Development of concrete eco-paving blocks using crumb rubber granules and Eco-Processed Pozzolan

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ABSTRACT This study entails processing and developing end materials in order to create reusable eco-friendly paver block products. The concepts of recycling, reuse, and recovery are critical to reduce the amount of environmental damage caused by indiscriminate trash disposal. As the necessity to recover maximum profits from the management approach is applied while guaranteeing environmental sustainability, the concept of waste to wealth emerges. The objectives of this research are to produce an "eco-friendly paver block" for pedestrian walkways formulated from waste materials such as Eco-Processed Pozzolan (EPP) and crumb rubber from waste tyres. Although the strength of the eco-paver blocks incorporating used EPP and crumb rubber increased by 33%, with water cement ratio is fixed at 0.5. The compressive strength of eco-paver blocks is higher when the EPP and crumb rubber contents are lesser. The strength increased by 35% when EPP and crumb rubber were lesser used. EPP and rubber crumb usage based on M1 design are recommended to use which only 33% of EPP content allowed. Therefore, incorporating EPP and crumb rubber as a component for cement-sand paver block allowed a more sustainable and low-cost paving blocks to be produced.

KEYWORDS: Watercress; Eco-Processed Pozzolan; Eco-paver; Crumb rubber; Cement-sand block
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Original Article

INTRODUCTION

Eco-Paver blocks were developed by using waste materials from crumb rubber and bio-diesel waste products identified as Eco-Processed Pozzolan (EPP). This research was developed by using cement and sand as the parents' materials and EPP used as cement replacement to improve the workability and strength of the Eco-paver block. The use of crumb rubber granules is extended to increase the aesthetic value and generates strength through load absorption and strengthen the bond between cement and sand. EPPs are seen to act by filling the voids in the mixed proportions through their finer particles. In present research studies, the effect of Eco Process Pozzolan (EPP) on the properties of foamed concrete as a replacement conducted for cement (Othman *et al.,* 2015). Eco Process Pozzolan (EPP) is obtained from the calcination of Spent Bleaching Earth (SBE) originating from the by-product of manufacture of the edible oils.

EPP has cementitious properties and used as a partial cement replacement in concrete (Kho, 2021). The research entails processing and developing end materials in order to create reusable eco-friendly paver block products. Paver block is a material that can be recycled to increase its usability in various conditions or as a placement material for road paving finishes as well as large flat spaces. Various mixed materials as well as modified materials from waste are applied in the production of block pavers such as Bio-diesel waste production known as Eco-Processed Pozzolan (EPP) which have been used in this research.

The use of discarded plastics in concrete pavement blocks is a partial solution to the environmental and ecological issues that come with plastic usage. The goal of this research is to reduce pollution by producing eco-friendly pavement blocks by using bio-diesel waste products known as Eco-Processed Pozzolan (EPP) and crumb rubber. EPP was first utilised to replace cement in the construction of pavement blocks, with crumb rubber being added as an addition to give the paver block an extra strength. In the same way, crumb rubber granules used in the production of paver blocks (Gamalath *et al.*, 2016). A previous study showed that, the toughness of crumb rubber increases with the increase in rubber content in concrete (Gupta *et al.*, 2015).

Comparatively, the skid resistance and water absorption of concrete were found to increase with the rubber content (Pacheco-Torgal *et al.*, 2012). Thus, the use of crumb rubber granules in this research in paver blocks is seen as workable and the production of the eco-paver blocks increases the use of crumb rubber granules in eco-friendly measures that make full use of waste materials. Concrete with waste rubber aggregates (crumb rubber) used to replace a weight fraction of sand in the manufacturing of concrete products (Corinaldesi & Donnini, 2019). The negative impacts of property development on the environment and resources efficient while recycling usable construction materials to reduce pollution and waste (USEP, 2016). A pollution free and environmentally friendly future can only be accomplished through the use of green materials in the building industry (Ha *et al.*, 2020). To protect the environment, where the main emphasis is to reduce environmental pollution and carbon dioxide emissions (Zhineng, 2017).

Green materials are generated through the efficient use of waste products in the construction industry specifically and it is one of the innovative methods that reduces environmental impact by reducing CO2 emissions. The development of cleaner technologies with waste minimization could benefit everyone in every aspect. By using natural resources as advancements in construction technology, the load of pollutants on the environment could be reduced (Akadiri, 2012). The concepts of recycling, reuse, and recovery are critical in reducing the amount of environmental damage caused by indiscriminate trash disposal.

