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The Study of Incorporation of Fly Ash and Lightweight Expanded Clay Aggregate (LECA) in Mortar

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ABSTRACT – The utilization of supplementary cementitious material as a cement replacement has become essential for providing sustainability to concrete. Fly ash is a by-product of coal combustion in thermal power plants and contributes significant waste generation annually. Moreover, improper disposal of fly ash in landfills has resulted in environmental concerns. Due to this obstacle, fly ash is used as a recycling material for substantial modification. This study is aimed to use fly ash as a cement replacement with percentages of 0%, 5%, 10%, 15%, and 20% of fly ash by weight of cement. In the study, LECA was also introduced as a partial replacement of sand for determining the final density of lightweight mortar. The percentages of LECA used were 0%, 5%, 10%, 15%, 20%, 25% and 30% of LECA in sand. The chemical composition for both cement and fly ash using XRF testing. Four types of trial mixes were used in the study. The mortar strength was investigated at room temperature and after exposure to water curing at 7, 14, and 28 days. The results indicated that cement replacement with 5% fly ash showed an optimum strength compared to the control sample. The incorporation of 10% LECA as a replacement of sand increased the compressive strength value compared to the control sample. Both optimum results gained from those trials were used to confirm the best combination mixes for achieving mortar strength. The final trial mix showed that the final compressive strength results in brick, achieving the strength according to MS 76: 1972. It can be concluded that the application of both fly ash and LECA can be used as a partial replacement for cement and sand. These combination percentages have resulted in good strength and reduced final product density.

KEYWORDS: Fly Ash, LECA, Mortar, Strength, Density, Lightweight Aggregate

1.0 INTRODUCTION

The consumption demands of cement and fine aggregate in the construction industry increase every year in Malaysia. The Malaysian construction market is expected to register a CAGR of 4.7% over the forecast period, 2019–2024. The Malaysian construction industry registered an average annual growth rate of 7.9% in 2010–2016 [1]. Due to these developments, the demands of cement and fine aggregate have become essential to meet the demands of the construction industry. Urbanization and land development have led to increased cement production and sand mining. According to J. Muller [2], cement production is approximately 19.5 million metric tons in Malaysia. The annual production of sand and gravel was 40 million tons in 2012, and most were found in Johor, Kedah, Perak, Sarawak, and Selangor [3]. Higher consumption of these materials leads to environmental problems and human health. Manufacturing the stone-like building material is responsible for 7% of global carbon dioxide emissions, more than what comes from all the trucks in the world [4]. The pollution caused by this mass production impacted the environment and health. Recycling is an optional method for reducing waste.

Nowadays, the application of lightweight concrete has become demanding. The application of lightweight aggregates used to produce lower density concrete has advantages in reducing the self-weight of structures and provides better thermal insulations than normal-weight concrete. According to the types of aggregates, lightweight aggregates concrete can be divided into full lightweight concrete (both the coarse and the fine aggregates are light aggregates) and sand lightweight concrete (all or part of the fine aggregate is the ordinary cement). The lightweight aggregate used in this kind of concrete has high porosity, small apparent density, higher water absorption, and lower strength. Lightweight aggregates can be divided into three types by their sources; industrial waste lightweight aggregate, natural aggregate and artificial lightweight aggregate [5]. Among artificial lightweight, the light expanded clay aggregate (LECA) is manufactured from clay as a widely available raw material that allows a process to manufacture lightweight pebbles with uniform density and better quality. It can be considered one advantage that makes it suitable for structural and non-structural lightweight concretes.

Numerous publications related to using LECA as a construction material are due to its unique properties and many applications. Most research focuses on applying LECA as a partial or complete substitution of normal weight concrete [6]. However, there is little information regarding LECA as a part of fine aggregate in mortar. Together with this study, supplementary cementitious material is also used to reduce the carbon footprint due to lesser used cement content. In this work, the research aims to utilise fly ash as cement replacement and lightweight expanded clay aggregate to produce lightweight concrete brick. The supplementary cementitious such fly ash is a waste material of coal firing In thermal plants, and its production in Malaysia was around 8.5 million tons annually [7]. This material can replace or minimise the use of cement in concrete work. The use of fly ash in brick properties provides many advantages such as being lightweight, less heat absorbed, high compressive strength and environmentally friendly [8].

