International Journal of Undergraduate Research 1 (2): 111-119, 2019
e-ISSN: 2682-8199

DOI: 10.26666/rmp.ijur.2019.2.17

Recycled High-Density Polyethylene (HDPE) As Partition Wall for Interior Building

Nor Alya Atiqah Mohidin and Muhammad Naim Mahyuddin
Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Seri Iskandar Campus, Perak, Malaysia.

Abstract: The global plastic production increased over years due to the vast applications of plastics in many sectors such as packaging, electrical and electronics, household, automotive, construction, agriculture and other sub-sectors (medical devices, plastic furniture and toys). The scope of this study is focusing on recycled high-density polyethylene (HDPE) such as detergent bottles to be compress in mould after reach its suitable melting point and subsequent effects of temperature by using pyrolysis method. Since polyethylene makes up the largest percentage of plastic produced globally, and has the potential to be recycled indefinitely, it makes an excellent starting point for mitigating the severe impacts plastic waste has on the global environment. Recycled HDPE is an incredible material for the entrepreneur, as it can be recycled indefinitely, using common household tools and appliances. The unique properties of HDPE result from the strong and rigid linear molecular structures that make up the material. The continuous demand of plastics caused the plastic waste accumulation in the landfill consumed a lot of spaces that contributed to the environmental problem. The ranking of the highest to the lowest plastic waste in municipal solid waste according to the categories of plastic containers. Plastic waste issue has been discussed from time to time. This issue is getting bigger when burning of plastic in the open air, leads to environmental pollution due to the release of poisonous chemicals. The polluted air when inhaled by humans and animals affect their health and can cause respiratory problems. The main objective of this study is to determine the melting point and subsequent effects of temperature on recycled HDPE through pyrolysis method.

Key words: *High-density polyethylene, Pyrolysis, Partition wall, Plastic waste, Recycling*

INTRODUCTION

According to Construction Industry Transformation Programme (CITP), there are four strategic thrusts where seeks to transform the industry and change the way it is being perceived. The four strategic thrusts are "Quality, Safety & Professionalism", "Environmental Sustainability", "Productivity" and "Internationalization" [1]. The research study is focusing on the innovation of recycled high-density polyethylene (HDPE) plastic waste as partition wall for interior building by using pyrolysis method. Plastic wastes are increasing at an alarming rate and adversely affecting environment as they are not easily degraded [2]. It is a key of innovation of many products in various industries such as construction, healthcare, electronic, automotive, packaging and others. The demand of plastics product has been increased due to the rapid growth of the world population [3].

This research study is included in the term of "Environmental Sustainability" of the strategic thrusts where it will benefit the industry as recycled materials can in turn be used for other projects and purposes. The outcome of Construction Industry Transformation Programme (CITP) is thus to transform the industry and achieve Malaysia's environmentally sustainable construction to be a model for the emerging world. The implementation of improved waste management practices will further benefit industry players by lowering the cost of disposal of waste and will help reduce amount of material procured from the outset [1].

The idea of HDPE wall panel is one of the solutions of recycling plastic waste into a valuable product

Corresponding Author: Nor Alya Atiqah Mohidin, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Seri Iskandar Campus, Perak, Malaysia.

other than recycling method in construction industry. Through literature review, pyrolysis is a method on how to melt the plastic waste (certain types of plastic waste) into a new product. According to National Solid Waste Management Department, there are seven types of plastic resins which are polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), other mixed plastic (nylon, acrylic, polycarbonate) [4]. Its recognition is through their respective symbol codes as shown in Figure 1.

Type of plastics	Plastics type marks
Polyethylene terephthalate (PET)	1 PET
High-density polyethylene	2 HDPE
Polyvinyl chloride (PVC)	3 V
Low-density polyethylene	4 LDPE
Polypropylene	5 PP
Polystyrene	6 PS
Polyethylene (PE) Acrylonitrile butadiene styrene (ABS) Polyamide (PA) or Nylons Polybutylene terephthalate (PBT)	7 OTHER

Figure 1: Type of plastics
Source: (Anuar, et al., 2016)

LITERATURE REVIEWS

Plastic product is important because pure HDPE will exhibit creep and breakage when put under long-term stress [5]. The recycling of plastics and the conversion of polymeric materials into useful products, on the large scale, have been occurring for more than 20 years. The recycling of plastics could be performed via pyrolysis, hydrolysis, hydrogenation, methanolysis and gasification. The most attractive technique for the recycling of hydrocarbon polymers, such as HDPE, low density polyethylene and polypropylene is pyrolysis. The pyrolysis process considers the thermal cracking of the polymeric material by heating in the absence of oxygen, which results in the formation of a solid residue (char), liquid product and gas. Yields of the products mainly depend on the pyrolysis temperature, the reactor type and the presence of catalysts [6].