As the necessity to recover maximum profits from the management approach is applied while guaranteeing environmental sustainability, the concept of waste to wealth emerges. A reliable product life-cycle analysis is one of the techniques for increasing product marketability and lowering costs so that it can compete with a similar traditional product. The existence of aggregate moisture content and accompanied by the irregular shape of course aggregate to produce a friction force (Mohamad *et al.*, 2021a) and crumb rubber's irregular shape increases the friction. Therefore, the potential of crumb rubber and EPP usage is in line with previous studies. The Eco-paver blocks are precast material and ready to install and identically can change the progress of construction for better improvement and keep restoration progress on track (Mohamad *et al.*, 2021b).

The compressive strength test was carried out adopting (Vila *et al.*, 2017) as the result of the quotient of the maximum test load (until rupture) and the cross section of the specimen tested. The usage of EPP and crumb rubber assessed accordingly with the PVC plastic is used in the form of powder as partial replacement (Arsod, 2019). The use of this waste material can also reduce the number of environmental pollutants such as water and soil pollution (Hamid *et al.*, 2019). The main aim of this study is to produce interlocking concrete paver blocks from industrial waste (Devudu & Ram, 2015). In other study using waste, the strength of the paving blocks decreased with the PWTA replacements, the paving blocks containing 20 % and 40 % (Djamaluddin *et al.*, 2020).

This research is made with the aim to provide crucial information and knowledge regarding the potential of crumb rubber and EPP as the artificial materials to produce new eco-paver blocks. This will be an instrument that will guide and navigate efforts in discovering credible, reliable, and tantamount factors that are known as indispensable data for further understanding on the paver block as construction material. The data have shown significant results and greater potential in producing eco-paver blocks from crumb rubber usage and EPP as partial cement replacement.

ECO-PAVER BLOCK DESIGN

The production of eco-paver blocks by using unipaver shapes with plastic molds. The unipaver design has a unique quality to interlock with each other and the thickness of paver makes block paving suitable for both domestic and commercial applications including patio, driveway, sidewalk, pool deck or any required open area. The interlocking segments of pavers are slip and skid resistant. It is easy to install without any equipment. Generally, the eco-paver blocks in this research manufactured in single range and remarkable for their durable life. The uni-paver shape is also known as rectangular eta shape paver blocks developed with size 225 mm in length and 112.5 mm width with thickness is 75 mm. Figure 1 shows the specification of plastic mold used in production of eco-paver blocks with three waves.

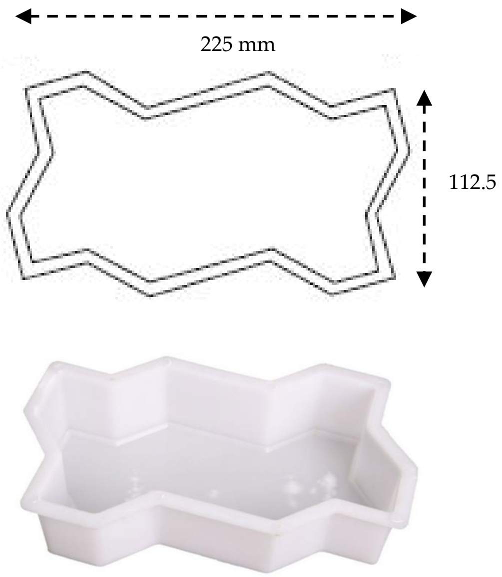

Figure 1. Uni-paver plastic mold with 3 waves.

Production of eco-paver blocks materials used in this research are from biodiesel waste production known as Eco-Processed Pozzolan (EPP). The EPP were used as a partial replacement for cement in the manufacturing of pavement blocks as the EPP has the pozzolanic characteristic which is similar to cement. The use of crumb rubber waste in concrete pavement blocks is a partial solution to the environmental and ecological challenges associated with the use of plastics. EPP were first used to replace cement in the production of pavement blocks and crumb rubber in granules shape used to increase the potential of paver esthetical value. The main ingredients used is still cement and sand.

