Utilization of LDPE Plastic Bag Wastes into Building Blocks

Raja Iman Nadiah binti Raja Sahrul Hishan, Dr. Fazlena binti Hamzah

Faculty of Chemical Engineering, Universiti Teknologi Mara

Abstract – Nowadays, blocks are commonly used in paths design, building materials, parking areas and pavements. Generally, block is produced by using cement, sand and aggregate as a main material. Current development in blocks has explored on utilization of agriculture and industrial waste to replace the aggregate materials. This is because one of the higher production costs is come from aggregate material. This present paper explored on the potential of waste plastic namely Low-Density Polyethylene (LDPE) as an aggregate material in blocks. As we concern, the amount of wastes plastic generated keep on increasing every year and can cause environmental pollution and caused danger to the human and animals. The use of LDPE plastic in thepaver block production is a partial solution to the environment and ecological challenges. The purposes of this study are to optimize the optimum ratio of LDPE plastic bag in the modified plastic building block and to determine the characteristics of modified building blocks. There are three tests have been conducted to support the study such as Compressive Strength Test, Water Absorption Test, Heavy Metal Analysis and Fourier Transform Infrared Analysis (FTIR). For study indicate that higher plastic content in the building block production resulted in the highest strength of block. For water absorption analysis, percentage of water absorption is lower for the highest content of plastic aggregate. For the heavy metal analysis, the higher plastic content in block, the least amount of heavy metals was obtained. The findings show that LDPE plastic as an aggregate in building block production able to change characteristic of block. The LDPE building block gave better characteristics as compared to standard block.

Keywords— LDPE, plastic bag wastes, compressive strength, water absorption, heavy metals, aggregates, fly ash, standard block, plastic building block

I. INTRODUCTION

Plastic is the common material that are abundant in the whole world. Plastic materials consist of synthetic and semi-synthetic organic compound. It is organic polymer with high molecular mass and mostly being derived from petrochemical. The groups that include in the chemical structure of the plastics are acrylic, silicones, polyurethanes and halogenated plastics [1]. Plastics has good properties such as high tensile strength, low density and resistance to heat and glass transition temperature. However, plastic degrades slowly. Therefore, plastic difficult to dispose and stay in the environment for hundred years. It also can cause drainage blockage as it contains properties of water resistance and can lead to excellent breading grounds that related to the disease-causing mosquitoes [2]. Wastes plastic especially in household is large and keep on increasing with time. The wastes composition is different for every country according to the socioeconomic and consumption patterns [3].

Conventional plastics are persistent material that accumulate in the environment as they cannot be mineralized. As the plastic waste dispose slowly, the waste become smaller pieces. The smaller the size of the plastic, the bigger chances to pollute the environment as the waste difficult to be removed from the environment and microorganism easily access to ingest. Thus, utilization of the plastic in various application has been explored such as in construction, electrical and electronic applications, packaging and transport.

Type of the plastic bag waste that contribute to the people concern is Low-Density Polyethylene (LDPE) plastic bag. LDPE is difficult to decompose and cannot be recycle because it is low grade plastic that have no value. Therefore, abundant of plastic bag is dumped without proper handling and become the main cause to the environmental pollution. Thus, researchers have studied many alternative ways to handle LDPE plastic bags and to convert it into useful products to the people [4]. One of the potential applications of LDPE is in paver block production.

Block also known as brick is widely used for construction which mainly for houses, offices, town center and roads [5]. It is very resistant to chemicals and durable because of high concrete. Block is mainly very attractive, versatile and cost effective. Mostly building block is made from cement, sand, aggregates and dyes. Normally, natural sources of aggregate are used in block production, but the cost is quite expensive. Aggregates are very important constituents in the block which gives body to the block and reduce shrinkage [6]. Therefore, a study on the utilization of LDPE for building block is made in this present research. Different mixture of the LDPE plastic waste, sand and other aggregates were used to evaluate the characteristics of modified building block.

II. METHODOLOGY

A. Preparation of Plastic Type LDPE with Coarse Materials

Waste of plastic bag with type of Low-Density Polyethylene (LDPE) at dry condition was collected and was shredded into an average size of 2.5 mm^2 by using grinder machine of Power Master with model of TPBG/100/3 at a speed of 1290 rpm. Drying condition is required to ensure that there is no presence of moisture during melting process. Next, the smaller size of plastic bag waste was melted into a black liquid by pouring the smaller size of plastic bag into the melting barrel. The melted plastic bag was mixed together with concrete mixture at proportion of cement, river sand, coarse aggregate and fly ash of 0%, 10%, 20%, 30% and 40% respectively. The process was conducted according to the method described by Eric Ababio and John Dadzie [7]. The percentage of LDPE was varied between 10%, 20%, 30% and 40% as tabulated in Table 1.