A study indicated that plastic waste can be used as a partial replacement of natural aggregate. This is mainly due to the size and aggregate decreases the slump of fresh concrete mix while spherical shaped plastic aggregate increases it. The incorporation of plastic aggregate can reduce the density of resulting concrete and cement mortar and it provides lightweight concrete by using plastic aggregates. Therefore, concrete containing plastic aggregate will be more durable in the face of aggressive chemical attack [7].

Besides, in a study on 2017, a same research study about fresh properties of self-compacting concrete with plastic waste as a partial replacement of fine aggregate/sand. The usage of plastic waste in the concrete mixture increased the slump flow and V-funnel flow time. It indicated that the utilization of plastic waste in self-compacting concrete manufacturing resulted in systematically decreasing of the compressive strength [8].

Moreover, based on the study of literatures, pyrolysis process was chosen by most researchers because its potential to convert the most energy from plastic waste to valuable liquid oil, gaseous and char. The pyrolysis could be done in both thermal and catalytic process provided lower operating temperature with greater yield of liquid oil for most plastics with the right catalyst selection. With pyrolysis method, the waste management becomes more efficient, less capacity of landfill needed, less pollution and also cost effective. Moreover, with the existence of pyrolysis method to decompose plastic into valuable energy fuel, the dependence on fossil fuel as non-renewable energy can be reduced and this solves the rise in energy demand [3].

Researchers from Humboldt State University, California explored in HDPE tiles and blocks creation for non-structural application. The focus on non-structural, plastic products is important because pure HDPE will exhibit creep and breakage when put under long-term stress. To strengthen the material, manufacturers commonly mix the polymer with another tensile material, creating composite materials that are unable to be incorporated in the recycling stream. The plastic is heated to its melting point while in the mould, then pressed to form the material. Compression moulding is traditionally used to form products such as slabs, tiles, and blocks, or other simply shaped products [5]. This technic will be used in release the innovation of HDPE wall panel.

Another existing innovation is exploiting recycled plastic waste as an alternative binder for paving blocks production. Concrete paving block specimens absorbed more water than the composite specimens did. Results revealed further that paving units could be made from recycled plastic wastes ranging from shrink-wrap, dry cleaning film, merchandise bags, grocery sacks and stretch wrap, recycle bags, redemption bags, pure water sachet rubber, bubble packaging film, commercial/industrial liners/bags to commercial overwrap. Waste plastic materials may be used as a binding material for making of paving blocks capable of supporting low loadbearing purposes such as walkways, footpaths, building premises among others in highly moist environments due to their low water absorption capacity. However, the potential practical implications of using the recycled plastic waste in paving blocks making in the municipality would heavily depend on 4A's (acceptability, accessibility, adaptability and affordability) concept of marketing this new product [9].

Moreover, used plastic bottles are also a significant waste management concern of the rapidly urbanizing society. The current work is aimed at combining these two waste products and generating an alternative for conventional bricks, thus yielding a sustainable and environment-friendly building material. Used plastic bottles were filled with crushed recycled aggregate and desired water content and were sealed. So far, a variety of materials have been suggested as the filler materials for preparing material-filled plastic bottles, including sand, bagasse ash, fly ash, etc. However, each of such filler options suffers from one or the other disadvantage, such as loss of top soil layer, energy consumption, and non-ubiquitous availability. One possibility is using the crushed recycled aggregates as a filler material for preparing such bottles and then using them as a replacement of conventional red clay bricks. Such waste material filled plastic bottles are not only cheap, zero-energy, and emission-less; they also obviate the necessity of disposal of the bottles and the waste materials. Such [10].

Last but not least, a research had been done which explores the possibility of using rubber and plastic wastes as partial replacement of traditional fossil fuel used in cement industry and the properties of the produced cement. The study is divided into two parts. First part is to study the efficiency of rubber waste and plastic waste as fuel sources as well as the characteristics of their ashes. Whereas in second part the effects of rubber waste and plastic waste ashes residue on the properties and hydration characteristics of Portland cement clinker were studied. Contamination of ordinary Portland Cement (OPC) clinker by 5 and 10 mass % of these solid ash residues lead to a reduction in setting times, an improvement in the compressive strength and acceleration in the hydration reactions [11].