Eco-Processed Pozzolan (EPP) is the final downstream product of the extraction process of Spent Bleaching Earth and Hexane through filtration process. The physical properties of EPP were free flowing particulate clay powder with spherical, amorphous with pozzolanic form. Table 1 shows the typical chemical analysis of EPP which is the composition of Silicon dioxide or also known as silica (SIO2) are dominant in EPP. In line with the statement of a partial replacement for cement or as an additive when special properties are desired (Jo *et al.*, 2007).

Table 1. Typical chemical analysis of EPP.

Compositions	Content, %
SIO_2	58.2
AI_2O_3	13.3
Fe_2O_3	8.7
MgO	3.3
CaO	2.8
Na_2O	0.1
K_2O	1.0
SIO_2	58.2
AI_2O_3	13.3
Fe_2O_3	8.7
MgO	3.3

Figure 4 shows the particulate clay powder of Eco-Processed Pozzolan (EPP), the powder was in clay or ash color in a micro size. Figure 3 shows the Scanning electron microscope (SEM) image of Eco-Processed Pozzolan (EPP). From the SEM image, it shows, the irregular shape and size with porous structure. Crumb rubber is recycled rubber produced from vehicle scrap tires. Tire cord was removed and grinded to the granular sizes with black granules size. Figure 2 shows the crumb rubber in granular forms. The crumb rubber used sorted through sieving process and passing size 300 mm.

Figure 2. Crumb rubber.

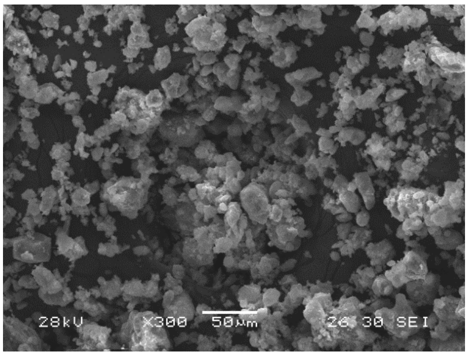

Figure 3. Scanning electron microscope (SEM) image of Eco-Processed Pozzolan (EPP).

Figure 4. Eco-Processed Pozzolan (EPP) in powder form.

TESTING AND METHOD

Eco-paving blocks are precast solid products made out of cement, sand, Eco-Processed Pozzolan (EPP) and crumb rubber. It has produced in a single shape and size with interlocking features in three waves. The process of manufacturing is straightforward and standardized amidst mixture of cement, sand, EPP and crumb rubber granules in designated proportions. The materials are mixed in water and churned thoroughly in a concrete mixer, rotated for 15 minutes. The process involves proportioning, mixing of materials and pour to mold for compacting. Concrete mixture placed in mold for drying up to 24 hours and continued with curing process until 28 days. A concrete mix ratio of cement: sand: EPP: crumb rubber by volume is used for manufacturing eco-paving blocks. Table 2 shows the mix proportions of materials used in manufacturing of Eco-paver blocks.

The paving design designated to BS 7533-101 accordingly. There are five (5) including control sample with different mixes are prepared which are cement and sand designated ratio is fixed to 1:3 and replaced by proportionate quantity of EPP and crumb rubber by volume at 0.3, 0.4, 0.5 and 0.6 for crumb rubber equivalent to 0.5, 0.6, 0.7 and 0.8 for the EPP. The raw materials required for manufacture of the eco-paver blocks are ordinary Portland cement and river sand. Figure 5 shows the concrete mixtures are placed in the plastic mold. Vibrators are employed during the process of pouring the mix so as to ensure that it sets well. Figure 6 shows the produced Eco-paver blocks.

Table 2. Mix proportions of Eco-paver blocks.

Materials	Mix Ratio			
	M1	M2	M3	M4
Cement	1	1	1	1
Sand	3	3	3	3
Crumb rubber	0.3	0.4	0.5	0.6
Eco-Processed Pozzolan (EPP)	0.5	0.6	0.7	0.8
Water	0.5	0.5	0.5	0.5

Figure 5. Pouring the mix into plastic mould.

Figure 6. Demoulded Eco-paver block.