On the other hand, the sand was partially replaced by lightweight expanded clay aggregate called LECA. This material is a special type of clay that has been pelletised and fired in a rotary kiln at very high temperatures [9]. LECA has been introduced instead of course aggregate for its lightweight property. The advantages of LECA include high fire resistance, relatively low water absorption, high resistance to pressing, and good sound absorption. Combining these materials with exact percentages in lightweight concrete brick is hoped to achieve sustainable compressive strength and durability for eco-friendly concrete brick.

2.0 EXPERIMENTAL PROGRAMME

2.1 Research design

The study conducted the experimental programme, as shown in Figure 1.

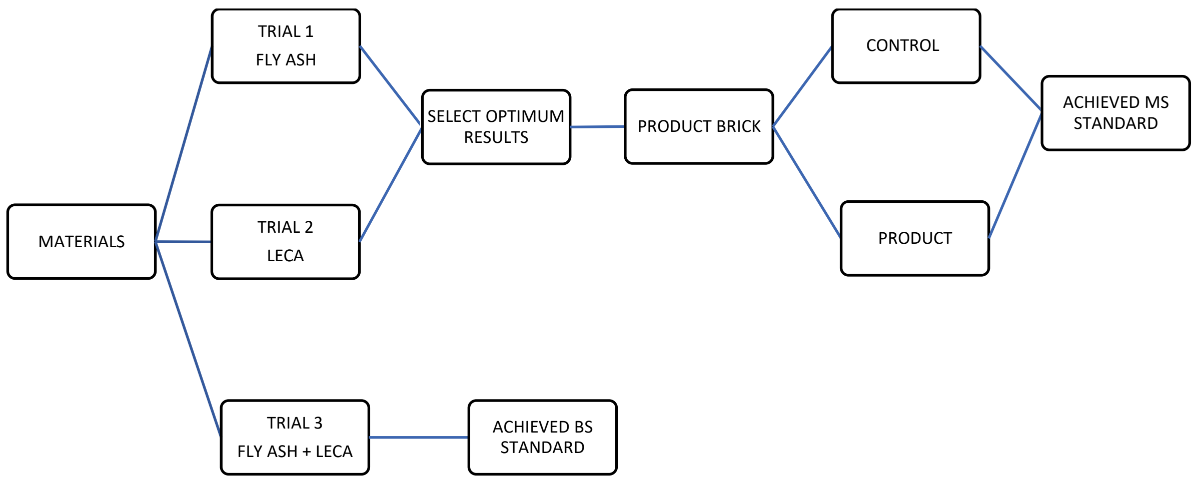


Figure 1: Research Workflow Chart

2.2 Material

Ordinary Portland Cement (OPC) complying with BS EN 197-1: 2011 was used throughout the experiment. Fly ash, a by-product of burning pulverised coal in a thermal power plant obtained from Kapar, Selangor, was used as a supplementary cementitious material. Both OPC and fly ash were sieved by 75 µm for fineness, respectively. The fly ash sample is shown in Figure 2. All samples were tested for chemical composition using Epsilon3-XL EDXRF spectrometer. The application of the EDXRF technique is fast, economical and fully suitable for the determination of many matrix elements [10]–[12]. The chemical composition is shown in Table 1.

Table 1: Concentration of elements with EDXRF analysis

Major Element	Portland Cement (%)	Fly ash (%)
Si	2.1	12.129
Al	0.497	6.285
Fe	2.476	5.321
Ca	49.01	4.814
Mg	0.201	0.165
S	0.496	658.4 (ppm)
K	0.384	0.921
Ti	0.123	1.808
P	-	0.412
Mn	973.2 (ppm)	545.7 (ppm)
Sr	-	0.521

Figure 2: Fly Ash

Figure 3: Lightweight Expanded Clay Aggregate (LECA)

2.3 Fine Aggregate

Natural river-washed quartz sand complying with BS 882: 1992 was used as fine aggregate. The sand grading is shown in Table 2, and the fine modulus of sand is 3.31.

