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Investigation Of HDPE Plastic Waste Aggregate On The Properties Of Concrete

Author

A. M. Mustafa Al Bakri
Green Concrete@UniMAP, School of Material Engineering,Universiti Malaysia Perlis (UniMAP), 01000, P.O. Box 77, D/A PejabatPosBesar,Kangar, Perlis, Malaysia.
E-mail: mustafa_albakri@unimap.edu.my

S. Mohammad Tamizi
Green Concrete@UniMAP, School of Material Engineering,Universiti Malaysia Perlis (UniMAP), 01000, P.O. Box 77, D/A PejabatPosBesar,Kangar, Perlis, Malaysia.
E-mail: tamizi@unimap.edu.my

A. R. Rafiza
Green Concrete@UniMAP, School of Material Engineering,Universiti Malaysia Perlis (UniMAP), 01000, P.O. Box 77, D/A PejabatPosBesar,Kangar, Perlis, Malaysia.
E-mail: rafizarazak@unimap.edu.my

Y. Zarina
Green Concrete@UniMAP, School of Material Engineering,Universiti Malaysia Perlis (UniMAP), 01000, P.O. Box 77, D/A PejabatPosBesar,Kangar, Perlis, Malaysia.
E-mail: zarinayahya@unimap.edu.my

Key words: polymer wastes HDPE; coarse aggregate; compressive strength; properties

Abstract

Quantities of polymer wastes have increased in recent years due to increases in industrialization and the rapid improvement in the standard of living. In Malaysia, most polymer wastes are abandoned and not recycled, causing serious problems, such as the waste of natural resources and environmental pollution. Polymer products, such as synthetic fibers, plastics, and rubber, are made from petrochemical compounds, and they degrade extremely slowly in the natural environment. Plastic materials are not easily biodegradable even after a long period. In fact, a wide variety of waste materials can be utilized as inert materials in the cement matrix. In this research, trash bag plastics were used as the polymer waste types high-density polyethylene (HDPE) for preparation of polymer concrete (PC). The aim of this work was to study the properties of polymer HDPE and to characterize this polymer as a potential replacement for coarse aggregate in concrete. Heating was conducted at five different temperatures, i.e., 160 °C, 170 °C, 180 °C, 190 °C, and 200°C. Five compositions of coarse aggregate with different crushed stone: HDPE waste volumetric ratios were used, i.e., 0:100, 15:85, 30:70, 45:55, and 60:40. Comparisons of conventional concrete with polymer waste as coarse aggregate were conducted. The effects of polymer wastes on the workability and strength of the concrete with fresh and hardened concrete tests were analyzed. Compressive strength was measured after 28 days, and it was found that the PC was suitable for non-structural usage. As for the cost analysis, the results showed that the PC was more cost effective than conventional concrete.

Introduction

Since landfill sites, in general, are becoming overcrowded and expensive for waste disposal, efforts must be made to minimize the quantities of materials that are delivered to landfills. If the production of waste cannot be prevented, then it is attractive to create an alternative use in another process instead of disposal. The benefits of this recycling can be economically advantageous, due lower costs of removing the waste and the reduction of pollution and contamination (G. Li et al., 2004; Senthamarai and Manoharan, 2005).

This paper presents data to show that the polymer wastes in Malaysia are not 100% recycled, i.e., reprocessing of the waste materials into other polymeric items or energy recovery from complete combustion. However, polymer reprocessing is has a limited number of recycling cycles, since contamination and thermal degradation result from the steps of melting and reshaping (Mustafa et al., 2007).

The development of concrete with non-conventional aggregate, such as polystyrene foam wastes, HDPE, polyethylene terephthalate (PET), and other plastic materials has been investigated for use in concrete in order to improve the properties of the concrete and reduce cost. The use of such plastic wastes in concrete will contribute to the sustainability of the concrete design and the natural environment.

Experimental Programme

The main goal of the experimental program was to determine the contribution of various types of waste aggregates to the strength of confined concrete. To that end, the experimental program had the following objectives:

1) To study the characterization of HDPE polymer waste aggregate for comparison to crushed stone coarse aggregate

2) To study the behaviour of fresh and hardened concrete with polymer waste coarse aggregate and compare its properties to those of conventional concrete

3) To produce lightweight polymer concrete for multi-purpose use

Raw Materials

Ordinary Portland Cement

The most important raw material is ordinary Portland cement (OPC) as cementitious material. OPC is suitable for normal concrete and many applications in the construction industry. The raw materials used to manufacture Portland cement are lime, silica, alumina, and iron oxide. To make OPC, a mixture of limestone and clay is heated until it almost fuses, and, then, the clinker is ground into a fine powder (M.Tawfik, 2006). Portland cement is a dry, flour-like substance that contains calcium, silicon, and aluminum, which hardens and holds the aggregate together.