By analysing the research question and objectives, the existing products from recycled HDPE in construction industry are being comprised. A comparative analysis is being used to show the comparison between the method used, the properties of valuable products from recycled HDPE and its applications. The similarities from the products as mentioned in the literature review (Chapter 2), is obviously the usage of recycled HDPE as main material to produce or form the product. Table 1 shows the previous research of recycled plastic waste products which highlighted from the literature review. With regard to timeline, a period of 5 years is selected (between 2015 and 2019), an adequate period of time to see the evolution and relevance of research.

Table 1: Previous research of recycled plastic waste products

No	Products	Year of Research
1	Partial replacement of natural aggregate for lightweight concrete	2012
2	Valuable energy fuel	2016
3	Partial replacement of fine aggregate/sand for lightweight concrete	2017
4	HDPE tiles and blocks for non-structural application	2018

5	Alternative binder for paving blocks production	2019
6	Recycled aggregate filled waste plastic bottles (PET) as a replacement of bricks	2019
7	Recycled plastic waste as refused fuel in cement industry	2019

However, HDPE is being tested for partial replacement of fine or coarse aggregate for lightweight concrete as shown in Table 2.1 (No. 1 & 3). It shows that the product to be produced is still relevant due to the continuous study between 2012 and 2017 respectively. From all the seven research products, “HDPE tiles and blocks” is selected as a reference for materials and method to realizing the innovation project of HDPE non-load bearing wall panel.

METHODOLOGY

To evaluate the outcomes of the innovation project research, the process of gathering and measuring data is through desk study and experiment.

(a) Desk Study

Desk study refers to available documents such as reports, journal articles and books. From journal articles, the review relied on two main journal databases; Emerald Premium and Science Direct. With regard to timeline, a period of 5 years is selected, between 2015 to 2019, and adequate period of time to see the recent evolution of the research products. The findings of data and information focused on the research of recycled plastic waste (HDPE) to a valuable product in construction industry. A review was also focused on the method used in the transformation from the recycled plastic waste (HDPE) into valuable products. There is various innovation created from the recycled plastic waste into new products in many industries as an alternative to reduce the plastic waste to the environment. Through research of book is a finding on the definition of pyrolysis method and advantages of recycled HDPE for its structure and properties.

(b) Experiment

Due to an environmentally friendly product, preferred method to be use is pyrolysis method where it works in a closed system (oven) at a desired temperature until the HDPE plastics get melted. The design formwork of prototype that match with this method where it will be working in the closed system, to ensure that no gas will be vaporized in the atmosphere if there is any. In this research, high density polyethylene is used because of its excellent impact resistance, high tensile strength, low moisture absorption and chemical resistance properties [2]. After reaching the suitable melting point and desired temperature, the sample of HDPE plastic will go through for a performance testing manually. The result of performance testing determines the durability of HDPE wall panel.

RESULT AND DISCUSSION

From the literature review, the selected method to be used is pyrolysis method. The word is coined from the Greek-derived elements pyro (fire) and lysis (separating) [12]. The materials used in the process of melting HDPE are HDPE detergent bottles/ shampoo bottles/bottle lids, oven, utility scissor, baking paper, mould, C-clamps, aluminium tray, face mask, high temperature resistant gloves and saw machine. When the plastic will be heated, it will release dangerous chemicals through liquid, gas and odour. Therefore, the face mask and high temperature resistant gloves are prior for health and safety considerations during the heat testing of HDPE plastics.

(a) HDPE melting point testing

The HDPE pyrolysis yielded liquid, gaseous and solid products. Temperature rise resulted in the increase of conversion of HDPE into liquid and gaseous product once it goes through pyrolysis method and then will be form in compression mould for a solid product [6]. Temperature is considered to be one of the most important factors during the pyrolysis of plastic waste since it dominates the cracking of the sample feed. The process takes place in the absence of oxygen at increased pressure and temperature for a short duration.

A testing had been done on four samples (Figure 2) in an oven which has been compressed with different temperature and time as shown in Table 4.2. Prior to the melt, the heating source (mould) should be preheated at from 180°C to 250°C for 15 to 20 minutes, and the material should be loaded hot whenever possible to create the most consistently melted final product. Sample A was being heated in the oven with selected temperature 180°C for 15 minutes. The result shows that there is no changing colour of detergent bottles after melted in the oven due to its suitability and well-balanced between quantity of HDPE plastics, time heated and temperature.