RESULTS AND DISCUSSION

The effect of EPP and waste tyre or rubber crumb on the workability, compressive strength and potential of the waste material mixed with concrete were investigated in this study. Figure 7 shows the weight changes over time of the eco-paver block. M1 at 7 days curing period seen as the weightier compare to M2, M3 and M4. This phenomenon seen as the content of EPP and crumb rubber is lesser compared to other mixes. The ratio of EPP and crumb rubber for M1 used is 0.5:03, while M2, M3 and M4 higher than M1 > 0.6:0.4. Thus, the mix proportion of EPP and rubber crumb seen as the main contributor to the higher weight of M1. The similar trends also discovered at 28 days, where M1 notched higher weight compared to M2, M3 and M4. It is slightly dropped from 21 days of curing and finally reached the constant weight at 28 days. These trends seen as equal behavior of all days of curing process. Similar trends observed in FMC changes with EPP and crumb rubber contents as shown in Figure 8.

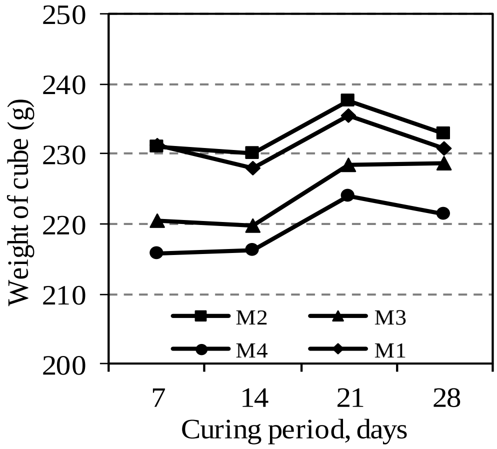

Figure 7. Weight changes over time.

Table 3. Compressive strength for 7 days.

Mix Design	Age of cube	Weight of cube (g)	Flexible Modified Cementitious, FMC (N)	Compressive strength (N/mm²)
M1	7 days	231.3	10068.80	4.02752
M2	M2	231.0	8803.13	3.52125
M3		220.5	6703.33	2.68133
M4	M2	215.8	5709.37	2.28375

Table 4. Compressive strength for 14 days.

Mix Design	Age of cube	Weight of cube (g)	Flexible Modified Cementitious, FMC (N)	Compressive strength (N/mm²)
M1	14 days	228.0	18168.0	7.2672
M2	14 days	230.0	14469.0	5.7876
M3	14 days	219.7	10579.0	4.2316
M4	14 days	216.3	7085.0	2.855

Table 5. Compressive strength for 21 days.

Mix Design	Age of cube	Weight of cube (g)	Flexible Modified Cementitious, FMC (N)	Compressive strength (N/mm²)
M1	21 days	235.4	20025.0	9.0638
M2	21 days	237.6	18356.3	6.3038
M3	21 days	228.5	15503.1	5.5950
M4	21 days	224.0	9496.9	4.125

Table 6. Compressive strength for 28 days.

Mix Design	Age of cube	Weight of cube (g)	Flexible Modified Cementitious, FMC (N)	Compressive strength (N/mm^2)
M1	28 days	230.7	16293.8	9.100
M2	28 days	232.8	13162.5	6.500
M3	28 days	228.8	12471.9	5.500
M4	28 days	221.3	11128.1	4.300

The amounts of EPP and crumb rubber seen as the stabilizer agent for FMC. This is due to the changes in FMC from 7 days to 28 days of curing periods. At 7 days of curing, M1 in the highest peak and M4 is the lowest. These trends are seen gradually increased up to 21 days of curing and dropped at 28 days and slightly higher than 7 days curing. This is due to the consumptions of EPP and rubber crumb as the main elements in production eco-paver block. The FMC changes for M1 from 7 days to 21 days is 47%. The FMC stabilized to the 17000 of equal to 11%. The origin FMC at 7 days notched 10000. This is show that, the EPP and crumb rubber contributed to the stabilization or called reduction in FMC changes. Similar trends for M2, M3 and M4. Table 3, 4, 5 and 6 shows the compressive strength results for 7, 14, 21 and 28 days of curing periods. These results translated into Figure 9. In general, the compressive strength of eco-paver blocks increased gradually form 7 days to 28 days. M1, M2, M3 and M4 recorded 4.03, 3.52, 2.68 and 2.3 N/mm2 compressive strength respectively. This is clearly showed that, the lesser amount of EPP and crumb rubber contributed to the higher strength of eco-paver block. From M1 to M4, the compressive strength slightly decreased to 33.5% and the mixed design and optimum ratio of EPP and crumb rubber usage ideally used for M1 design. The strength of an eco-paving block is determined by the maximum carrying capacity under distributed load.