Table 1: The Material Proportion in Percentage Batching

Material Proportion in Percentage Batching (%)							
No	PB	Cement	Fine Sand	Aggregates		Water	Fly Ash
				Coarse Aggregate	Plastic		
1	BB-A	5	30	60	0	5	0
2	BB-B	5	30	50	10	5	0
3	BB-C	5	30	40	20	5	0
4	BB-D	5	30	30	30	5	0
5	BB-E	5	30	20	40	5	0
6	BB-F	5	20	10	50	5	10

B. Molding Process of Plastic Building Blocks

The hot mixed materials were poured inside a steel moulder with size of 50 mm x 50 mm x 50 mm. The moulder was coated with grease first before poured the hot mixed materials. The poured mixed materials were compacted inside the moulder manually with tamping steel rods. The mixed materials were filled inside the moulder in three layers and each layer was tamped 25 times to avoid voids [8]. The mixture must be compacted properly to remove the water and air voids. As the water removed from the mould plastic paver block, the product become more denser and it will increase the strength of the plastic building block.

C. Drying of Plastic Building Blocks

After the mixture was compacted into moulder, the moulded plastic paver was allowed to dry for 24 hours in normal atmospheric temperature [9]. The plastic building block was demoulded, and the blocks were cured with water to allow complete moisturization for 7 days. After the curing process, the plastic building block was dried in natural atmosphere.

D. Preparation of Standard Block

The standard block of M30 grade cement was prepared and actas a control for the plastic building blocks. Raw materials are cement, fine sand with size of 500 mm and coarse aggregate with size of 10 mm. 415 kg/m3 cement, 1135 kg/m3 coarse aggregate, 650 kg/m3 fine sand and 195 kg/m3 of water were mixed to form paver blocks mixture. Water was added in the formulation with a ratio of 1:2 which is 1 cement and 2 water.

After thoroughly mixed, the mixed materials were poured into a moulder of 50 mm x 50 mm x 50 mm. The moulder was coatedfirst with a grease before poured the mixed materials. Then, the moulder was left on the vibrator machine to fully compact the moulder with the mixed materials and remove all the voids that presence. After moulding process, the block was dried for 24 hours. After dried, the block was demoulded and undergo curing process using ponding method for 7 days. In ponding method, the standard block was immersed in the pond for 24 hours. The purposes of curing method are to maintain the moisture of the block and to produce the top-quality product. After 7 days, the sample was removed from the pond to prevent from excess of water absorption and analysis was conducted.

E. Water Absorption Test

This test was conducted to observe the influence of plastic content for the water absorption in the production of building blocks. After undergoes curing process for 7 days, the block was left to dry for 24 hours in ambient atmosphere. After the drying period is completed, the samples were immersed back in the water for 24 hours for water absorption test. Then, the blocks were removed from the water and allowed to drain for 5 minutes by placing the samples on the dried surface and the visible water surface is removed with a damp cloth. After this process, the samples were immediately weighed to avoid an error. Percentage of water absorption is calculated using Equation 2.1.

$$\text{Water Absorption} = \frac{W_w - W_d}{W_d} \qquad (2.1)$$

Where; W_w = Wet weight of paver blocks (g)
W_d = Dry weight of paver blocks (g)

F. Compressive Strength Test

This test was conducted to determine the compressive load of the produced building blocks using compression testing machine (Compressive Strength & Bending Test Apparatus, ELE (1887-1-1196)) at 3000 kN. The compression testing machine is equipped with two steel bearing blocks for holding the samples. The samples were placed between the steel plates. The load was gradually applied until the samples undergoes failure. The maximum load applied on the specimen is noted in N and compression strength is calculated using Equation 2.2.

$$\text{Compression Strength} = \frac{\text{Applied Load}}{\text{Plan Area}} = \frac{\text{N}}{\text{mm}^2} \qquad (2.2)$$

G. Heavy Metals Analysis

This test was conducted to determine the presence of released heavy metals from paver blocks using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) with model of iCAP 6300 DUO and serial number of ICP-20074310. The test was conducted by soaking of the samples for 2 days to measure the amount of cadmium, mercury and lead that released in the water samples. The water samples were analyzed using ICP test. 20 mL of water sample was acidified to keep the metals in the solution. The samples were placed in a tube inside the ICP-OES. Then, the analysis was run until the results appeared.