For Sample B which heated in temperature 220°C for 15 minutes, is not well-compressed as can be seen in Figure 2 through its texture and surface. This sample resulted a little bit overheated. This unsuitability subsequent effect of temperature made a darker colour of pink and blue HDPE plastics. The consideration in the quantity of HDPE plastics must be emphasize to avoid overheated.

Sample A and C have been cut on every surface due to rough and uneven part. Other reason is also due to not well-compressed too. The chosen of compression mould is important to have a well-compacted surface which may resulted a smoother wall panel. Sample C is the most aesthetic due to its combination colour of blue and white detergent bottles. This was because after take the melted HDPE plastics from the oven, it had been blended by using hands to bond the two colours of plastics. This sample was cut into hexagon shape to show the blended surface of every part. For its melting point, the temperature (200°C) and time (15 minutes) are suitable for a less quantity of HDPE plastics subsequently.

Sample D resulted overheated which can be seen on the HDPE surface with temperature 220°C for 20 minutes. There was only one colour of detergent bottles used in this stage. The black colour is due to overheated on the top surface during in the oven which it's not turns dark colour for the whole surface of the HDPE plastic. However, in compression mould for Sample D is quarter-well compressed which show a little rougher on its surface.

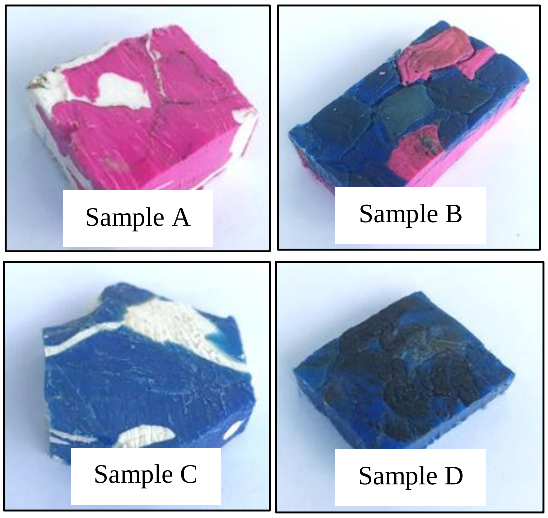

Figure 2: Samples of compressed HDPE for determination of melting point

Table 2: Result of melting point

Sample	**A**	**B**	**C**	**D**
Temperature	180°C	220 °C	200 °C	220 °C
Time (min)	15	15	15	20
Changes of Colour	No change	Darker	No change	Darker

A trial-and-error process was required when exploring melting methods for HDPE due to a lack of public information available on the process of selecting the exact and suitable melting point of recycled HDPE. Overall, heating for too long will resulted in a lot of off-gassing. Oven should be used at lower temperature for a slower melt, which would reduce off-gassing significantly. The trials produced a solid, fully melted block when the melted material was pressed into a mould in one single compressed. For HDPE surface finishes, it can be sanded but only up to a point. No matter how much to try sanded the HDPE surface, there will always be scratches because the material is naturally soft as shown in Figure 3.

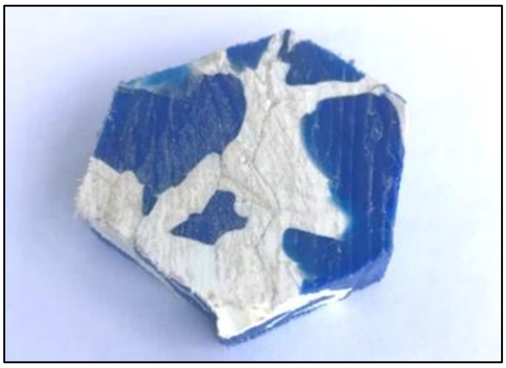

Figure 3: Sanded HDPE surface

(b) Procedure of HDPE partition wall

Step 1: HDPE plastic bottles can be collected from around home, recycling bins or recycling centre. The recycled HDPE such as detergent bottles, shampoo bottles and bottle lids are sorted by colour, granulated and placed in a particle piece. HDPE plastics can be recognised through the respective symbol codes as shown in Figure 4 which mark "2" in the universal recycle symbol and it stated the types of plastic "HDPE" on the bottle. The pieces are then cut to shape and moulded in an oven.

Figure 4: HDPE respective symbol code

Step 2: Cut the plastic into smaller pieces with a pair of utility scissor for an efficient method in manually (Figure 5). The pieces should be small enough to fit and easily melt in the aluminium tray. At the same time, preheat the oven to approximately 180 ºC, the minimum range of heating.