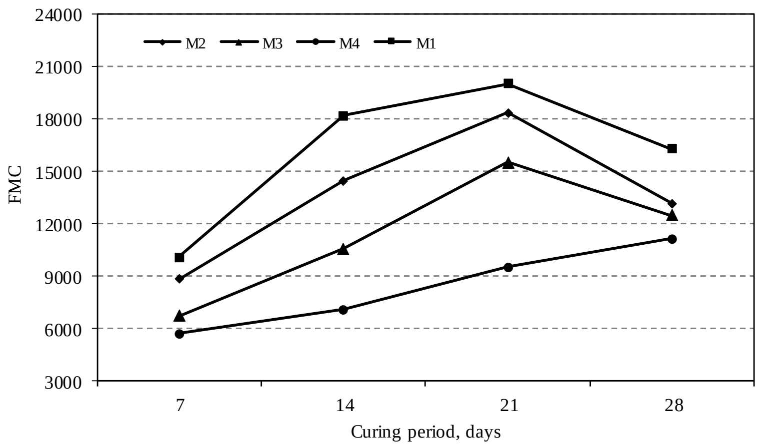

Figure 8. Amount of EPP and crumb rubber in accordance with FMC change.

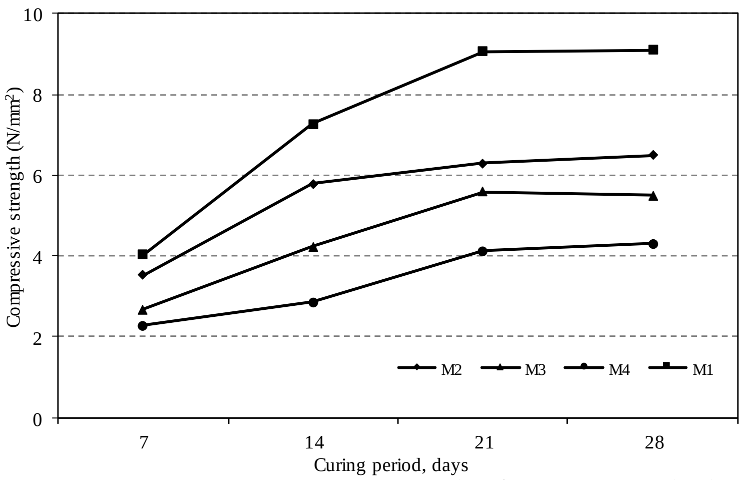

Figure 9. Compressive strength of Eco-Paver Block.

CONCLUSION

Subsequent to various mixed design from M1, M2, M3 and M4 that conducted in producing eco-paver blocks and used EPP and crumb rubber sand-cement incorporated eco-paver blocks, it is worthwhile to arrive at the conclusions which are the compressive strength of eco-paver blocks incorporating used EPP and crumb rubber increased up 33% with water cement ratio is fixed to 0.5. The compressive strength of eco-paver blocks is higher when the EPP and crumb rubber contents is lesser. The strength increased 35% when EPP and crumb rubber are lesser used. The higher usage of EPP and crumb rubber, the lower the compressive strength of eco-paver blocks. EPP and rubber crumb usage based on M1 design are recommended to use which only 33% of EPP content allowed. The ratio of EPP and crumb rubber for M1 used is 0.5:03, while M2, M3 and M4 higher than M1 > 0.6:0.4. Thus, the mix proportion of EPP and rubber crumb seen as the main contributor to the higher weight of M1. The amounts of EPP and crumb rubber seen as the stabilizer agent for FMC These trends are seen gradually increased up to 21 days of curing and dropped at 28 days and slightly higher than 7 days curing.

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REFERENCES

[1] Akadiri, P. O., Chinyio, E. A. & Olomolaiye, P. O. 2012. Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector. *Buildings*, 2(2), 126-152.

[2] Arsod, M.N. 2019. A Paper on Experimental Investigation on Concrete Paver Block and Plastic Paver Block. *International Journal for Research in Applied Science and Engineering Technology*, 7(3), 2151-2157.

