The Study on Using HDPE and Crumb Rubber on Concrete Mixture

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Abstract. In 2018, about 24% of waste in Indonesia has not been managed properly, which resulted in about 15 out of 65 million tons of garbage produced in Indonesia every day ended up polluting the environment. One solution that has been applied was to recycle certain types of waste, such as crumb rubber and high-density polyethylene (HDPE) plastic and mix them in concrete mixture. The purpose of this research is to analyse the effects of waste usage in concrete mixtures against compressive strength, porosity, electrical conductivity (EC), total dissolved solids (TDS), and pH. The waste material used was processed into a fine grain shape and passes a filter of 2.36 mm. The percentage of waste that will be used to replace the fine aggregate levels of concrete was 5%, 7.5%, 15%, and 17.5%. From the research results, it can be observed that increasing the waste content in conventional concrete increases the compressive strength but reduces the EC value.

Keywords: Crumb rubber, High Density Polyethylene, Porous Concrete, Recycling, Water filtering

1. Introduction

The average annual increase of road lengths in Indonesia for national roads was 11313.3 km and for provincial roads was 1082.3 km between 1987 and 2011 [1]. A road functions to continue the stress received from the vehicles above it to the ground underneath. Road pavement is divided into two categories namely rigid pavements, that have a surface coating made of concrete, and flexible pavement formed by bitumen material [2]. Conventional concrete used for the surface layer of rigid pavement usually has a strength of 20 MPa – 35 MPa, depending on the application of the road.

Concrete also has a porous form with compressive strengths ranging from 8 MPa to 12 MPa, but is usually used for sidewalks or roads with lower traffic volume. This porous concrete is achieved by reducing the use of fine aggregates in concrete mixtures or by not using them at all [3]. Porous concrete has a number of advantages, including having good permeability, which can be useful to recharge groundwater, able to absorb sound and hence able to reduce noise, and able to reduce pollutant in water [4,5].
Due to the needs of construction materials and the build-up of waste that continues to increase, natural resources were explored to be used as an alternative material for concrete mixture. One solution that has been already applied was utilizing rubber [6,7] and plastic waste [8,9] onto the concrete mixture. In Indonesia, plastic waste and rubber are usually burned or thrown into the sewers, which resulted in flooding and air pollution by the chemical content of the combustion process. So far, the use of waste as a substitute for the aggregates in conventional concrete have been applied in rigid pavement and high-rise buildings [1].

Some research studies have already been conducted to analyze the influence of rubber and plastics waste towards concrete characteristics. For example, [10] replaced the coarse aggregate of conventional concrete with used rubber tires. The percentage of used tires utilized to replace concrete aggregates were 0.3%, 0.75%, and 1%. Compressive strength test results showed that concrete samples with rubber content of 0.3% and 0.75% were able to compare with concrete samples without a rubber mixture. When testing concrete samples with a rubber content of 1%, the compressive strength experienced a drastic decrease of 63%. From the various research that has been done and supported by the existing data, this research was conducted with the purpose of identifying the effects of use of rubber and plastic waste against conventional concrete and porous concrete properties. Crumb rubber and High-Density Polyethylene (HDPE) were used due to its abundant supply and its capability to be easily formed into different gradations. In addition, rubber and plastic waste used had a density value closer to the fine aggregates when compared with other waste producers that have been used as concrete mixtures such as styrofoam and paper. If the waste successfully improves the quality of the concrete, then the expected construction costs can be cheaper and the accumulation of garbage decreases.

This research study aims to evaluate the performance of both conventional and porous concrete mixtures that was mixed by HDPE plastic and crumb rubber. Both HDPE plastic and crumb rubber were added at dosages of 5 %, 7.5 %, 15%, and 17.5%. The concrete specimens were evaluated for their compressive strength, permeability, and porosity. Additionally, the water quality that has passed through the concrete specimens were also tested for their pH, electrical conductivity (EC), and total dissolved solids (TDS)

2. Experimental design

2.1. Materials

Natural aggregate sourced from a quarry was used for the patching. Preliminary tests, including specific gravity and absorption tests, were conducted according to Standar Nasional Indonesia (SNI). The test results are shown in Table 1.