H. Fourier Transform Infrared (FTIR)

FTIR spectra of the paver block powder were recorded by using FTIR (Perkin-Elmer Spectrum One). The paver block was grinded into small sizes. The small amount of paver block powder is used to analyses with using FTIR to detect functional groups that exists in the samples. This analysis used infrared light to scan the powder and obtained the chemical properties. The spectra were recorded at CPU32 from 4000 to 600 cm^{-1} with 4 scans to detect the spectra contained in the powder.

III. RESULTS AND DISCUSSION

A. *Water Absorption*

Water absorption test was conducted to observe the influence of LDPE plastic composition on water absorption of building block and the result is recorded in Figure 2. The comparison of water absorption for LDPE plastic building blocks and standard block was conducted. From the recorded data, it is noticeable that the water absorption for building block was decreased as the LDPE plastic content increases. The water absorption on the samples of block B (BB-B) that contain only 10% plastic was 1.07% and the water absorption for samples with 20% LDPE (BB-C) was 0.867% decreased about 0.2%. For samples BB-D, 0.087% of water absorption was detected with decreased of 0.8% from BB-C. This result can be related to the decreasing of voids in the paver blocks due to the LDPE plastic material that filled the voids in block as illustrated in Figure 1. For block samples E and F, the percentage of water absorption is 0.187% and 1.10% respectively. The amount of water percentage for block samples F is higher due to the addition of fly ash material, which is introducing new porous material. However, the higher amount fly ash in the block will reduced the amount of water absorption as it filled the voids and increased the density [10]. Meanwhile, the amount of water absorption for standard paver control (PB-A) is 1.830% which is higher than paver block with addition of LDPE plastic.

Figure 1: Sample of BB-C

Beside the formation of void during building block production, characteristic of material also plays on important role in water absorption. It is reported that cement and fine sand has a tendency to absorb more water. This can be seen through similar result that has been reported by Thirugnanasambantham et al. [11] where the water absorption for plastic building block is 1.033% and for standard block is 6.97%. The study also indicated that the water absorption for plastic building block is low as compared to the water absorption of the standard block. While, Dinesh et al. [12] claimed that the amount of water absorption for plastic building block is 1.082% while for standard block is 3.70%. The water absorption is merely based on the characteristics of materials used for the building blocks production. Plastic is known as high resistance towards water and cement has lower resistance towards water absorption. Technical data sheet of plastic stated that the percentage of water absorption is less than 0.01 [13]. Thus, these properties reflect the water absorption result as recorded in Figure 2.

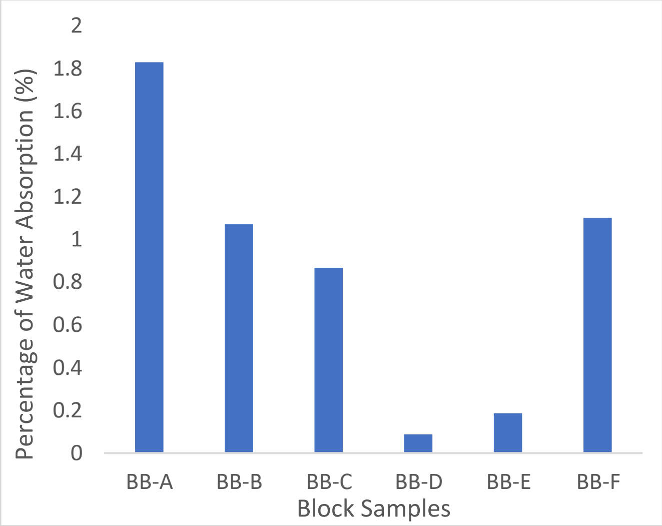

Figure 2: The Percentage of Water Absorption

B. *Compressive Strength Test*

Compressive strength test was conducted to observe the correlation between types of raw materials with the compression strength. All of the samples required to undergo curing process before running the compressive strength test. Curing process is very important in production of paver blocks to produce a top-quality product. The process helps to ensure that the samples are in a good condition by the presence of mixing water in the samples during the early hardening. It helps in hardening and accelerate the strength of the samples. The samples were undergoing twice trial and the average of the data was collected as the compression strength result. From the collected data, the lower strength was observed through BB-A which is a standard paver block. The compressive strength for standard block was 6.16 N/mm^2. For building block BB-B, the compressive strength was recorded as 7.74 N/mm^2. While, for BB-C, the compressive strength was 7.64 N/mm^2 which is almost similar with BB-B. BB-D and BB-E gave a compression strength value of 9.78 N/mm^2 and 10.84 N/mm^2 respectively. The highest compression strength was gained from sample BB-F that recorded the strength at 16.66 N/mm^2. According to Jennifer et al. [14] Low-Density Polyethylene is a tough and flexible polymer characterized by long branches carbon. There are some of other researchers obtained the same result with the study such as reported by Lairenlakpam et al. [15] with a result of 1.77 MPa for standard block and 10.6 MPa for plastic building block. The obtained results for the compressive strength are recorded in Figure 3.

