Development of Paver Block Containing Recycled Plastic

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Abstract. Disposal of accumulated plastic waste daily is an exigent in solid waste management. Hence, this study investigated the possibility of utilizing plastics waste in paver block fabrication for the pedestrian walkway. The development of paver block containing recycled plastic was started with a trial mix in order to identify the appropriate method for paver block fabrication. Two methods which are heating and compression were observed during the trial mix before proceeding to full scale casting. Compression method was selected in the production of paver block for further test. There were two ratios of cement, sand and soil used in the design mix namely mixture A and mixture B. The plastic content used in each mix were 0%, 5%, 10%, 15%, 20%, 25% and 30% by weight of sand. Laboratory tests conducted on the specimen were compressive strength, water absorption and skid resistance. Both mixtures were compared in terms of compressive strength in order to select the appropriate ratio. The results showed that mixture B produced higher compressive strength compared to mixture A. Replacement of 5% recycled plastic exhibits the highest compressive strength for mixture B, however for economical consideration the replacement can be utilized up to 30% recycled plastic content. Based on the water absorption test, the recycled plastic increases the water absorption. However, the skid resistance of the paver block was found higher than the requirements. Therefore, paver block made of recycled plastic incorporating locally available material has the potential for use in the construction of pedestrian path.

1. Introduction

Plastic is one of the most utilized and used materials in most communities in the world. In contrast with the past, the availability of plastic wastes is now enormous due to the fast growth of the modern day’s urbanization and development. According to a study in 2015, out of 192 coastal countries in the world, Malaysia is the eighth largest producer of mismanaged plastic waste [1]. The production of plastics is increasing day by day as it is used in everyday usage. Identically, plastics used are polyethylene terephthalate (PET) bottles, containers and groceries bag. Due to its low biodegradability and presence in enormous quantities which remain for decades or centuries, disposal of waste plastics has thus become one of the significant environmental problems nowadays. Although most of the waste plastics are sent to the landfill for disposal, the quantity of waste is never reduced due to the rapid development and production of these materials.

There are four major options for the disposal of plastic waste, which are landfilling, incineration, biodegradation and recycling [2]. All types of plastics can be disposed of by landfilling or incineration. However, landfilling is considered to be highly wasteful as it requires a large space that may leak pollutants into the soil and surrounding environment, which thrives it to be not eco-friendly. The plastics
will mix with other municipal wastes to leach the ground in the form of toxic chemicals hence contaminate the underground water. These will not only cause pollution to the water bodies, but the land and air will also be affected. When plastic wastes are disposed of in water, it will form small pallets, swallowed by the aquatic life which may lead to their death and even worse, threatened facing extinction. The second option, incineration, is a way of extracting a minimum amount of energy from plastic burning. Burning plastic produces hazardous and toxic gasses which produce adverse environmental and health effects. Biodegradable plastics are workable, but it consumes much time to the extent that plastic waste continues to build up. Biodegradable plastics also can contaminate and disrupt the current recycling stream due to their similar appearance. Unsystmatic waste management and littering routine will contribute to a significant problem for city authorities, especially in the urban areas, thus makes recycling is the best option to dispose of waste plastics other than the three options because it uses minimum energy consumption.

Since plastic is one of the significant components of Municipal Solid Waste (MSW), efforts to recycle plastic waste has resulted in intensive research works such as in concrete blocks. Other than to enhance sustainability, plastic waste was also investigated for potential use as an aggregate or cement replacement to produce a concrete block with value-added performance. Recycled plastic can be mixed in the concrete without significant effect on its properties or slight compromise in strength. Although waste materials can be beneficially incorporated in concrete, either as part of the cementitious binder phase or as aggregates, it is essential to realize that not all waste materials are suitable for such use [3]. Civil engineers are therefore required to investigate appropriate materials that can wholly or partially replace typical concrete ingredients.

