.

KEYWORDS Brick; Expanded polystyrene beads; Silica fume; Sand; Cement

1 INTRODUCTION

Bricks are used to construct walls separating the spaces in a building. It comprises about 25% of the overall building materials in a typical building (Gawatre and Vairagade, 2014). As a result of the rapid growth of the construction industry and population, there is an increased demand for bricks. Such growth is not sustainable, considering the fact that over time, there eventually will be a shortage of the raw materials used to produce these bricks, thereby increasing their cost.

In previous years, several kinds of research have been conducted concerning the production of bricks using waste materials. These research works include those intended (a) to reduce the density of bricks using expanded polystyrene (EPS) (Xu et al., 2012), and empty fruit bunch (Ling et al., 2021*a*,*b*), (b) to improve the strength of bricks using silica fume (SF) (Gawatre and Vairagade, 2014), and (c) to reduce the consumption of raw materials used in bricks production by utilizing quarry dust and rice husk (Kartini et al., 2012).

Due to poor waste management, the production of wastes, such as polystyrene, is increasing alongside human population growth and per capita consumption. Malaysia is presently one of the world's largest manufacturers of polystyrene waste, with a production record of 23,000 tons since the year 2017 (Stephen, 2017). Admittedly, if there are no measures in place to reduce waste, there could be an increase in the volume of waste produced in the coming years.

On the other hand, many heavy industries were established, mainly for the production of ferroalloy and manganese such as OM Materials

Table 1. Physical properties of materials

Materials	Descriptions
Fine aggregates	• River sand passing through 1 mm and retained on 600 µm • Density within 1,540 kgm^{-3} to 1,600 kgm^{-3}
Ordinary portland cement	• Size within 7 µm to 200 µm • Density of 1254 kgm^{-3} • Strength class 42.5 Nmm^{-2} (complied with MS EN 197-1:2014)
EPS beads	• Size within 2 mm to 5 mm • Density of 32 kgm^{-3}
SF	• Passing through the 600 µm • Density within 1,540 kgm^{-3} to 1,600

Table 2. Chemical composition of materials

Composition	Cement (%)	SF (%)
SiO_2	19.34	85.45
Al_2O_3	5.20	-
Fe_2O_3	3.41	-
CaO	64.75	0.16
MgO	1.44	4.43
SiO_3	2.85	0.69
K_2O	0.47	0.15
Na_2O	0.10	0.14
CI^-	-	0.02
$Na_2O + 0.658\,K_2O$	-	0.24
Free silicon	-	0.03
Loss on ignition	3.42	1.91

(Sarawak), Sakura Ferroalloys, and Pertama Ferroalloys (Adrian, 2015). These factories produce a lot of SF as a by-product. For instance, OM Materials (Sarawak) Sdn Bhd. with 16 furnaces produces 1,369.96 mt of micro-silica per day and 308,000 of 75% Si ferrosilicon per year. Based on the Scheduled Waste from the Department of Environment (DOE) in Malaysia, and due to the potential health concern upon massive inhalation, SF is forbidden from being disposed directly into the environment. Hence, there is a desperate need to rapidly utilize this waste for environmental sustainability.

This study aims to use EPS Beads and SF, which are both by-products, to positively impact the environment. The EPS beads and silica fume are being used as partial replacements for sand and Ordinary Portland cement, respectively and these products can change the brick's properties. The substitution of EPS beads is expected to decrease density and compressive strength (Xu et al., 2012). Meanwhile, SF improves the brick's compressive strength (Ling et al., 2019). This shows that SF could help to compensate for the performance loss caused by EPS beads. Therefore, the combined effects of EPS beads and SF could lead to the production of lightweight bricks that satisfies industry requirements.

This experimental study was conducted for this purpose, to verify the hypothesis by determining (a) the mechanical properties of brick and (b) optimum mix proportions. Lastly, the successful application of EPS and SF in sand-cement brick may lead to several benefits such as (a) the reduction of sand and cement volume used in the production of bricks, (b) the creation of economic values for both EPS and SF which will, in turn, lead to the rapid consumption of these waste materials and hence reduce their impacts on the environment.

2 MATERIALS AND METHODS

2.1 Materials

The physical properties and chemical composition of materials used in this study are summarized in Tables 1 and 2 respectively.