It can be seen that the aggregates used can be categorized as marginal aggregate as it did not satisfy the required values. However, the aggregates were decided to be used in this study to see the if the usage of alternative materials could improve the performance of the concrete.

| Tests                  | Results | Requirements |
|------------------------|---------|--------------|
|                        | Coarse  | Fine         |               |
| Bulk Specific Gravity   | 2.3     | 2.071        | ≥ 2,5 gr/cc   |
| SSD Specific Gravity    | 2.4     | 2.151        |               |
| Apparent Specific Gravity| 2.6    | 2.253        |               |
| Absorption (%)          | 5       | 3            | ≤ 3           |

For the concrete mixture, a Portland cement type I was used. The concrete and the porous concrete were designed to achieve the compressive strength values of 25 MPa and 12 MPa, respectively. The
recycled wastes used in this study, which were HDPE and crumb rubber (as seen in Figure 1), were added onto the concrete to replace some of the natural aggregates used. Both HDPE and crumb rubber added were varied from 5%, 7.5%, 15%, and 17.5%. These materials were sieved so their sizes were the same as the fine aggregates.

![Figure 1. Crumb Rubber and HDPE](image1)

The conventional concrete specimens, that were mixed by crumb rubber and HDPE, were denoted as CR-CC and HDPE-CC, respectively. For the porous concrete specimens, the samples were symbolised as CR-PC for the ones that were mixed with crumb rubber and HDPE-PC for the ones that were mixed with HDPE.

2.2. Laboratory Tests

There were two laboratory tests conducted, namely the compressive strength and the permeability tests. The compressive strength test was conducted based on [11] when the concrete specimen was 7 and 28 days old. Each test was conducted three times to obtain a statistically significant data.

A falling head permeameter, as shown in Figure 2, was used to determine the permeability and the porosity of the concrete specimens. The falling head permeameter was made by connecting PVC pipes into U shape and by installing a valve in the middle to control the water flow. The left side of the apparatus was made lower than the right side. The height difference will create water pressure, so that the water will flow through the pipe and hence, through the concrete specimen, which was placed on the right side of the apparatus.

![Figure 2. Falling Head Permeameter](image2)

The water filtered through both conventional and porous concrete specimens were then tested for their pH, total dissolved solids (TDS) and electrical conductivity (EC) values.
3. Results and Discussion

3.1. Compressive Strength Test Results

Figure 3 shows a comparison of the compressive strength between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates. From Figure 3, it can be seen that the conventional concrete had a higher compressive strength value than the porous concrete. This is due to the compressive strength of conventional concrete press was already being designed to be stronger than porous concrete and porous concrete for rigid pavement. It can be observed that conventional concrete with HDPE and crumb rubber mixtures experienced a constant decline along with the increase in volume of waste added, while porous concrete hardly underwent any changes. Conventional concrete aged 28 days with a 17.5% crumb rubber mixture experienced the biggest decline of compressive strength at 38.12%, while the porous concrete underwent a maximum change of approximately 0.36 MPa from the designed compressive strength.

As a comparison, a research conducted by [10] used rubber mixtures in conventional concrete resulted in compressive strengths of 28.6 MPa; 29.2 MPa; 10.9 MPa. Even though the designed compressive strength of past researcher’s plan was slightly different, it can be seen the same pattern occurs, where increased levels of waste in concrete will lower its compressive value. The main cause of the strong decline in the previous researcher is the substituted aggregates were coarse aggregate instead of the fine aggregates, so the volume of room in the concrete eaten by the waste is much greater.

![Figure 3 Compressive Strength Results](image1)

### Figure 3 Compressive Strength Results

3.2. Permeability Test Results

Figure 4 shows the comparison of the permeability between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates.

The comparison of porous concrete permeability and conventional concrete indicates that porous concrete has a much higher permeability coefficient than conventional concrete. The highest permeability was produced by porous concrete with crumb rubber contents of 5% resulting in a permeability of 0.008 m/s, while the lowest coefficient produced was by conventional concrete with a 7.5% HDPE resulting in a permeability of 2.72 E-07 m/s. Conventional concrete is used for structures with high strength and to achieve such power the porosity and permeability possessed must be low. The
method of permeability testing used for conventional concrete and porous concrete were slightly different. The difference is that porous concrete permeability testing is not time constrained as conventional concrete tests because water only takes mere seconds for concrete penetration. This is due to the cavities in porous concrete that have been designed by not using fine aggregates in large amounts. Conventional concrete permeability testing is limited to 3 hours and water decline occurring in the falling head pipes were analysed. The permeability and high porosity in conventional concrete will produce a low compressive strength, so it must be ensured the fine aggregate levels are used appropriately to cover the resulting gap of coarse aggregate, and the concrete curing process is done correctly.

![Permeability Test Results](image)

**Figure 4.** Permeability Test Results

### 3.3. Porosity Test Results

Figure 5 shows the comparison of the porosity between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates.