Figure 5: HDPE bottles that have been cut

Step 3: Before bake the HDPE plastics, next stage is preparing a baking paper on tray and mould for compression. There are two types of baking paper which the brown colour (Figure 6) is high resistant baking paper and the white colour (Figure 7) is common baking paper. The high resistant baking paper is suitable to use during heating the HDPE plastic in the oven to avoid the melted plastics attached the aluminium tray.

Figure 6: High resistant brown baking paper in aluminium tray

Figure 7: Common white baking paper in compression mould

Step 4: Place the pieces of HDPE pieces on the aluminium tray to be heated in oven (Figure 8). The plastic is heated to its melting point while in the mould, then pressed to form the material. From the testing that has been done, the selected temperature is 200 oC for 15 minutes. It is important to keep the melting time to a minimum as to avoid over heating the plastic and producing toxic gases. Be sure to perform these methods in a well-ventilated area, or preferably outside.

Figure 8: Pieces of HDPE plastics before melting in the oven

Step 5: From previous testing, the preferable time is 15 minutes. However, at this stage the time is add to 20 minutes due to the greater quantity of HDPE plastics. It is important to watch the material as it is melting to ensure it will melt perfectly (Figure 9). Because it is a thermoplastic, the material may be heated and reheated repeatedly, making it an excellent material for recycling, when done properly. After 20 minutes, the melted blue HDPE plastics is taken out from the oven and add on the white bottle lids to provide an aesthetical value in the product itself as shown in Figure 10. At this second bake, the time heated is only 15 minutes as preferable.

Figure 9: Melted HDPE plastics

Figure 10: Melted two colours of HDPE plastics

Step 6: Quickly transport the melted HDPE plastic to the compression mould (Figure 11). The most important aspects of the compression moulding process are melting temperature, pressure, and mould design. Higher pressure in the mould will result in a smoother face. Tighten C-clamps as shown in Figure 12 until plastic begins to flash. Wait 5 minutes and continue to tighten C-clamps every 10 minutes until the plastic is cool.

Figure 11: Place the melted HDPE plastic into the compression mould

Figure 12: Compression mould by using tighten C-clamps

Step 7: Loosen up the C-clamps and once cooled, take out the harden HDPE plastic and remove the baking paper. There will be uneven part on the

HDPE plastic due to flash during compression. For finishing, use a saw machine to cut the uneven part to make a smooth surface as shown in Figure 13 and the final sample product of HDPE non-load bearing wall panel (Figure 13).

Figure 13: Cutting uneven part of harden HDPE plastic

Figure 14: The final sample product of HDPE non-load bearing wall panel

(c) HDPE features

Plastic materials can be categorised either thermoplastics or thermosetting. Both, thermoplastics and thermosetting have different properties in different structures. Figure 15(a) and (b) shows the polymer chains in thermoplastics and thermosetting polymers. In thermoplastics the polymer chains are free to slide past each other, so it is easy to change the shape. While in thermosetting polymers, the chains are cross-linked. Instead of each chain being separate, neighbouring chains are linked together. This makes it difficult for polymer chains to move past each other, so the polymer is hard and rigid. Even when it is heated, the chains are still unable to move, so the polymer does not melt [13].

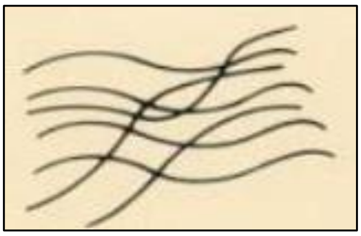

Figure 15(a): Polymer chains in a thermoplastic

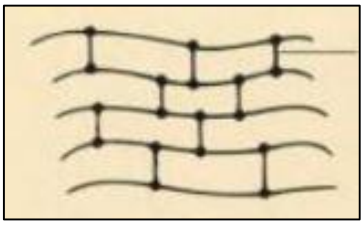

Figure 15(b): Polymer chains in a thermosetting

A thermoplastic behaves like a fluid above a certain temperature level, but the heating of a thermosetting leads to its degradation without its going through a fluid state. Typical examples of thermosetting polymers are phenolic and urea formaldehyde resins, unsaturated polyesters and epoxy resins. Typical thermoplastics are polyethylene, polypropylene, polystyrene and polyvinyl chloride (PVC) [14].

High-density polyethylene (HDPE) is selected due to its semi-crystalline material with excellent chemical resistance, good corrosion resistance, and good fatigue. It provides good resistance to organic solvents and strength with low moisture absorption. Moreover, it is light weight material, non-toxic material, resistance to stain, and offers excellent impact resistance and high tensile strength [15].