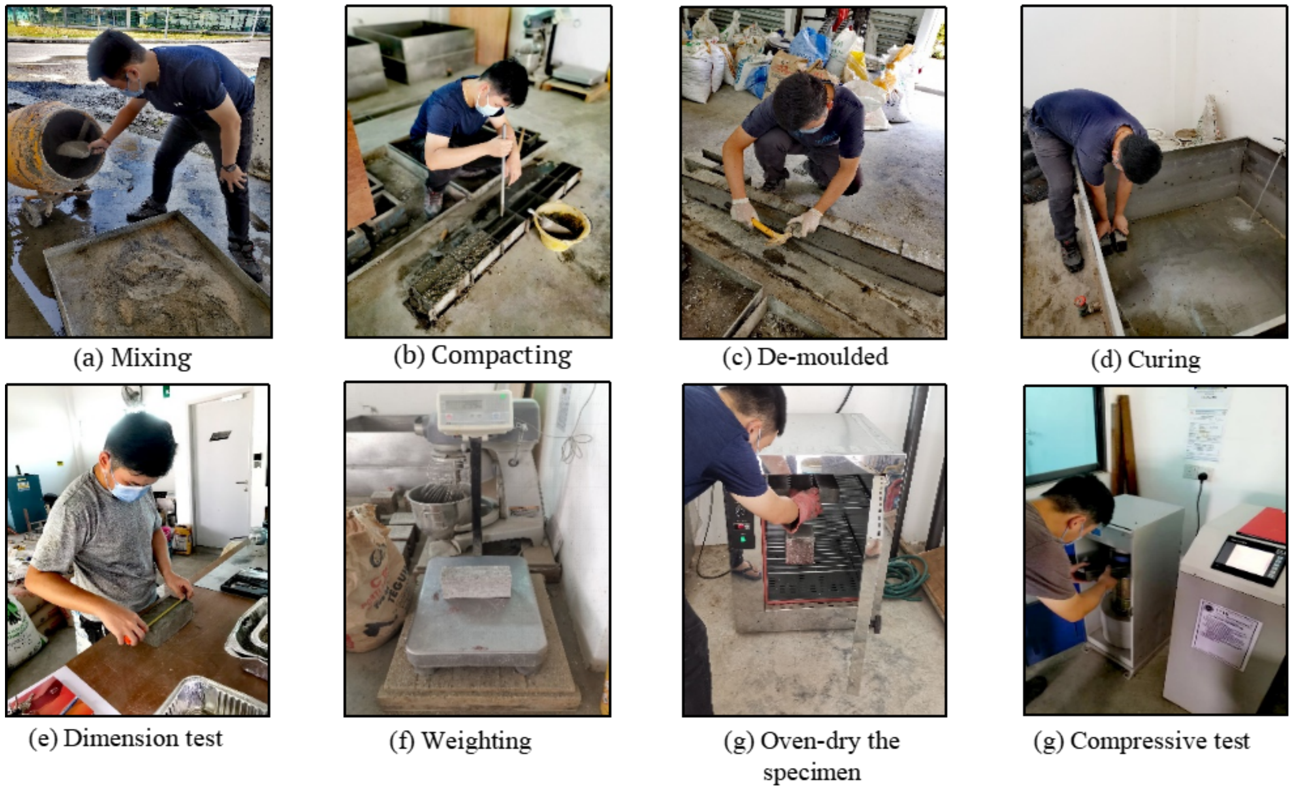

Figure 1. Preparation and testing

Table 3. Specimens details

Mix	EPS beads (%)		No. of specimens
C1	-	-	12
S1	10	10	12
S2	10	12.5	12
S3	10	15	12
S4	15	10	12
S5	15	12.5	12
S6	15	15	12
S7	20	10	12
S8	20	12.5	12
S9	20	15	12
		Total	120

2.2 Mix Proportion

All the mixtures in this study were prepared with the (a) cement-to-sand ratio of 1:2.5, and (b) water-to-cement ratio of 1:0.5 for all compositions. These mixtures are classified into two groups, which are (a) those without EPS and SF and (b) those with EPS and SF, where the percentages of substitution were within the range (a) 10% to 20% for EPS, and (b) 10% to 15% for SF as presented in Table 3.