Table 2: Grading of fine aggregate

Sieve size (mm)	Mass of each sieve (g)	Weight retained (g)	Net weight (g)	Cumulative net weight retained (g)	Cumulative net weight percentage retained (%)	Cumulative net weight passing (g)	Cumulative net weight percentage passing (%)
4.75	460	480	20	20	5.56	340	94.44
2.36	440	460	20	40	11.11	320	88.89
1.18	390	430	40	80	22.22	280	77.78
0.60	350	430	80	160	44.44	200	55.56
0.30	330	420	90	250	69.44	110	30.56
0.15	320	360	40	290	80.56	70	19.44
0.075	310	370	60	350	97.22	10	2.78
Pan	290	300	10	360	100	0	0

2.4 Light Expanded Clay Aggregate (LECA)

LECA, as shown in Figure 3, is the abbreviation of lightweight expanded clay aggregate. LECA is produced from special plastic clay with no or very little content of lime. The clay is dried, heated, and burned in rotary kilns at 1100–1300 °C. LECA is a porous ceramic product with a uniform pore structure with almost potato shape or round shape due to the kiln circular movement. The abundant numbers of small, air-filled cavities in LECA give its lightweight, thermal, and sound isolation characteristics [6]. LECA size used was below 10mm. The grading of LECA aggregates is tabulated in Table 3.

Table 3: Grading of LECA aggregate

Sieve Size	Mass of each sieve (g)	Weight Retained (g)	Net Weight (g)	retained weight	passing weight	cumulative percentage passing (%)
28	1354	1354	0	0	500	100
25	1360	1360	0	25	475	95
20	1312	1312	0	192	308	62
10	1229	1672	443	286	214	43
6.3	1268	1326	58	453	47	9
5	1165	1165	0	493	7	1
pan	903	904	7	500	0	0

2.5 Mix Proportions

Determination of compressive strength using fly ash and LECA in mortar mixes is investigated. Three mixes determine the optimum values of fly ash and LECA in mortar. The mixed proportion of bricks is to achieve the final strength products. The mix ratio used was 1:3, and the water to cementitious ratio was maintained constant at 0.5 for all mortar mixes.

2.5.1 Trial Mix 1

Table 4 shows the mortar mixes as a partial replacement of cement with fly ash. The mortar samples used are 100mm x 100mm x100mm. The percentages of replacement used are 0%, 5%, 10%, 15%, and 20% of fly ash in cement.

Table 4: Mix proportion of fly ash in mortar cube

Specimen	0%	5%	10%	15%	20%	25%
Cement (g)	6900	6555	6210	5865	5520	5175
Sand (g)	20700	20700	20700	20700	20700	20700
Water (ml)	4000	4000	4000	4000	4000	4000
Fly Ash (g)	0	345	690	1035	1380	1725

2.5.2 Trial Mix 2

Table 5 shows the mortar mixes as a partial replacement of sand with LECA. The mortar samples used are 100mm x 100mm x 100mm. The percentages of replacement used are 0%, 5%, 10%, 15%, 20%, 25% and 30% of LECA in sand.

Table 5: Mix proportion of LECA in mortar cube

Specimen	0%	5%	10%	15%	20%	25%	30%
Cement (g)	2300	2300	2300	2300	2300	2300	2300
Fly Ash (g)	0	0	0	0	0	0	0
Sand (g)	6900	6555	6210	5865	5520	5175	5175
LECA (g)	0	345	690	1035	1380	1725	1725
Water (ml)	1150	1150	1150	1150	1150	1150	1150

2.5.3 Trial Mix 3

From the trial mixes 1 and 2, the final optimum results for fly ash and LECA were used to cast the trial for mix 3. Trial mix 3 was made by combining the fly ash and LECA in one mortar mixture. There are 5 batches of the mixes, as shown in Table 6. This mixture is produced by maintaining the value of 5% fly ash as partial cement replacement, and the value of LECA used were 0%, 3%, 7%, and 10% by weight of sand. The value of 5% fly ash and 0% was used as control samples. After casting the mortar cube, all the samples are sent to a compression strength test.