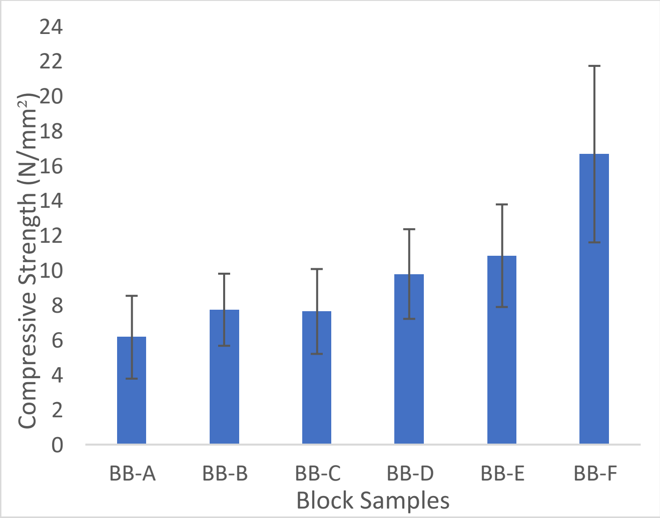

Figure 3: The Compressive Strength

The result indicated that the highest amount of LDPE plastic in block formulation gave the higher compression strength of material.

C. *Heavy Metals Analysis*

Heavy metals analysis was conducted to identify the presence of heavy metals in the paver blocks as illustrated in Figure 3. All of the samples were analysed for cadmium, lead and mercury. The results were recorded after 2 days of soaking as the heavy metals might sediment for the next days.

For standard block, the heavy metals that detected are mercury and lead while the cadmium content is zero. The mercury content was 0.1192 ppm and the lead content were 0.0088 ppm

Building block with 10% plastic content recorded with none cadmium content but contained lead and less mercury concentration compared with standard block. The mercury content was 0.0084 ppm while lead content was 0.0104 ppm. For 20% plastic building block, the reading of mercury content was 0.0012 ppm. The lead concentration is recorded at 0.0076 ppm. From the data recorded that cadmium did not exist in the 20% plastic block and only a slight amount of mercury content was detected in the 20% plastic building block.

In addition, for 30% plastic building block, the cadmium content was present in the water sample at 0.0014 ppm and 0.0078 ppm for lead content. The amount of heavy metals concentration might different towards every samples of paver block as the heavy metal contents in every samples were different according to the quantity of material inside the paver blocks.

Moreover, for 40% plastic building block, there are cadmium and mercury were detected. This is probably because the more the plastic usage, the least usage of cement and other aggregates which affect the amount of heavy metals. For lead content, it was recorded as 0.0077 ppm. According to the recoded data, the percentage of plastic replacement towards the materials of building block production affected the heavy metals content. The amount of plastic capable to reduce the amount of heavy metals present in paver block due to the reduction of cement and aggregate. The heavy metals concentrations were recorded in Figure 4.

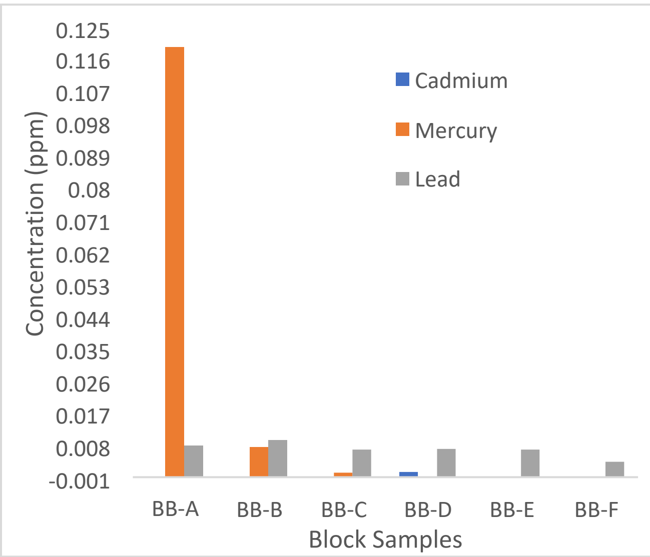

Figure 4: The Heavy Metals Concentration of Building Blocks for Day 2

D. *Fourier Transform Infrared Spectroscopy (FTIR)*

The FTIR spectra was done to analyses functioning groups for standard paver block, 10%, 20%,30%,40% and 50% of plastic building blocks. According to Sacithraa et al. (2013) [16], the mid infrared spectrum (4000 – 400) cm^{-1} can be divided into four different regions. The first region is for fingerprint region (1500 – 600) cm^{-1} followed by the double bond region (2000 – 1500) cm^{-1}. Next, the triple bond region (2500 – 2000) cm^{-1} and last region is H-X stretching region (4000 – 2500) cm^{-1}.