Table 4. Limit of size for bricks

Work size (mm)	Dimension of 1 brick	
	Minimum (mm)	Maximum (mm)
215.0	211.8	218.1
102.5	100.6	104.3
65.0	63.1	66.8

Furthermore, each mixture comprised 12 specimens. 9 of these specimens were used for the compressive strength test on the 3rd, 7th, and 28th day with 3 specimens per day. Meanwhile, the remaining 3 specimens were used for density and water absorption tests on the 28th day. Also, the size of the brick used was 215 mm x 102.5 mm x 65 mm.

2.3 Test Procedures

All the specimens with the dimension of 215 mm x 102.5 mm x 65 mm, were prepared using the brick mold as shown in Figure 1. They were cast un-

Table 5. Test results of specimens

Specimen	Results					Evaluation criteria		
	Compressive strength, fc (Nmm^{-2})			Density, p (kgm^{-3})	Water absorption, WA (%)	Strength	Density	Water absorption
	Day 3	Day 7	Day 28	Day 28	Day 28	fc>7 Nmm^{-2}	p<1690 kgm^{-3}	WA<20%
C1	6.85	8.22	11.90	2,052.45	17.91	√	X	√
S1	5.93	7.39	10.85	1,712.70	16.84	√	X	√
S2	4.71	5.84	8.83	1,652.20	15.63	√	√	√
S3	3.81	5.07	7.56	1,561.44	14.24	√	√	√
S4	4.07	5.68	8.49	1,482.32	17.31	√	√	√
S5	3.26	4.14	7.19	1,424.15	15.92	√	√	√
S6	2.81	3.34	5.70	1,382.26	14.90	X	√	√
S7	3.06	3.66	5.94	1,296.16	17.76	X	√	√
S8	2.68	3.21	5.12	1,233.33	16.23	X	√	√
S9	2.21	2.71	4.10	1,165.84	15.45	X	√	√

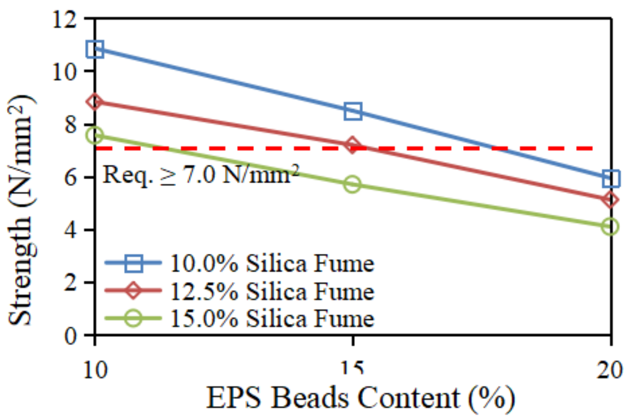

Figure 2. Compressive strength of specimens

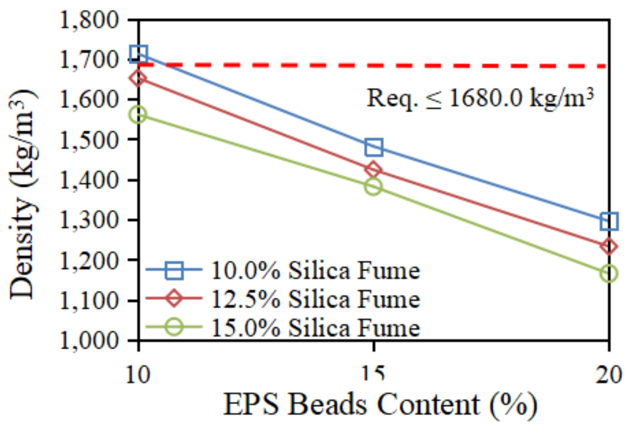

Figure 3. Density of specimens

der a humidity and temperature level of 60% - 80% and 30 ± 5°C respectively. Each mixture was compacted 25 times in 3 layers using a rod compacter. Then the specimens were de-molded after 1-day of casting and curing was carried out for 3, 7, and 28 days.