Various types of waste plastics can be used in the manufacturing of concrete as an alternative to replace aggregates. Expanded polystyrene (EPS) based waste, high-density polyethylene (HDPE), polyethylene terephthalate (PET) waste bottles, polypropylene fibres and polyethylene bags have been used in different forms by researchers in concrete [4]. Low-density polyethylene (LDPE) provides good resistance to chemical substances and has a broader range of applications. Although LDPE has a low melting point, high flammability and reduced thermal stability, LDPE has better binding properties that make plastic bends easier. In the past few years, several types of research were done on producing paving blocks made from recycled plastics. Jrn et al. [5] has produced LDPE-bonded sand block by mixing LDPE water sachets and sand, which is currently used to form paving blocks for hard standing areas and pavements in Ghana. Concrete paver block that constructed in a rural area gives an excellent aesthetic view as compare to cast in situ concrete [6]. According to Meng et al. [7], recycled plastic can be used to enhance the abrasion, skid and freeze-thaw resistance of concrete paving blocks. In terms of compressive strength, utilization of plastic waste slightly reduced but still acceptable to be used as pedestrian paver block at park, footpath and yards [8-9]. The unique feature of a concrete paving block is its ability to be moulded in various shapes, thicknesses, densities and strength. However, the long-term performance of paving block is based on the material composition, which determined from the mix design. Therefore, this study explores the possibility of using recycled plastic as a paver block using locally available materials.

2. Methodology

2.1. Materials

Recycled plastic (RP), quarry dust, sand, soil, cement and water were the primary materials used in this study. The selected RP were polyethylene terephthalate (PET) polymer from the mineral water bottle (figure 1). The bottles were manually shredded using scissors to make the melting process easier. The shredded bottles were used either as binder or sand replacement in the paver block production depending on the methods of fabrication. In the heating method, RP acts as a binder and heated in oven before mixing it with quarry dust and sand. Whereas in the compression method, RP was processed and became fine particles that passing 0.6 mm sieve. Fine sand was supplied by a local quarry and passed through sieve 0.6 mm. It was dried and cleaned before the sieving process to remove any unwanted materials such as roots, debris and any organic matter. Similar preparation was applied to 1.4 mm size quarry dust which was obtained from a local quarry. In the compression method, other materials were 25 grade
Ordinary Portland Cement (OPC), soil and water. The soil was obtained from Kampung Numbak, Kota Kinabalu.

Figure 1. Recycled plastic.

2.2. Design Experiment and Testing

2.2.1. Trial Mixes.
Trial mixes were prepared to observe the suitable method of paver block production and mix design. There were two approaches used in paver block fabrication, namely heating method and compression method. In the heating method, shredded PET bottles were mixed with quarry dust in a mixing mould and heated together inside the oven with a maintained temperature of 250 - 300°C. After heating, the mixture was stirred thoroughly by hand to ensure well it is mixed. The mixture was then and poured into a mould (figure 2) and left 24 hours to cool down and harden. Another method was compression which consists of sand, soil, cement and RP. In the compression method, the PET bottles were shredded and then melted and then left to harden. The hardened plastic was crushed and turn it to finer particles, as shown in figure 3 by using the Los Angeles Abrasion Machine. In this method, the plastic powder act as a sand replacement. The casting was done by pouring the mixture into a mould and compressed using it the compressive strength machine. Based on observation during trial mixing the most efficient procedure was selected and employed in full scale casting.

Figure 2. Melted RP mixes with quarry dust and sand.

Figure 3. RP processed into fine particle.

2.2.2. Mix Proportion. Both methods used in the trial mixes have different mix proportions. In the heating method, the mix proportions of RP to sand was in the ratio of 1:1, 1:2, 1:3, 1:4 and 1:5 by weight
of sand. Whereas, in the compression method, the mix proportion of cement, sand and soil obtained by weight of batching method were 1:2:3 (mixture A) and 1:1:2 (mixture B) respectively. RP were added into the mix as replacement of sand at 0%, 5%, 10%, 15%, 20%, 25% and 30% by weight sand. The best mixture proportion for paver block fabrication was decided by performing basic properties tests.

2.2.3. Soil Sieve Analysis and Atterberg Limit. The soil was tested for basic properties such as soil sieve analysis and Atterberg limit in order to determine the types of soil. Sieve analysis was conducted according to BS 1377:1990[10]. Whereas, Atterberg limit test was conducted to obtain the Liquid Limit (LL) and Plastic Limit (PL) of soil sample. The Fall cone test method was used to obtain the LL, and the hand-rolling method was used to obtain the PL. The value of LL and PL were then used to calculate the plasticity index.