[3] Corinaldesi, V. & Donnini, J. 2019. Waste rubber aggregates. *In:* de Brito, J. & Agrela, F. (Eds). *New Trends in Eco-efficient and Recycled Concrete*. Sawston: Woodhead Publishing.

[4] Djamaluddin, A.R., Caronge, M.A., Tjaronge, M.W., Lando, A.T. & Irmawaty, R. 2020. Evaluation of sustainable concrete paving blocks incorporating processed waste tea ash. *Case Studies in Construction Materials*, 12(6), 1-12.

[5] Gamalath, H. G. P., Weerasinghe T. G. P. L. & Nanayakkara S. M. A. 2016. Use of waste rubber granules for the production of concrete paving blocks. *Proceeding of the 7th International Conference on Sustainable Built Environment*. 16-18, December, 2016, Kandy, Sri Lanka. pp 68-74.

[6] Gupta, T., Sharma, R. K. & Chaudhary, S. 2015. Impact resistance of concrete containing waste rubber fiber and silica Fume. *International Journal of Impact Engineering*, 83(2015), 76-87.

[7] Ha, C. Y., Radzi, I. & Khoo, T. J. 2020. The Barriers of Implementing Green Building in Penang Construction Industry. *Progress in Energy and Environment*, 12(20), 1-10.

[8] Hamid, N.B., Razak, S.N., Mokhtar, M., Sanik, M.E., Masiri, Kaamin, Nor, A.H. & Ramli, M.Z. 2019. Development of Paving Blocks using Waste Materials. *International Journal of Innovative Technology and Exploring Engineering*, 8(9S3), 1329-1335.

[9] Jo, B. W., Kim, C. H. & Tae, G. H. 2007. Characteristics of cement mortar with nano-SiO2 particles. *Construction Building Materials*, 21, 1351–1355.

[10] Kalingarani, K., Harikrishna, D. P., Jegan, R. M. & Sriramkumar, V. 2015. Development of Paver Blocks from Industrial Wastes. *National conference on advances in Traffic, Construction Materials and Environmental Engineering (ATCMEE)*. 15 May, 2015, Chennai, India. pp 12-17.

[11] Kho, J. H. 2021. Incorporation of Eco Process Pozzolan (EPP) as Partial Cement Replacement and Superplasticisers in Concrete. *IOP Conference Series: Earth and Environmental Science,* 682, 2021. 012014.

[12] Mohamad, H. M., Asman, N. S., Mirasa, A. K., Saad, I., Bolong, N., Steven, C. K. C. & Razali, M. S. N. 2021a. A Consistency Check of Concrete Compressive Strength using Pearson's Correlation Coefficient. *Civil Engineering Journal*, 7, 541-548.

[13] Mohamad, H.M., Mohamad, M.I., Saad, I., Bolong, N., Mustazama, J. & Mohd Razali, S.N. 2021b. A Case Study of S-Curve Analysis: Causes, Effects, Tracing and Monitoring Project Extension of Time. *Civil Engineering Journal*, 7, 649-661.

[14] Othman, R., Ali, N. M. & Muthusamy, K. 2015. Influence of Eco Process Pozzolan on the properties of Foamed Concrete. *Proceeding of the 9th Asia Pacific Structural Engineering and Construction Conference & 8th ASEAN Civil Engineering Conference (APSEC-ACEC 2015)*. Universiti Teknologi Malaysia, Kuala Lumpur. 3-5, November, 2015, pp. 1-6.

[15] Pacheco-Torgal, F., Ding, Y. & Jalali, S. 2012. Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles). *Construction and Building Materials*, 30(2012), 714–724.

[16] USEP (United States Environmental Protection Agency). 2016. *Introduction to Green Building.* (https://archive.epa.gov/greenbuilding/web/html/about.html). Last accessed on 3 May 2013.

[17] Vila, M. & Pereyra, A. 2017. Compressive strength in concrete paving blocks. Results leading to validate the test in half-unit specimens. *International scientific electronic journal of the Latin American Association of Quality Control, Pathology and Recovery of Construction*, 7 (3), 247-261.

[18] Zhineng, T. 2017. Review of the Application of Green Building and Energy Saving Technology. *IOP Conference Series: Earth and Environmental Science,* 100(2017), 012141.