The specimens' dimension was acceptable, considering the fact that it was within limits stated in BS 3921:1985 (1985) as shown in Table 4. The compressive strength, f_c, density ρ, and water absorption were tested using the ELE International compression machine (capacity of 3000 kN) and, an electronic balance (having a capacity of 30 kg). The results were calculated using the ASTM International (2011a) equations.

$$\rho = \frac{w_d}{w_s - w_i} \times 100\% \quad (1)$$

$$WA = \frac{w_s - w_i}{w_d} \times 100\% \quad (2)$$

Where:
W_i = weight of the immersed specimen, kg
W_s = weight of the saturated specimen, kg
W_d = weight of the oven-dry specimen, kg

3 RESULT AND DISCUSSION

3.1 Test Results

Table 5 summarizes the result of the tests conducted on the specimens. The compressive strength, density, and water absorption of the specimen on day 28 was between 4.10 Nmm^{-2} to 11.90 Nmm^{-2}, 1165.84 kgm^{-2} to 2052.45 kgm^{-2}, and 14.24% to 17.91%, respectively.

The mixtures were analyzed based on the following criteria:

(a) The brick's load sustainability and its self-weight. Therefore, the compressive strength

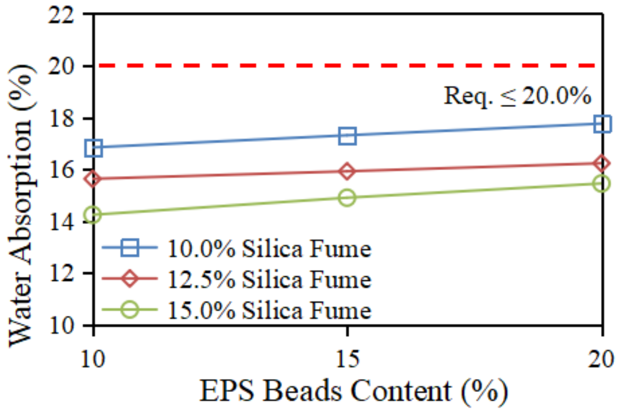

Figure 4. Water absorption of specimen

must not be less than 7 as stated in BS 3921:1985 (1985).

(b) Lightweight brick is recommended. Hence, density should not be greater than 1,680 (ASTM International, 2011b)

(c) Excessive moisture extracted from the mortar plaster could influence the bonding. Hence, the water absorption level should be less than 20% (Bureau of Indian Standards, 1992).

Based on the results displayed in Table 5, it can be observed that:

(a) 60% of the specimens met the required strength of 7 as specified by BS 3921. However, the specimens failed to achieve this strength when the substitution of EPS beads reached 20%.

(b) Most of the specimens (80%) were categorized as lightweight with densities below 1,690.

(c) All the specimens met the water absorption requirement of less than 20%.

(d) Specimens S2, S3, S4, and S5 attained the minimum requirements of the industry in the aspect of compressive strength, density, and water absorption.

3.2 Compressive Strength of Specimens

The specimens show an increase in compressive strength due to the cementitious mix. The strength reached about (a) 1/3 on day 3, and (b) 2/3 on day 7. Furthermore, the EPS beads influenced the compressive strength of the specimens. The strength decreases as the content of EPS beads increases, as shown in Figure 2. This was due to the mechanical properties of the beads which include (a) low compressive strength (Miled et al., 2004) and (b) higher porosity (Laoubi et al., 2018).

Table 6. Strength to weight ratio of specimens

Specimens	Reduction of strength, S%)	Reduction of weight, W (%)	Strength to weight ratio, (s-w ratio)	Remarks (A/NA)*1
Equation	4	5	3	-
C1	-	-	1.0	A
S1	8.82	16.55	1.1	A
S2	25.80	19.50	0.9	NA
S3	36.47	23.92	0.8	NA
S4	28.66	27.78	1.0	A
S5	39.58	30.61	0.9	NA
S6	52.10	32.65	0.7	NA
S7	50.08	36.85	0.8	NA
S8	56.97	39.91	0.7	NA
S9	65.55	43.20	0.6	NA

Meanwhile, the strength loss caused by the EPS beads can be compensated for by the addition of SF. Substituting a fraction of cement with SF increases the compressive strength of the brick. Excessive use of SF, however, was not recommended because of the material's high-water demand which will usually lead to clogging and segregation. This positively affected the compressive strength considering the fact that it decreases the pozzolanic reactions in the mixture.

3.3 Density of Specimen

The density of the specimen decreased as EPS beads increased (Figure 3). Specimen S1 had the highest density, which was 1,712.70 kgm^{-3} while specimen S3 had the lowest density of 1,561.44 kgm^{-3} when 10% SF content was added to the mixture. This was 16.55% and 23.92% lower compared to the control brick. This observation is consistent with Askar's analysis (ASKAR et al., 2019). It was due to the fact that EPS beads are ultralight particles consisting of 98.0% of air.