2.2.4. Compressive Strength Test. Compressive strength test was carried out to determine the compressive strength development of the paver block at 0, 7, 14 and 28 days. Specimens were cured by sprinkling the water on specimen every day for 28 days. The compressive strength test was performed following MS 76:1972[11].

2.2.5. Water Absorption Test. Water absorption test was conducted on the selected mix design which was the mixture B after 28 days of curing in accordance to MS76:1972[11]. The water absorption value is based on the average of three specimens.

2.2.6. Skid Resistance Test. To ensure that the paver block is safe to be used on the pedestrian path, skid resistance test was measured using the Pendulum Skid Resistance tester in accordance to BS EN 1338:2003. It was set up on the paver block to determine the skid resistance on a dry and wet surface. The skid resistance values are the mean of three readings and shall not be less than 45.

2.3 Optimum Mix Design and Paver Block Prototype

After analysing the results taken from the compressive strength result, the optimum mix design was determined for the paver block prototype fabrication. The amount of RP utilised in the production of the paver block was also considered in the selection of optimum mix design. This was conducted to maximise the utilisation of recycled plastic, which will produce a more economical and efficient paver block with satisfying properties. The developed prototype was used for the construction of a pedestrian path at Universiti Malaysia Sabah and shown in figure 4. Development of paver block containing RP is summarised in figure 5.

Figure 4. Paver block construction at UMS.
3. Results and Discussions

3.1 Observation on Methods for Development of Paver Block
There were two methods used to produce specimens for paver block, which were heating and compression. Both methods are analysed and observed before the full scale casting of paver block. The most efficient method is then selected in the production of the paver block. The observations are considering the complexity of preparation and its effects on the environment. In the heating method, the RP acts as a binder. The processes involve melting the RP in the oven together with sand and quarry dust and then pour it mixture into a concrete casting mould. The challenges were controlling the temperature when mixing the RP with sand and quarry dust as melted RP harden quickly and hence causes segregation in the mixture. Other than that, this method produces much smoke during manual mixing of heated RP mixture and thus negatively affect the environment.

In the compression method, RP was utilised as a sand replacement, and there were four materials needed in the production of paver block, which was cement, sand, soil and recycled plastic. Compression method was adopted from interlocking brick system (IBS) production at Universiti Malaysia Sabah [12]. Recycled plastics used in this method need to be processed to become powder. This process started with melting the recycled plastic using an oven. After that, it was left to harden for 24 hours before crushing it using Los Angeles Abrasion machine to produce 600 µm plastic particles. Using the oven to melt the plastic can minimise smoke production. By comparing the two methods used for processing the plastic either as a binder or sand, two factors are considered, which are the complexity of production and effects to the environments. In the heating method, it is not easy to control the temperature and smoke during manual mixing. Whereas, the compression method used the oven for heating the plastic and mixing were done at room temperature. Therefore, odour from melted plastic is not an issue during mixing. For that reason, the compression method was selected to produce the block paver prototype.

3.2 Mix Design
The primary materials used in this study were tested for basic properties test to ensure the suitability of the materials. The properties of the soil are shown in table 1. From table 1, the type of soil is silty or clayey gravel and sand.
Table 1. Properties of soil.

| Properties                      | Value  |
|---------------------------------|--------|
| Coefficient of uniformity, Cu   | 1.85   |
| Coefficient of curvature, Cc    | 0.9135 |
| Liquid Limit, LL (%)            | 38     |
| Plastic Limit, PL (%)           | 15.4   |
| Plastic Index                   | 22.6   |

For determination of mixture ratio, two mixtures composition of cement, sand and soil were prepared as described in section 2.2.2. Both ratios (mixture A and B) were prepared based on a water-cement ratio of 0.5. Recycled plastic was incorporated as sand replacement (0%, 5%, 10%, 20%, 25% and 30%). Compressive strength was conducted to investigate the strength development in order to gauge the performance of materials throughout service conditions. Figure 6 and 7 showed the compressive strength development of paver block 28 days.