CONCLUSION

The innovation of recycled HDPE into non-load bearing wall panel is fulfil the requirement of precast element concept in one of Industrialised Building

System types in Malaysia. This idea of HDPE non-load bearing wall panel for interior building usage is developed into product to meet this opportunity from the improvised design framework. From the research study, many published research papers [2] [3] [5] [6] [7] [8] [9] [10] [11] [15] [16] are available on the potential of pyrolysis processes on recycled HDPE for non-load bearing wall panel production.

According to the research aim and objectives, the idea is suitable by using a relevant method for the sustainability of built environment. Pyrolysis is mostly employed over common recycling processes since handling is much easier and flexible with an achievement of melting point and subsequent effect of temperature for HDPE to be heated. Moreover, pyrolysis does not require intense sorting process and hence it is less labour-intensive process [16]. For the aspect of performance and marketability, this innovation idea in itself is not a business until it is developed into a commercial opportunity. The process is economical and cost effective too. Therefore, performance testing will be done manually to show its durability while data collection through questionnaire survey will be done for reaching the marketability of product.

REFERENCES

[1] CIDB, C. I. (2015). Construction Industry Transformation Programme 2016-2020. Kuala Lumpur: Construction Industry Development Board (CIDB) Malaysia.

[2] Dominique, I., Fulgence, N., Gitare, M., Serge, I. R., & Theogene, T. (2018). Recycling High-Density Polyethylene (HDPE) Into Construction Materials As A Key Step In Plastic Waste Reduction: Case of Kigali City. Rwanda Journal of Engineering, Science, Technology and Environment, 1-9.

[3] Anuar, S. D., Abnisa, F., Daud, W. M., & Sharuddin, M. K. (2016). A Review On Pyrolysis Of Plastic Waste. Energy Conversion and Management, 308-326.

[4] Golden Ecosystem, S. B. (2011). A Study On Plastic Management In Peninsular Malaysia. Petaling Jaya: National Solid Waste Management Department.

[5] N. Contreras, I., Jenna, B., Patricia, D., & Lonny, G. (2018). An Analysis of Recycling High Density Polyethylene with Limited Resources. International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, 45-68.

[6] Kojic, I., Bechtel, A., Friedrich Kittinger, Nikola, S., Marko, O., & Ksenija, S. (2018). Study of Pyrolysis of High Density Polyethylene In The Open System and Estimation of Its Capability For Co-Pyrolysis With Lignite. Journal of The Serbian Chemical Society, 923-940.

[7] Saikia, N., & Brito, J. d. (2012). Use Of Plastic waste As Aggregate In Cement Mortar and Concrete Preparation: A Review. Construction and Building Materials, 385-401.

[8] Sheelan M.Hama, N. N. (2017). Fresh properties of Self-Compacting Concrete With Plastic Waste As Partial Replacement of Sand. International Journal of Sustainable Built Environment, 299-308.

[9] Agyemana, S., Obeng-Ahenkorac, N., Assiamahd, S., & Twumasid, G. (2019). Exploiting recycled plastic waste as an alternative binder for paving blocks production. Case Studies in Construction Materials, 1-8.

[10] Paihtea, P. L., Lalngaihawmaa, A. C., & Sainia, G. (2019). Recycled Aggregate Filled Waste Plastic Bottles As A Replacement of Bricks. Materials Today: Proceedings, 663-668.

[11] Hashem, F. S., Razak, T. A., & Mashout, H. A. (2019). Rubber and Plastic Wastes As Alternative Refused Fuel In Cement Industry. Construction and Building Materials, 275-282.

[12] Zolin, L. (2017). Large-scale Production of Paper-based Li-ion Cells. Switzerland: PoliTO Springer Series.

[13] Holman, J. S., & Stone, P. (2001). Chemistry 2nd Edition. United Kingdom: Nelson Thornes Ltd.

[14] Pascault, J.-P., Sautereau, H., Verdu, J., & Williams, R. J. (2002). Thermosetting Polymers. New York: Marcel Dekker.

[15] Jassim, A. K. (2017). Recycling of Polyethylene Waste to Produce Plastic Cement. Procedia Manufacturing, 635-642.

[16] Vijayakumar, A., & Sebastian, J. (2018). Pyrolysis Process To Produce Fuel From Different Types of Plastic – A Review. IOP Conference Series: Materials Science and Engineering, 1-8.