Theoretically, SF does not affect the density of the mixture, as long as the mixture is compacted uniformly according to ACI Committee 234 (2006). The reduction in density was probably due to the large water absorption characteristic of SF, which results in the reduction of free water in the mixture (Ling et al., 2019). This would lead to low compatibility of the cement mixture, thereby having compaction difficulties.

The results showed that 80% of the specimens had a density lower than 1,680.0 kgm^{-3} which are considered lightweight bricks as indicated in Table 6.

These bricks are preferred due to their lower self-weight, which makes it possible to easily handle them during construction.

3.4 Water Absorption of Specimens

The water absorption increased as the EPS beads increased. This finding is similar to that of some previous studies (Sulong et al., 2019; Shi et al., 2021). The high level of water absorption was due to the fact that (a) the beads are vapor-permeable, and (b) there are fine interstitial channels between the beads, which subsequently increases the absorption of water. Furthermore, as the water absorption decreased, the SF increased. This was probably due to the smaller size of the material filling the microscopic voids during mixing, thereby reducing the permeability and porosity of the brick.

Referring to Table 6, all the specimens attained the water absorption requirement, which is less than 20.0% (Bureau of Indian Standards, 1992). This implies that the specimens could prevent excessive extraction of water from mortar during the laying of bricks.

3.5 Strength to Weight Ratio

The effectiveness of sand-cement brick was evaluated using the strength-to-weight ratio (s-w ratio) as shown in Equation 3. W and S in Equations 4 and 5 represent the weight and strength reductions respectively, with respect to the control brick (Specimen C1). For effective brick, the reduction of weight should be greater than strength. Hence, the s-w ratio at least equivalent to 1 is preferable.

$$s - wratio = \frac{100 - S}{100 - W} \tag{3}$$

where:

$$W = \frac{W_C - W_L}{W_C} \times 100\% \tag{4}$$

$$S = \frac{S_C - S_L}{S_C} \times 100\% \tag{5}$$

WC = weight of control brick
WL = weight of lightweight brick
SC = ultimate strength of control brick
SL = ultimate strength of lightweight brick

From Table 6, it can be seen that the least $s - w$ ratio of specimens S1 and S4 was equal to 1.0. The lightweight brick may not necessarily be stronger than the control brick but the weight reduction should exceed the strength reduction. Hence, the brick was more effective than the control brick in the aspect of strength per unit weight.

Lastly, for construction purposes, the raw materials used as partial replacements for sand and cement, i.e. the EPS beads and SF, should be significant so that the initiative of reducing the brick's weight will be meaningful. For this reason, all the mixtures with more than 15% replacement were acceptable.

4 CONCLUSIONS

This study aimed to (a) investigate the properties of the sand-cement brick and (b) determine the optimum mix proportion of EPS beads and SF. The specimens were analyzed in the aspect of (a) the compressive strength, (b) the density, (c) the water absorption, and (d) the $s - w$ ratio. From the results, it was concluded that (a) there will be a decrease in compressive strength with an increase in the EPS beads and SF materials, (b) the density also decreased as the EPS beads and SF increased, and (c) when there is an increase in the volume of beads used in the mixture, the water absorption will also increase. However, the water absorption decreases when the SF content is increased. For construction purposes, it is recommended that the EPS beads and SF acts as sand and cement replacement at 15% and 10% respectively, in order to achieve comparable performance with the control brick.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

ACKNOWLEDGMENTS

This work was supported by the Research Grants of the University of Technology Sarawak,

UTS/RESEARCH/4/2021/01.

SYMBOLS

f_c,	Compressive strength of brick (Nmm^{-2})
S	Reduction of strength (%)
S_c	Strength of control brick (N)
S_L	Strength of lightweight brick (N)
$s\text{-}w\ ratio$	Effective strength-to-weight ratio
W	Reduction of weight (%)
WA	Water absorption of brick (%)
W_c	Weight of control brick (kg)
W_d	Weight of the oven-dry specimen (kg)
W_i	Weight of the immersed specimen (kg)
W_L	Weight of lightweight brick (kg)
W_S	Weight of the saturated specimen (kg)
ρ	Density of brick (kgm^{-3})

REFERENCES

ACI Committee 234 (2006), Guide for the use of silica fume in concrete, American Concrete Institute.