Table 6: Mix proportion of Fly Ash and LECA in mortar cube

Specimen	0%	3%	5%	7%	10%
Cement (g)	2185	2185	2185	2185	2185
Sand (g)	6900	6693	6555	6417	6210
LECA (g)	0	207	345	483	690
Fly Ash (g)	115	115	115	115	115
Water (ml)	1150	1150	1150	1150	1150

2.5.4 Mix Proportion of Brick

Table 7 shows the brick mixes as a partial replacement of sand with LECA. The samples use standard brick sizes. Comparisons are made in terms of strength and density properties

Table 7: Mix proportion or brick

Specimen	Control 0%	Product: 5% Fly Ash & 10% LECA
Cement (g)	3300	3135
Sand (g)	9900	8910
Fly Ash (g)	0	6555
LECA (g)	0	165

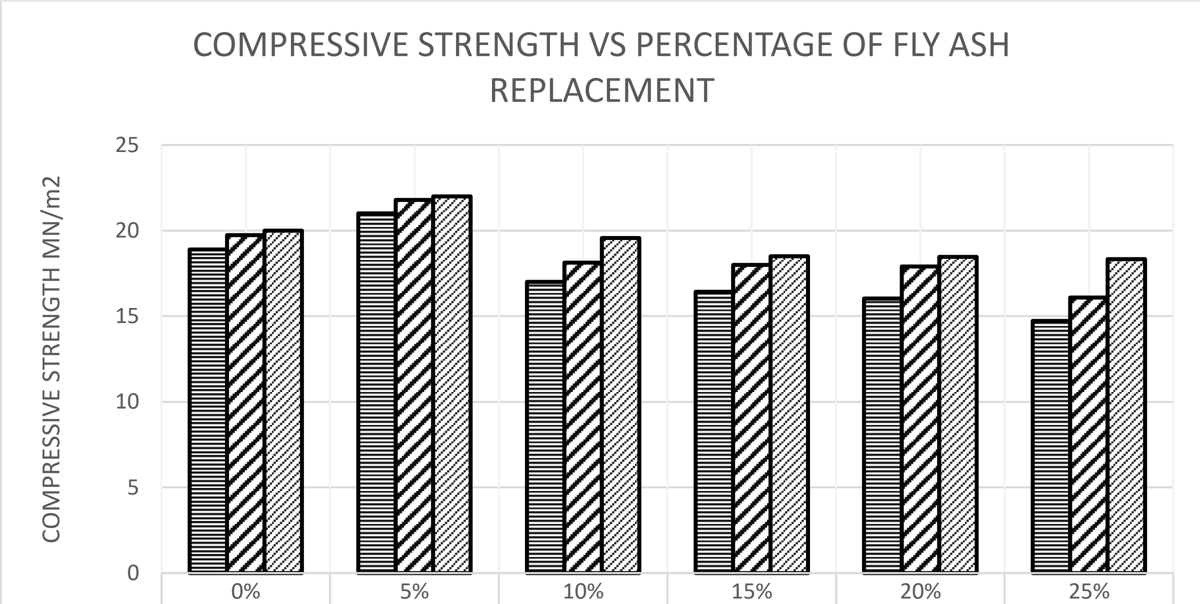
2.6 Compressive Strength Test

The trial mix of mortar cubes with 100mm x 100mm x 100mm was prepared for compressive strength testing. The test was carried out according to BS EN 12390-3: 2009. The samples were tested at 7,14, and 28 days for the fly ash cube and 7 and 28 days for the LECA cube. On the other hand, the brick product was tested at 7 and 28 days.