LDPE plastics film has been tested using FTIR to detect its functional groups by other researchers. Based on studies, the most likely functional groups that detected in the LDPE plastics were C-H stretching (2600 - 2800 cm^{-1}) [17], O-H stretching (3580 – 3590 cm^{-1}), C double bond O of COOH group (1700 – 1712 cm^{-1}), C double bond O of olefinic group (1620 – 1627 cm^{-1}) abundantly methyl group (1400 – 1330 cm^{-1}) [18] and ethyl functional group (770 cm^{-1}) [19]. Throughout the analysis, there were several functional groups that detected in the LDPE plastic as illustrated in Figure 5. The abundant functional group that existed in LDPE plastic is methylene C-H asymmetrical (2935 – 2915 cm^{-1}) and (2865 – 2845 cm^{-1}). Next, methylene C- H bend (1485 – 1445 cm^{-1}). The other functional group is phosphate ion (1100 – 1000 cm^{-1}). In addition, carbonate ion (880 – 860 cm^{-1}) also existed in the LDPE. Other than that, is aliphatic chloride compounds C-Cl stretch (800 – 700 cm^{-1}). Last peak that existed is alcohol, OH out of-plane bend (720 – 590 cm^{-1}).

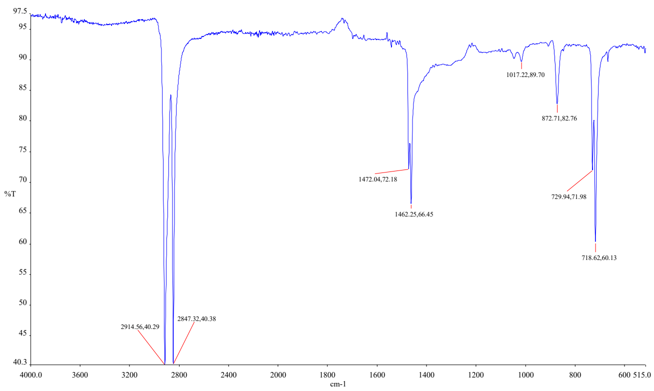

Figure 5: The Infrared Spectroscopy for LDPE Plastic

The analysis of Infrared Spectra for standard block is shown in Figure 6. From the analysis, there can be seen vigorous noise present. This is because the analysis was set on first differentiation and the samples were in black color. The black color became a resistance to analyze the samples due to the thickness[20]. Based on Figure 1, there are three functional groups detected in standard paver block. The peak region for this sample is in double bond region where it is at 1738.76 cm^{-1}. It is an ester functional group. For the peak at 1366.25, 1217.07 and 874.27 cm^{-1} are located in fingerprint region. The functional group for peak at 1366.25 cm^{-1} is related to tertiary alcohol of OH bend and the peak at 1217.07 and 874.27 cm^{-1} are P-O-C stretch for aromatic phosphates.

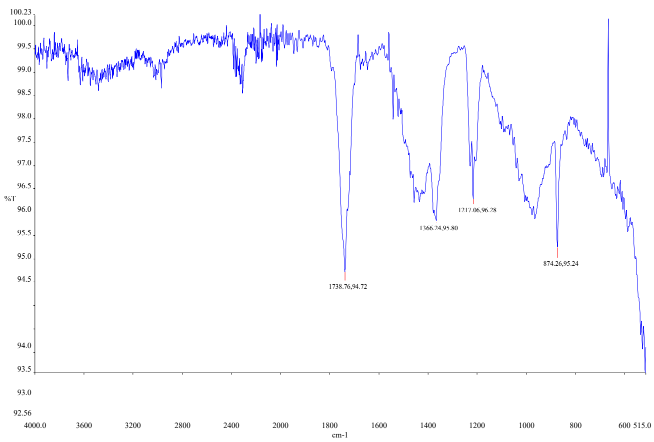

Figure 6: The Infrared Spectroscopy for Standard Block

For 10% of plastic building block, there are four functional groups were observed as illustrated in Figure 7. The first peak is at H-X stretching region with 2848.19 cm-1. It is located in methyl ether functional group. For the rest of the peaks are in fingerprint region. The next peak is at 1462.68 cm-1 and it is in methyl C-H asymmetrical. The peak at 873.47 cm-1 was observed in P-O-C stretch of aromatic phosphates and lastly is 719.13 cm-1 is located in C-Cl stretch [21].