Adrian, L. (2015), 'Sarawak scores high on foreign investments'. Accessed October 5, 2021.
URL: *https://www.theborneopost.com/2015/05/23/sarawak-scores-high-on-foreign-investments/*

ASKAR, L. K., ALBARWARY, I. H. M. and ASKAR, M. K. (2019), 'Use of expanded polystyrene (eps) beads in silica-fume concrete', *Journal of Duhok University* **22**(1), 30–38.
URL: *https://doi.org/10.26682/sjuod.2019.22.1.5*

ASTM International (2011a), *Standard test methods for sampling and testing concrete masonry units and related units*, ASTM C140 – 11a.

ASTM International (2011b), *Standard Specification for Concrete Facing Brick*, ASTM C1634-11.

BS 3921:1985 (1985), *Specification for clay bricks*, British Standards Institution.
URL: *https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=72040*

Bureau of Indian Standards (1992), *Common burnt clay building bricks - specification*, IS 1077: 1992.

Gawatre, D. W. and Vairagade, L. N. (2014), 'Strength characteristics of different types of bricks', *J. Sci. Res* **3**(1), 2247–2252.

Kartini, K., Ernida, Z. N., Fazilla, B. N. and Farhan, A. (2012), 'Development of lightweight sand-cement bricks using quarry dust, rice husk and kenaf powder for sustainability', *International Journal of Civil & Environmental Engineering* **12**(6), 1–7.

Laoubi, H., Bederina, M., Djoudi, A., Goullieux, A., Dheilly, R. M. and Queneudec, M. (2018), 'Study of a new plaster composite based on dune sand and expanded polystyrene as aggregates', *The Open Civil Engineering Journal* **12**(1).
URL: *https://doi.org/10.2174/1874149501812010401*

Ling, J. H., Lim, Y. T., Leong, W. K., Jusli, E. and Sia, H. T. (2019), Properties of cement brick with partial replacement of sand and cement with oil palm empty fruit bunches and silica fume, *in* 'Journal of the Civil Engineering Forum', Vol. 5, pp. 289–300.
URL: *https://doi.org/10.22146/jcef.47982*

Ling, J. H., Lim, Y. T., Leong, W. K. and Sia, H. T. (2021*a*), 'Effects of adding silica fume and empty fruit bunch to the mix of cement brick', *Indonesian Journal of Computing, Engineering and Design (IJoCED)* **3**(1), 19–30.
URL: *https://doi.org/10.35806/ijoced.v3i1.141*

Ling, J. H., Lim, Y. T., Leong, W. K. and Sia, H. T. (2021*b*), 'Utilization of oil palm empty fruit bunch in cement bricks', *JACEE (Journal of Advanced Civil and Environmental Engineering)* **4**(1), 1–10.
URL: *https://doi.org/10.30659/jacee.4.1.1-10*

Miled, K., Le Roy, R., Sab, K. and Boulay, C. (2004), 'Compressive behavior of an idealized eps lightweight concrete: size effects and failure mode', *Mechanics of materials* **36**(11), 1031–1046.
URL: *https://doi.org/10.1016/j.mechmat.2003.08.004*

Shi, G., Liu, T., Li, G. and Wang, Z. (2021), 'A novel thermal insulation composite fabricated with industrial solid wastes and expanded polystyrene beads by compression method', *Journal of Cleaner Production* **279**, 123420.
URL: *https://doi.org/10.1016/j.jclepro.2020.123420*

Stephen, N. (2017), 'No more plastics and polystyrene, please'. Accessed October 5, 2021.
URL: *https://www.malaysiakini.com/news/381960*

Sulong, N. H. R., Mustapa, S. A. S. and Abdul Rashid, M. K. (2019), 'Application of expanded polystyrene (eps) in buildings and constructions: A review', *Journal of Applied Polymer*

Science **136**(20), 47529.
URL: *https://doi.org/10.1002/app.47529*

Xu, Y., Jiang, L., Xu, J. and Li, Y. (2012), 'Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick', *Construction and Building Materials* **27**(1), 32–38.
URL: *https://doi.org/10.1016/j.conbuildmat.2011.08.030*