Sand as fine aggregate

River sand as fine aggregate consists of particles ¼ inch (600 μm) or less in size. River sand is the fine aggregate most commonly used in concrete to provide volume at low cost (George R. White, 1991). Sand and gravel are types of aggregate. A good concrete mix will contain both aggregate types.

Plastic Wastes

Waste trash bag plastics were collected from the landfill and from other locations in the environment and used to manufacture lightweight aggregates. The plastic waste sheet was shaped as desired, e.g., as a ball with a diameter of 25-30 mm. The heating temperature was in the range of 160 °C to 200 °C. The plastic waste aggregate was modified by heat treatment, which consisted of heating it at temperatures above the melting point, i.e., 160°C, 170 °C, 180 °C, 190 °C, and 200 °C, for 10 minutes in a laboratory oven. Then, the hot aggregate was removed from the oven and allowed to cool at room temperature. Thus, the heating process induced changes in the physical characteristics of the plastic wastes (shrinkage) and in the microstructure. The spherical diameters of the sample plastic wastes shrunk to the range of 14 - 20 mm. The shapes and textures of the samples were not homogenous or circular, but they were a mixture of angular shapes and round shapes, much like crushed stone.

Crushed Stone or crushed gravel

Crushed stone is the source of the basic properties of natural aggregate used in concrete. Crushed stone is a coarse aggregate that is produced by crushing hard stone. Coarse aggregates are materials retained on a 5-mm (3/16-inch) BS 410 test sieve that contain no more fine materials than is permitted in MS 29:1995.

Water

Water is a very important component that must be mixed into the concrete. The appropriate use of water is the single most important consideration that governs the workability of concrete because the particles requires a certain amount of water. Water is absorbed on the surface of the particles, and in the spaces between particles, providing the "lubrication" that is required for the particles to move past one another more easily. Therefore, finer particles, which are necessary for plastic behavior, require more water. Water that contains impurities will hinder the curing strength of concrete, so only potable water is used for mixing concrete. Additional small amounts of water can always be added if needed, but no water can be removed. The less water that is used, the stronger the concrete will be.

Characterization

Thermal analysis was performed using a differential scanning calorimeter (DSC) (Research Instruments, City, Country) with a constant nitrogen flow rate at 20 ml/min. The investigated temperature range was 20 -180 °C. The samples were heated at 15 °C/min up to 180 °C, held at that temperature for five minutes, and cooled at 15 °C/min to 20 °C. Each sample (4-6 mg) was weighed and sealed in the aluminium vessel.

After shaping, the plastic waste was heated in an oven above the melting temperature, following the results obtained from the DSC. The plastic waste was heated to different temperatures in the range of 160-200 °C to determine the optimal temperature that produced the best properties for the aggregate in concrete.

After heat treatment, the aggregate was tested to determine its characteristics, such as size and shape, surface texture, water absorption, color, and compression test results.

The compression test cube test and a beam flexural test were conducted using the Universal Testing Machine, operated at a crosshead speed of 3.0 kN/sec. Data were collected until the cubes failed. The results of the compression and flexural tests were obtained by averaging the values of at least three measurements.

Experimental Procedure

Mixing
The raw materials, i.e., water, Portland cement, sand, and coarse aggregate, were mixed. The design mix proportions were 1:1.75:2.75, which was based on the earlier research of Yun-Wang Choi et al. (2005) and waste PET bottles were used as the coarse aggregate. In this research, two different plastic waste-to-crushed stone ratios were used (100% plastic waste, 80:20; 60:40 and 100% crushed stone) with the water-to-cement ratio of 0.5. The mixing process created a homogeneous mixture to ensure the proper coating of cement on the aggregate. Thus, the mixing process must be thorough and not rushed. While the raw materials are being mixed, small amounts of water were repeatedly added until a consistency similar to the consistency of cookie dough was obtained.

Mix proportion
The constituents were used in different fractions to determine mixture proportions that would yield the targeted compressive strength at the test age of 28 days. The optimum mix proportions included cement, sand, coarse aggregate, plastic waste, and water to yield a cubic meter of concrete. Table 1 shows the compositions of the sample plastic waste coarse aggregate concrete mixes based on the volumetric method with the same water-to-cement ratio of 0.5.