3.0 RESULT AND DISCUSSION

3.1 Effect of fly ash on mortar strength

Figure 4 shows the results of the compressive strength test conducted for mortar cubes by using fly ash as a cement replacement at 7, 14, and 28 days of curing period. In compressive strength test, 5% fly ash as a cement replacement attains the highest strength result for 7 days curing period with the value of the strength of 18.93 Mn/m^2 compared to other percentages of fly ash and 25% of fly ash as a cement replacement with a lower result of compressive strength with the value of the strength of 14.73 Mn/m^2 for 7 days curing period. This trend shows the decrease in compressive strength after using 10% fly ash until the last proportion for 7 days curing period. For 14 days curing period, the graph shows that 5% of fly ash obtains the highest strength with 21.8 Mn/m^2, and 20% of fly ash has the lowest strength value of 12.9 Mn/m^2. For 28 days curing period, the graph shows that 20% of fly ash promotes a high strength value of 19.67 Mn/m^2 and 5% of fly ash gains the lowest strength value of 16.33 Mn/m^2. The compressive strength of 5% for 14 days has the highest strength of fly ash as a cement replacement and shows an increase for 14 days curing period compared to 7 days and 28 days curing period. From these results, 5% fly ash improved the mortar strength in this first trial mixed. The fly ash is a pozzolanic and amorphous material. When mixed with cement and water, it reacts with the calcium hydroxide released from the hydration of portland cement to produce calcium silicate hydrates (CSH) and calcium aluminate hydrates. These pozzolanic materials reactions are beneficial to concrete, improving strength and durability [8], [14].



	0%	5%	10%	15%	20%	25%
7 DAYS	18.9	21	17	16.43	16.03	14.73
14 DAYS	19.73	21.8	18.13	18	17.9	16.1
28 DAYS	20	22	19.57	18.5	18.47	18.33

Figure 4: Graph of Compressive Strength for Concrete Cubes of Fly Ash mixture

3.2 Effect of LECA in mortar strength

Figure 5 shows the result of the compressive strength test conducted for cubes by using LECA as a sand replacement for 7 and 28 days of the curing period. The results showed that incorporating 10% LECA gave higher strength at 7 days of age with the value of 18.05 Mn/m2 compared to the control sample. However, the increased percentages of LECA until 30% showed reducing the strength of mortar. After curing at 28 days, the 10% LECA showed strength degradation. More percentages LECA in mortar showing reduction strength values. The effect of lower strength is due to water absorption by LECA according to the curing conditions. The strength value was reduced, which could be due to lightweight particle coarse aggregate particles being relatively weak[15]. Particle shape and surface texture might also influence factors that contributed to the reduction strength [16], [17].

Furthermore, It is also observed that incorporating the higher percentages of LECA in mortar presents a rough surface texture, as shown in Figure 6. It is noted that LECA in water curing absorbs more water in conjunction with the curing period. These phenomena create pores in the mortar and reduce the compressive strength at 28 days.