![Figure 6. Compressive strength of mixture A.](image)

From figure 6, in general, the compressive strength of the specimen increased with the ageing of the specimen (0 days to 28 days). However, there is no consistent trend of compressive strength with related to RP content. It can be seen that the sample with 5% RP content showed the highest strength and the lowest value is 15% at 28 days of curing. From the compressive test results, the highest strength recorded was 13.67 MPa (sample after 28 days with 5% RP). Reduction of compression strength associated with RP usage in paving concrete blocks reported in previous research [8,13]. According to Ohmeng et al. [14], the decreased in compressive strength is attributed to the smooth surface of plastics which weaken the adhesion between the RP fine particle and cement paste. Udawattha [15] stated that the minimum strength requirement for pedestrian walkways was 15 N/mm². Therefore, to enhance the adhesion of materials used for manufacturing paving block, a new mixture ratio 1:1:2 (cement: sand: soil) named mixture B with a similar water-cement ratio was used in paver block fabrication. The compressive strength results of mixture B is presented in figure 7.
It can be seen in Figure 7 that the addition of RP reduces the compressive strength. However, the compressive strength at 28 days duration for all specimens is higher than the compressive strength in mixture A. A slight increase in compressive strength can be seen at 25% and 30% RP. The highest strength recorded at 32.29 MPa at 0% replacement followed with 22.98 MPa at 5% RP. All specimens passed the minimum strength requirement for the use of pedestrian walkways (15 N/mm²). This indicates that the new ratio enhances the adhesion of materials used for paver block.

Another essential property of the paving block is water absorption. In this study, a water absorption test was conducted on mixture B since it passed the minimum requirement for a paver block. Water absorption test was conducted after 28 days of curing. Water absorption properties are related to the understanding of pedestrian paving materials performance when exposed to rain. Figure 8 shows the fluctuation of water absorption after 28 days of curing. There are no specific trends observed, and water absorption values ranging from 15% to 17%. The highest value was recorded at 20% RAP with 17.06% water absorption. In contrast, the lowest recorded at 0% RP with 15.32% water absorption. According to ASTM C936 [16], the water absorption of solid interlocking paving units is 5%. In this study, the water absorption level is high and failed to meet the standard requirement. The high-water absorption could be due to the soil used in paving fabrication. Udawattha et al. [15] reported comparatively high-water absorption in their study attributed to the soil used in the paving block.

Based on the compressive strength results of the two materials composition, mixture A does not meet the minimum requirements in terms of strength. Whereas mixture B, able to meet the minimum strength requirement. However, further test on water absorption shows that none of the mixture composition meets the water absorption requirement. Therefore, continuous monitoring on the constructed block paver will be conducted in order to study the effects of rain. For production, 30% of RP content is proposed for economic consideration in the production of paver block.
3.3 Skid Resistance of Paver Block

Skid resistance is one of the crucial elements in paver block for safety reason. The skid resistance of the surface of blocks was measured using the pendulum skid resistance tester for 30% RP content. The skid resistance values were the mean value of the three readings. The results of the skid resistance test were tabulated in Table 2.

| Skid Resistance Average Reading |
|-------------------------------|
| Dry  | Wet  | Dry  | Wet  |
| 74.5 | 59   | 70.2 | 61   |
| 68   |      | 70.9 | 60   |

The results showed that all skid resistance values were higher than the standard requirement, which is 45. Higher skid resistance is due to the rough surface of the soil and sand particles on the pavement block after being compressed. When the test was repeated by wetting the surface, all rough particles of soil and sand were removed and thus reduces the skid resistance. However, both readings of the dry and wet surface showed higher values than 45. Hence, the paver block fulfilled the skid resistance requirements and suitable for use in the construction of a pedestrian path.

4. Conclusion

The preliminary study explored the possibility of producing soil-based paver blocks. From this study, the following conclusion can be drawn:

a) The initial test to determine the suitable method for the development of recycled plastic for pavement block indicated that the compression method is the best option.

b) The mix design involved selection of appropriate mix proportion and optimum percentage of replacement to produce paver blocks. Based on the compressive strength and water absorption tests, mixture B is the most suitable composition. The highest compressive strength recorded at 0% plastic replacement and the strength gradually decreases as the replacement percentage increases. For economical consideration 30% RP content was selected as more amount of plastic can be utilized for the production of pavement block.

c) The paver block passed the minimum requirement of skid resistance. However, further study is required for the water absorption test.

5. References

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