Table 1: Mix proportion for concrete design

Model	Cement (kg/m^3)	Sand (kg/m^3)	Crushed stone (kg/m^3)	Plastics Waste aggregate (kg/m^3)	Water (kg/m^3)	Ratio Mix Proportion
M1	380	665	0	286	190	1:1.75:2.75
M2	380	665	209	229	190	1:1.75:2.75
M3	380	665	418	172	190	1:1.75:2.75
M4	380	665	1045	0	190	1:1.75:2.75

Mix Proportion (Plastic waste:Gravel, in volumetric percentage)

M1 - (100:0)

M2 - (80:20)

M3 - (60:40)

M4 - (0: 100)

Preparation of Test Samples

To evaluate the mechanical properties of concrete, such as compressive and flexural strength by age and mixing ratios, concrete test specimens were prepared in accordance British Standards and Malaysian Standards. After the mixing process, samples were made in cubic molds (100 x 100 x 100 mm) and as a beam (100 x 500 x 100 mm) and air dried for one day. Then, the samples were removed from the molds and cured for 28 days in water so that they were at the required age.

Results and Discussion

Analysis of DSC Results

DSC results indicated the melting temperature of the samples, Tm, as shown in Figure 1. Various types of plastic waste polymers were used in the research to make the coarse aggregate. From the analysis of the DSC results, the plastic waste was shaped into small, spherical balls and heated above the melting temperature, Tm. Figure 1 shows that the plastic waste began to melt at a temperature of 130 °C.

Size and shape

Figure 2 shows that the aggregate sizes used in this research were in the range of 14 - 20 mm. Before the heating process, the plastic waste was shaped small, spherical balls with diameters of approximately 30 mm. After heating in the oven at a temperature of 180 ^oC, the small balls shrank to a size that was smaller than the original size. The plastic waste was allowed to melt, and, after a few minutes, the aggregate was removed from the oven. Then, after cooling, the plastic maintained the shape of small, spherical balls with diameters in the range of 14 - 20 mm, which is the standard size for the coarse aggregate in concrete.

Surface, Texture, and Water Absorption

Aggregates are three-dimensional masses. Their shape, size, and surface texture influence the properties of the concrete, significantly influence the workability of fresh concrete, and influence the bond between the aggregate and the mortar paste. Shape and surface texture are considered to be external characteristics.

Aggregate particles that have smooth and rounded surface were used to produce concrete. On the other hand, the aggregate particles interlock, which reduces the strength of the aggregate-mortar bond. Smooth and rounded aggregate plastics result in lower compressive strength than a crushed aggregate with the same water-to-cement ratio.

From the equation below, the results show the percentage of water absorption of the aggregate is very low, i.e., around 0 – 0.5%.

$$\%\ \text{water absorption} : \frac{W_2 - W_1}{W_1} \times 100\ \%$$

where W_1 = weight before immersion (dry condition)

W_2 = weight after immersion (wet condition)

Compression test for aggregate

Figure 3 shows the results obtained for compressive strength of the aggregate. Five pieces with different color aggregates were heated to different temperatures. After a few minutes, the aggregate was cooled and the compression test was conducted for each aggregate. From Figure 3, it is evident that the temperature of 180 °C provided the best result. The aggregate that was heated at 180 °C had the best properties. Their strength is highest which up to 25 MPa. From this result, it can be concluded that the optimal temperature for heating plastic waste is 180 °C.

The mechanical properties of plastic waste coarse aggregate are presented in Table 2. The results show that fresh plastic waste coarse aggregate has lower water absorption and a smoother surface texture. Usually, plastics do not absorb water, but the heating process modified the aggregate, giving it a higher density. Thus, during the mixing process, less water can be used.

The compressive strength of the sample cubes ranged from 11 to 19 MPa. Concerning strength, the basic trend in the behaviour of plastic waste coarse aggregate concrete was not significantly different from that of the conventional crushed stone aggregate for lightweight concrete.

The flexural strength varied from 9 to 15 MPa. The variations in flexural strength between plastic waste concrete and conventional concrete were very small. From the surface of the fractured samples, it was apparent that the plastic waste did not have strong, interlocking bonds with the cement.

Conclusion

The aim of this research was to evaluate the recyclability of domestic plastic waste as coarse aggregate for concrete. From the results and discussion, the following conclusions were drawn:

1) The physical analysis of plastic waste coarse aggregates gave the value of 12-17 MPa in compressive strength, 1400-1550 kg/m^3 for the density of the concrete, 5-7% water absorption for the aggregate, indicating its suitability as a coarse aggregate for concrete. Although the size of the aggregate material was in range of 14 - 20 mm, the aggregate had a smooth surface, which is considered to severely affect its workability.