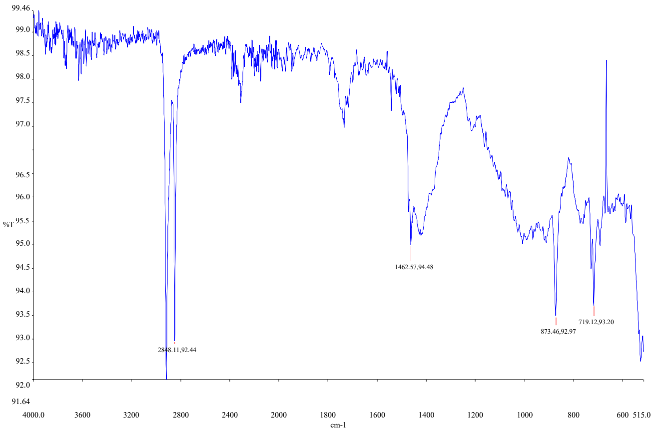

Figure 7: The Infrared Spectroscopy for 10% of Building Block

There is only one functional group detected for 20% of plastic building block. The peak is at 1735.48 cm^{-1} and is in aldehyde functional group. The existence of functional group for LDPE plastic is in the range of 3000to 2500 cm^{-1}. However, there is no peak that existed in that range for 20% of plastic building block. There might be possibilities that the material did not equally distributed during mixing process. The peak is recorded in Figure 8.

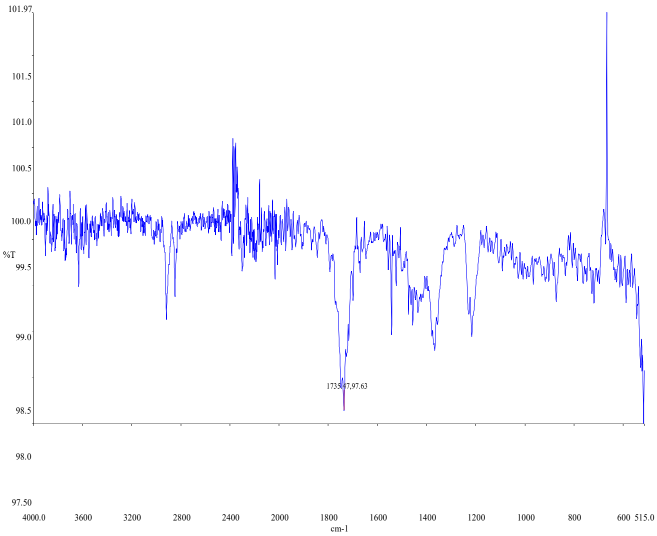

Figure 8: The Infrared Spectroscopy for 20% of Building Block

For 30% of plastic building block in Figure 9, only two functional groups were existed in the sample. Both of the peaks were located in the fingerprint region. The first peak is at 1366.09 cm^{-1} existed in dimethyl functional group and the peak at 1216.92 cm^{-1} is located in aromatic C-H of in plane bend. For 30% of plastic paver block also did not detected the presence of LDPE plastic functional group that in the range of 3000 to 2500 cm^{-1}. This is because the distribution of the materials was not equally distributed during mixing process.

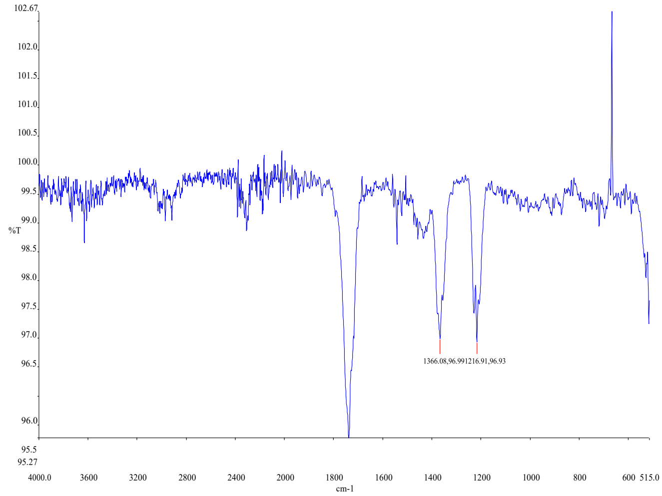

Figure 9: The Infrared Spectroscopy for 30% of Building Block

The next analysis is for 40% of plastic building block. For this sample, four functional groups were recorded in Figure 10. There were two peaks that observed in H-X stretching region. The peaks were at 2916.56 cm^{-1} and 2848.32 cm^{-1} existed in Methylene C-H asymmetrical functional group. The next peak is at 1738.74 cm^{-1} and it is in the double bond region that represented ester functional group. The other peaks were located in fingerprint region. The peaks at 1366.25 cm^{-1} is located in dimethyl functional group and 1008.49 cm-1 was related to aromatic C-H bond in plane bend. The last peak at 719.43 cm^{-1} is located in C-Cl stretch.