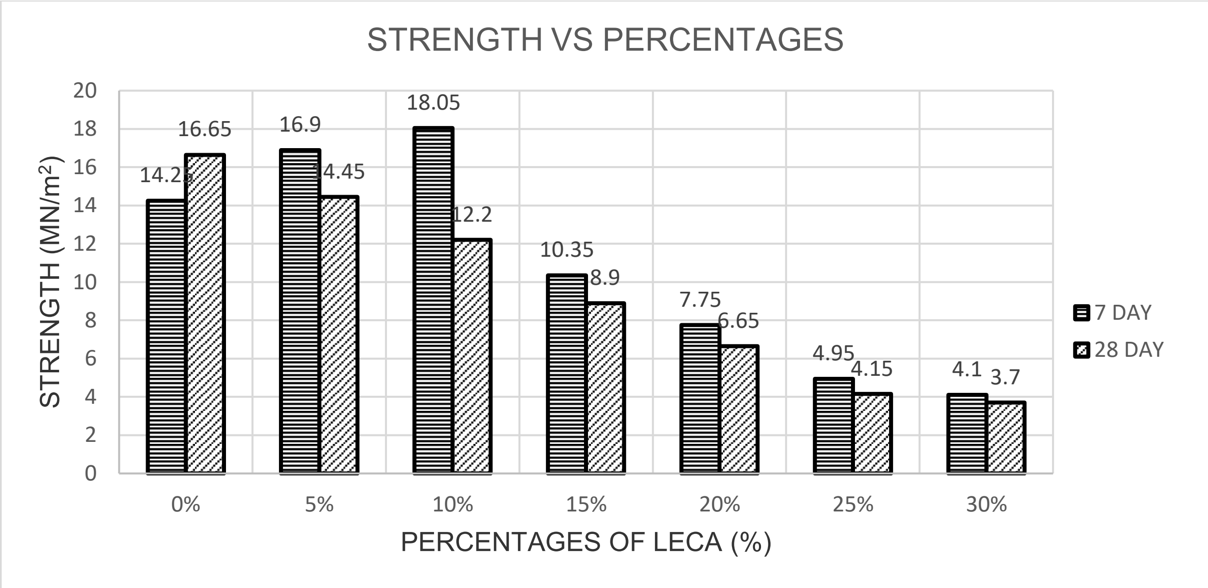


Figure 5: Graph of Compressive Strength for Concrete Cubes of LECA Mixture

Figure 6: The surface texture of mortar cube of LECA mixture

3.3 Effect of optimum percentages of Fly Ash and LECA in mortar strength

Based on trial mix 3, the result is shown in Figure 7. The percentages of LECA used were 0%, 3%, 5% and 10% by weight of sand. The graph shows that substitution of 3% LECA show strength increases compared to the control sample at 7 days. However, at 5%, 7% and 10% of LECA showed degradation in strength. At 28 days, the compressive strength values increased from LECA mortar samples compared to the control samples. The increases in strength are possibly due to the effect of fly ash as filler and improved the particle bonding between sand and cement. The addition of fly ash in a mixed design leads to a change in the rate of hydration [14]. Partial replacement with fly ash generates retardation of hydration cement at the initial stages. This behaviour reflects the strength values at 7 days. Fly ash is a pozzolanic material that can react with calcium hydroxide and can be assessed by the extent and rate of the pozzolanic reaction to gain strength over time [18].