2) The compressive and flexural strengths of concrete containing the plastic waste decreased as the proportion of plastic waste increased. The concrete that contained a 60:40 ratio of plastic waste to gravel gave the highest strength properties. The connection between the plastic waste aggregate and crushed stones will give increased strength and better properties.

3) The mechanical properties of the concrete did not display any notable differences depending on the color of the plastic waste aggregate. The color or pigment of plastic waste will make the decorative products it is used in attractive.

4) This research also has potential application for the production of lightweight concrete, cost savings for raw materials, for minimizing the amount of polymer wastes in landfills, and the creation of decorative, attractive landscaping products.

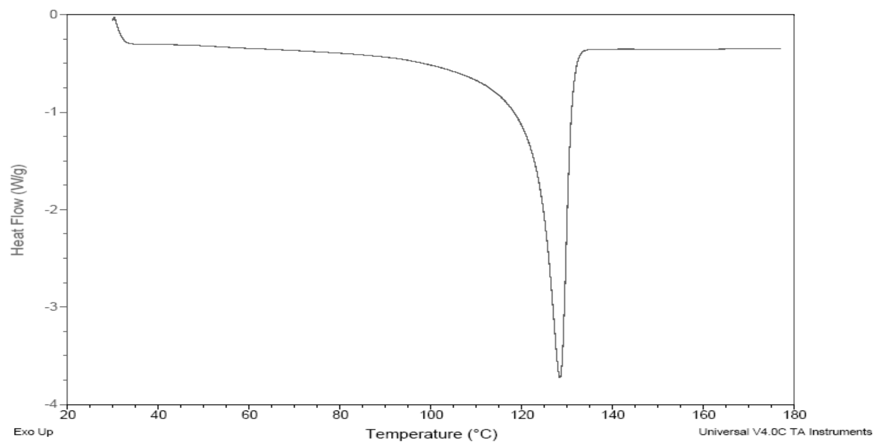
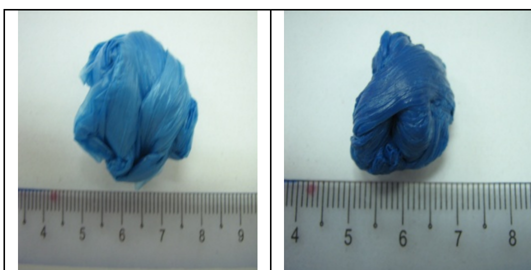


Figure 1: Analysis of DSC results for plastic waste



Before heating	After heating

Figure 2: Comparison of the plastic waste aggregate before and after heating

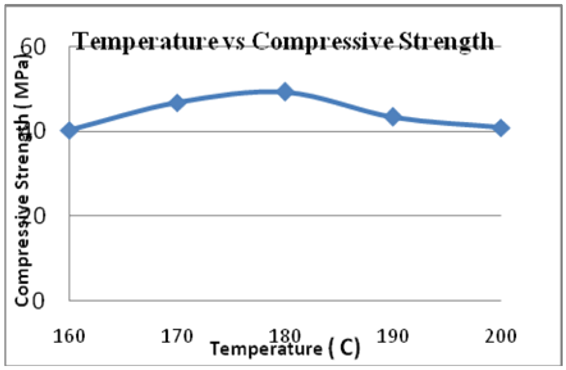


Figure 3: Compressive Strength for Aggregate for Various Heating Temperatures

Compressive Strength and Flexural Strength

Table 2: Properties of Plastic Waste Coarse Aggregate Concrete and Conventional Concrete Mixes at 28 days

Mix	**w/c**	**Cement content** (kg/m^3)	**Types**	**Slump** (mm)	**Compressive Strength** (MPa)	**Flexural Strength** (MPa)
100% Waste	0.5	380	Cubes	13	11.79	
80:20 (Waste:Gravel)	0.5	380	Cubes		13.37	
60:40 (Waste:Gravel)	0.5	380	Cubes		19.85	
100 % Gravel	0.5	380	Cubes	55	29.19	
100% Waste	0.5	380	Beam	13		9.37
80:20 (Waste:Gravel)	0.5	380	Beam			12.56
60:40 (Waste:Gravel)	0.5	380	Beam			15.47
100% Gravel	0.5	380	Beam	55		17.56

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Appendix: At the end of the paper

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