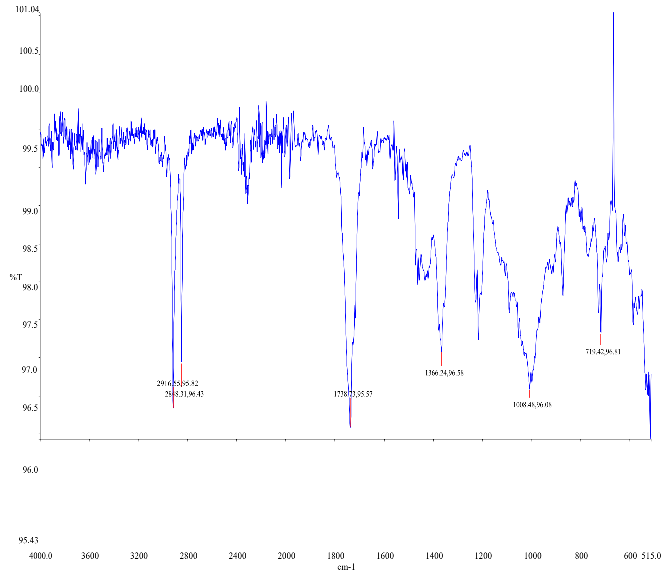

Figure 10: The Infrared Spectroscopy for 40% of Building Block

For 50% of plastic building block, the Infrared Spectroscopy has determined six functional groups as shown in Figure 11. This is because the addition of other aggregate in plastic building block production which is fly ash. The first peak is located in H-X stretching region with 2848.13 cm^{-1} that shown methylene C-H asymmetrical functional group. Then, the next peak at 1736.44 cm^{-1} is existed in double bond region where the functional group is ester. For 1366.77 cm^{-1}, the functional group of dimethyl was detected while the peak at 1216.91 cm^{-1} is located for aromatic C-H of in plane bend. Next, the remaining peak that exist in fingerprint region was at peak 873.56 cm^{-1} which represented P-O-C stretch for aromatic phosphates. The last peak is at 718.93 cm^{-1} which is existed in C-Cl stretch functional group.

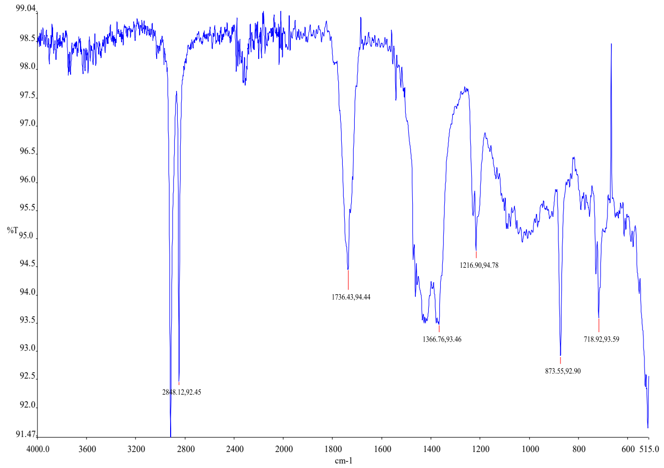

Figure 11: The Infrared Spectroscopy for 50% of Building Block

IV. CONCLUSION

In a nutshell, from the above discussion it can be concluded that the used of plastic can be possible to improve the properties of the block that generated from the wastes of LDPE plastic bags. The productions of plastic building blocks are with replacement of 10%, 20%, 30%, 40% and 50% of plastic waste. From the above obtained results concluded that both physical and mechanical properties of plastic building blocks were affected when utilized plastic in replacement of aggregates. There are several tests that being conducted to measure the properties of the plastic building blocks compared with the standard block. From the obtained results, the water absorption and strengths increase as the percentage of plastic content increases. For the heavy metal analysis, the higher plastic content of building block recorded the lowest amount of heavy metals. From the above tests conducted, it clearly shows that the higher amount of plastic content which is 30% portrayed the best replacement for standard block with lowest water absorption, 0.087% and higher compressive strength, 9.78 N/mm^2. The highest plastic content with 50% recorded the best compressive strength with highest value which is 16.66 N/mm^2 however, the percentage of water absorption increases from previous plastic building block which is 1.1% with an addition of fly ash material.