It can be seen from Figure 5 that porous concrete results in a higher porosity value than conventional concrete. Without designing a specific porosity value in conventional concrete, the fine aggregate volumes help the conventional concrete to cover the gaps created by the varying coarse aggregate gradation and creating low porosity figures. Results of the porosity test in porous concrete using HDPE waste showed almost the same results as the standard concrete. For conventional concrete with a mixture of crumb rubber, there was an increase of 75%-100% towards the control concrete. The range of porosity of crumb rubber mixed concrete was 7%-8%, while the standard concrete had a porosity of 3%-4%. It shows that crumb rubber can increase the coefficient of permeability and the porosity of conventional concrete. The increase in the crumb rubber mixed conventional concrete permeability was directly proportional to the increase in porosity value.
3.4. pH Test Results

Figure 6 gives a comparison of the pH between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates.

It can be seen that only porous concrete aged 28 days with a mixture of crumb rubber had a stable pH value. Each variation of the mixture experienced changes after the waste mixture used in concrete was 7.5% or more. Conventional and porous concrete with HDPE mixture shows almost the same results on any variation of waste, only the pH value of conventional concrete is different than the control concrete. There is a considerable change in pH value when looking at the graph briefly, but when...
evaluating the exact values, it can be seen that the changes are meaningless. The margin between the smallest and largest pH value is only 0.4 and the concrete penetration water still passes the criteria of World Health Organization for drinking water and irrigation, which is 6.5 – 8.5 [12].

3.5. Total Dissolved Solids Test Results

Figure 7 gives a comparison of the total dissolved solids between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates.

![Figure 7. TDS Test Results](image)

The highest value of TDS is produced by conventional concrete samples with a mixture of 15% crumb rubber reaching 350.67 mg/L. The smallest TDS value is 342.33 mg/l by conventional concrete with 15% HDPE. Any variation of conventional concrete with a mixture of crumb rubber produces a higher TDS value than the control porous concrete. Test results in porous and conventional concrete using crumb rubber and HDPE range from 338 mg/L – 353 mg/L. Based on (WHO) World Health Organization standards, this indicates that the water results in the penetration of the porous concrete and conventional concrete samples can be used for irrigation and drinking water purposes.

3.6. Electrical conductivity Test Results

Figure 8 gives a comparison of the electrical conductivity between conventional concrete and porous concrete at the age of 28 days with a mixture of HDPE and crumb rubber of 5%, 7.5%, 15%, and 17.5% towards the volume of fine aggregates.

Figure 8 shows that the EC values of conventional concrete and porous concrete are fairly consistent with the control concrete. All conventional concrete samples with HDPE and crumb rubber mixtures had a lower EC value compared to the control concrete excluding concrete samples with 5% and 7.5% mixtures of crumb rubber. In each type of concrete, the variation that produces the highest EC value is concrete with a mixture of waste of 5% or 7.5%. EC test results in porous concrete and conventional concrete ranged from 735 µs/cm – 747 µs/cm. The EC value was compared to [13]. It was stated in the document that the water penetrating the concrete is safe for irrigation, livestock, and drinking water resources. When the value of EC reaches 2500 µs /cm, then the water is not recommended to be consumed and used for other applications without special maintenance.
4. Conclusions
Based on the results of the research and discussion in the previous chapters the following can be concluded:

- Compressive strength decreased as the rate of crumb rubber and HDPE in conventional concrete increased. In porous concrete, the mixture of crumb rubber and HDPE resulted in a compressive strength value consistent with the control concrete.
- Between HDPE and crumb rubber mixed concrete, HDPE was able to create the higher compressive strength. Concrete samples with a mixture of 5% HDPE produced the strongest compressive strength of 23 MPa.
- In conventional concrete, mixing crumb rubber will result in an increase of permeability & porosity up to 75%-100% towards the control concrete. The addition of HDPE in conventional concrete produces a coefficient of permeability and porosity that is quite consistent with the control concrete. Porous concrete with mixtures of crumb rubber and HDPE showed the same pattern, where both types of concrete are consistent with the control concrete.
- When comparing HDPE and crumb rubber mixed concrete, the highest permeability and porosity was produced by concrete with a mixture of crumb rubber. The highest permeability was produced by concrete with a mixture of crumb 5% rubber and the highest porosity was produced by concrete with a mixture of 17.5% crumb rubber.
- The larger the waste content in conventional concrete and porous concrete, the EC value of water that penetrates the concrete will further decrease, while with TDS, the exact opposite occurs. In addition, the pH value of water is consistent with the control concrete. The lowest value of TDS was produced by conventional concrete mixed with HDPE, while the lowest EC was generated by porous concrete with mixtures of HDPE.
- Application of conventional concrete crumb rubber and HDPE for rigid pavement can be done if the waste rate used in concrete is less than 2.5%. This variation avoids a huge reduction in the quality of concrete.

For further research, it is recommended that the more water is added to the concrete mixture with crumb rubber to improve its moisture and to increase the percentage of waste in the size similar to the fine aggregates as substitute material.
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