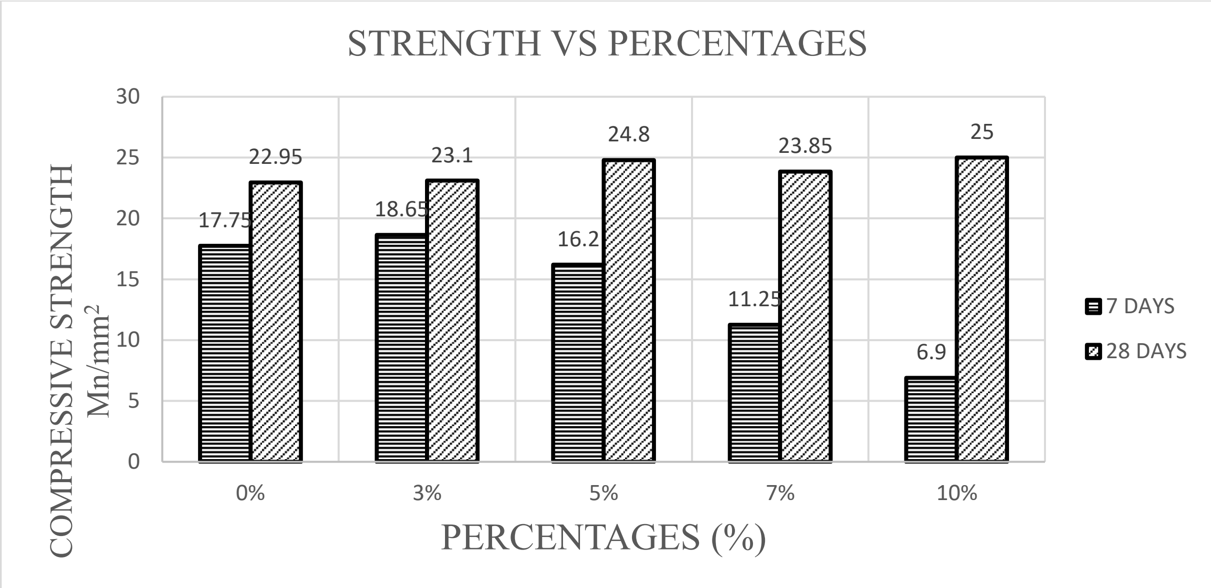


Figure 7: Graph of Compressive Strength for Mortar Cube Test 3 (Fly Ash + LECA)

3.4 Performance brick in strength

Table 8 and Table 9 show the comparison results of the control sample and modified sample. After obtaining compressive strength value of mortar cube of cement and fly ash mixture and mortar cube containing LECA, the value of 5% fly ash as cement replacement produces the highest strength value than control sample while mortar cube with LECA produces the highest strength value compared to control cube at 10%. This finding shows that the best percentage values are used as the final percentages for making bricks. The optimum values of fly ash and LECA in percentages were mixed, and the result is tabulated as indicated above. Performance strength in brick at 7 and 28 days is achieved following MS 76:1972 standards. The final product is shown in Figure 8.

It was found that using LECA as partial replacement sand reduces the density of the final product compared to the control sample.

Table 8: Result of comparison between control and product brick at 7 days.

No.	Sample	Age (days)	Initial Weight (Kg)	Weight (Kg)	Initial Density (Kg/m^3)	Density (Kg/m^3)	Strength Mn/m^2	Standard Brick Compressive Strength MS 76: 1972	Achievement Status
1.	0% Control	7	3.010	3.065	2081	2119	17.8	7 N/mm^2	Achieve
2.	0% Control	7	2.960	3.000	2046	2075	17.3	7 N/mm^2	Achieve
1.	Product	7	2.410	2.375	1666	1642	7.1	7 N/mm^2	Achieve
2.	Product	7	2.460	2.440	1701	1687	7.0	7 N/mm^2	Achieve

Table 9: Result of comparison between control and product brick at 28 days

No.	Sample	Age (Days)	Initial Weight (Kg)	Weight (Kg)	Initial Density (Kg/m³)	Density (Kg/m³)	Strength Mn/m²	Standard Brick Compressive Strength MS 76: 1972	Achievement Status
1.	0% Control	28	2.990	3175	2067	2304	17.4	7 N/mm²	Achieve
2.	0% Control	28	2.980	3165	2060	2297	21.9	7 N/mm²	Achieve
3.	Product	28	2.420	2550	1673	1851	10.5	7 N/mm²	Achieve
4.	Product	28	2.400	2570	1659	1865	9.8	7 N/mm²	Achieve

Figure 9: Final brick product with dimension 216mm x 103mm x 65mm

4.0 CONCLUSION

The following conclusions are drawn from this investigation: 1) Cement replacement with fly ash increases the mortar's compressive strength at optimum percentages. 2) LECA is utilised as partial replacement sand, showing increasing strength in the mortar at 10%. 3) The modification of mortar sample using fly ash and LECA shows better strength when used 5% fly ash and 10% LECA. 4) The compressive strength of the product brick achieves the minimum standard compressive strength based on the Malaysia standard. 5) The density of the final product shows a little decrement compared to the normal density control sample.

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REFERENCES

[1] "Malaysia Construction Market- Growth, Trends and Forecast (2020-2025)," *Mordor Intelligence*, 2019. [Online]. Available: https://www.mordorintelligence.com/industry-reports/malaysia-construction-market-growth-trends-and-forecast-2019-2024.