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REFERENCES

[1.] Gnanavel, G., M. Thirumarimurugan, and J.v.P. Mohana, *Current Scenario of Biodegradation of Plastics – Review.pdf.* Australian Journal of Basic and Applied Sciences,, 2015. **9**(23): p. 408-417.

[2.] Saikia, N. and J. de Brito, *Use of plastic waste as aggregate in cement mortar and concrete preparation: A review.* Construction and Building Materials, 2012. **34**: p. 385-401.

[3.] Tapkire, G., *RECYCLED PLASTIC USED IN CONCRETE PAVER BLOCK*. Vol. 03. 2014. 33-35.

[4.] Mohan, D.M.S., et al., *Utilization of Plastic Bags in Pavement Blocks.pdf.* International Journal of Pure and Applied Mathematics, 2018. **119**(15): p. 1407-1415.

[5.] Ahmed, A.M. and B. Singhi, *Overview on structural behaviour of concrete block pavement.* International Journal of Scientific and Engineering Research, 2013. **4**(7): p. 782-789.

[6.] Achitra, M., et al., *Recycled Plastic and Coconut Fibre used in Concrete Paver Block.pdf.* International Journal of Engineering Science and Computing,, 2018. **8**(4): p. 16827-16830.

[7.] Eric Ababio Ohemeng, P.P.-K.Y., John Dadzie & Susan Dzifa Djokoto, *Utilization of Waste Low Density Polyethylene in High Strengths Concrete Pavement Blocks Production.* Civil and Environmental Research, 2014. **6**(5): p. 126-135.

[8.] Sarang, S.P. and A.B. Shubhankar, *Use of Fly ash and Plastic in Paver Block.pdf.* International Research Journal of Engineering and Technology (IRJET), 2017. **4**(11): p. 1542-1547.

[9.] Mahadevi, R., et al., *An Experimental Investigation on Concrete Paver Block by Using PVC Plastic Material.* International Journal of Modern Trends in Engineering and Research, 2018. **5**(3): p. 2393 - 8161.

[10.] Aparna, S., D. Sathyan, and K.B. Anand, *Microstructural and rate of water absorption study on fly-ash incorporated cement mortar.* Materials Today: Proceedings, 2018. **5**(11, Part 3): p. 23692-23701.

[11.] Thirugnanasambantham, N., et al., *Manufacturing And Testing Of Plastic Sand Bricks.pdf.* International Journal of Science and Engineering Research (IJOSER), 2017. **5**(4): p. 1150-1155.

[12.] Dinesh, S., A. Dinesh, and K. Kirubakaran, *UTILISATION OF WASTE PLASTIC IN MANUFACTURING OF BRICKS AND PAVER BLOCKS*. 2016.

[13.] Plastics, L., *TECHNICAL DATA SHEET Low-Density Polyethylene (LDPE)*. laminatedplastics.com. p. 1.

[14.] Jennifer, L.J., et al., *Mechanical Properties of Low Density Polyethylene.pdf.* CrossMark, 2016. **2**: p. 411-420.

[15.] Lairelakpam, B.S., et al., *Manufacturing Bricks from Sand and Waste Plastics.pdf.* International Journal of Engineering Technology, Management and Applied Sciences, 2017. **5**(3): p. 2349-4476.

[16.] Sacithraa, R., M. Mohan, and D.S. Vijayachitra, *Quantitative Analysis of Tapioca Starch using FT-IR Spectroscopy and Partial Least Squares*. Vol. ICIIIOES - Vol.1. 2013. pp.29-33.

[17.] Bag, D.S., V.P. Kumar, and S. Maiti, *Chemical modification of LDPE film.* Journal of applied polymer science, 1999. **71**(7): p. 1041-1048.

[18.] Jung, M.R., et al., *Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms.* Mar Pollut Bull, 2018. **127**: p. 704-716.

[19.] Prasad, A., *A quantitative analysis of low density polyethylene and linear low density polyethylene blends by differential scanning calorimetery and fourier transform infrared spectroscopy methods.* Polymer Engineering & Science, 1998. **38**(10): p. 1716-1728.

[20.] Matthew, J.B., et al., *Using Fourier Transform IR Spectroscopy to Analyze Biological Materials.* US National Library of Medicine National Institues of Health, 2014. **9**(8): p. 1771-1791.

[21.] Coates, J., *Interpretation of Infrared Spectra, A Practical Approach*, in *Encyclopedia of Analytical Chemistry*, R.A. Meyers, Editor. 2000, John Wiley & Sons Ltd, Chichester. p. 10815–10837.