[2] J. Muller, "Production of Cement in Malaysia 2013-2020," *Statista*, 2021. [Online]. Available: https://www.statista.com/statistics/719188/cement-production-malaysia/.

[3] "Mineral Resources," *Department of Mineral and Geoscience, Malaysia. Malaysian Minerals.com*, 2009. [Online]. Available: http://malaysianminerals.com/index.php?option=com_content&task=view&id=21&Itemid=45.

[4] Vanessa Dezem, "Bloomberg: Cement Produces More Pollution Than All The Trucks In The World," *Uplift Investing*, 2019. [Online]. Available: https://upliftinvesting.com/resource/cement-produces-more-pollution-than-all-the-trucks-in-the-world/.

[5] H. Zhang, *Building Materials in Civil Engineering. A volume in Woodhead Publishing Series in Civil and Structural Engineering*. Woodhead Publishing Limited, 2011.

[6] A. M. Rashad, "Lightweight expanded clay aggregate as a building material – An overview," *Constr. Build. Mater.*, vol. 170, pp. 757–775, 2018.

[7] M. Rafieizonooz, J. Mirza, M. Razman, M. Warid, and E. Khankhaje, "Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement," *Constr. Build. Mater.*, vol. 116, pp. 15–24, 2016.

[8] S. Abbas, M. A. Saleem, S. M. S. Kazmi, and M. J. Munir, "Production of sustainable clay bricks using waste fly ash: Mechanical and durability properties," *J. Build. Eng.*, vol. 14, pp. 7–14, 2017.

[9] J. Latosińska and M. Zygadło, "Effect of sewage sludge addition on porosity of lightweight expanded clay aggregate (LECA) and level of heavy metals leaching from ceramic matrix," *Environ. Prot. Eng.*, vol. 35, no. 2, pp. 189–196, 2009.

[10] O. Dogan and M. Kobya, "Elemental analysis of trace elements in fly ash sample of Yatağan thermal power plants using EDXRF," *J. Quant. Spectrosc. Radiat. Transf.*, vol. 101, no. 1, pp. 146–150, 2006.

[11] A. Eser, E. Kahraman, and M. Demiray, "Comparison of atomic absorption spectroscopy and energy dispersive X-ray fluorescence spectrometer methods for chemical analysis," *Asian J. Chem.*, vol. 26, no. 20, pp. 6982–6988, 2014.

[12] G. Budak, A. Karabulut, O. Dogan, and M. Levent, "X-ray fluorescence analysis of trace elements in Mazi mountain ore," *J. trace microprobe Tech.*, vol. 17, no. 3, pp. 309–314, 1999.

[13] N. Mijatović, A. Terzić, L. Pezo, L. Miličić, and D. Živojinović, "Validation of energy-dispersive X-ray fluorescence procedure for determination of major and trace elements present in the cement based composites," *Spectrochim. Acta - Part B At. Spectrosc.*, vol. 162, p. 105729, 2019.

[14] M. Thomas, "Optimizing the Use of Fly Ash in Concrete," *Concrete Thinking for a sustainable world*, 2007.

[15] T. W. Bremner and T. A. Holm, "Elastic Compatibility and the Behaviour of Concrete," *Am. Concr. Inst.*, vol. 83, no. 2, pp. 244–250, 1986.

[16] T. A. Holm and J. P. Ries, *Lightweight concrete and aggregates. Significance of test and Properties of Concrete & Concrete making materials*. ASTM International, West Conshohocken, PA, 2016, 2006.

[17] F. M. Wegian, "Strength properties of lightweight concrete made with LECA grading," *Aust. J. Civ. Eng.*, vol. 10, no. 1, pp. 11–23, 2012.

[18] N. Longarini, P. G. Crespi, M. Zucca, N. Giordano, and G. Silvestro, "The advantages of fly ash use in concrete structures," *Inz. Miner.*, vol. 15, no. 2, pp. 141–145, 2014.