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PROPERTIES OF DIFFERENT ARTIFICIAL LIGHTWEIGHT AGGREGATES AND THEIR EFFECT ON CONCRETE STRENGTH

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ABSTRACT

Plastic bags have become an essential part of people's lives. Hence, the amount of plastic bags used annually has been growing steadily. In this two-part study, the mechanical and physical properties of three different types of plastic bag aggregates were described. These lightweight plastic aggregates were then used as substitute for natural aggregates at percentages of 0%, 3%, 6%, and 9%. Recyclable plastic bags measuring 10–20 mm were gathered then heated in an oven at approximately 150 °C for nearly 10 min. The first part of the study investigated the properties of the three different types of plastic bag aggregates and those of normal aggregates in terms of aggregate impact value, aggregate crushing value, specific gravity, and water absorption. The second part involved a compressive test on the different concretes and a comparison of the results with those obtained for the control concrete. A significant improvement in compressive strength was observed in the concrete mixes that contained 6% directly heated plastic bag aggregates and 6% and 9% glass-covered plastic aggregates. These aggregates were found to be a feasible replacement for coarse aggregates used in conventional concrete.

Keywords: artificial aggregates, chemical properties, physical properties.

INTRODUCTION

Plastic is a widely used material in Malaysia, where it is utilized by virtually all industries. Its production and usage are increasing rapidly because of its perceived feasibility, long life, and low cost. This increasing utilization has correspondingly increased the amount of waste. In Malaysia, 0.8 kg of polyethylene material is wasted daily. In urban areas, waste production has been estimated to amount to 1.5 kg daily. Waste plastic bags considerably contribute to the increasing production of solid waste in Malaysia, with only 1% to 3% of such waste being subjected to recycling. Plastic waste comprises low density polyethylene (23%), polypropylene (18.5%), high density polyethylene (17.3%), polystyrene (12.3%), polyvinyl chloride (10.7%), polyethylene terephthalate (8.5%), and others (9.7%) (Zoorob, 2000).

The disposal of plastic bags, particularly by burying them, can be problematic for any society because most of these materials are non-biodegradable. The use of plastic bags is not only a major problem in landfills but also presents adverse effects on the environment. Thus, innovative solutions must be developed to solve this growing problem. One proposed solution is to turn waste plastic bags into artificial aggregates that can be used to produce concrete. Given the large amount of recyclable plastic materials in disposal sites, the reuse of plastic in the concrete industry is considered highly feasible. Recycled plastic can be used as coarse aggregates in concrete. Mustafa *et al*. (2011) and Mokhatar *et al.* (2014) noted that although the compressive strength of normal concrete is higher than that of concrete comprising recycled plastic, the use of plastic bags as coarse aggregates in concrete is acceptable in terms of their physical properties. In particular, the application of recycled plastic as aggregates results in lightweight concrete (Siddique, 2008).

Lightweight concrete is an extremely important material in the construction industry. Most current studies on concrete focus on high performance concrete, which is a cost-effective material that satisfies demanding performance requirements, including durability. Lightweight concrete can be defined as a type of concrete that includes an expanding agent, which increases the volume of the mixture while providing additional qualities such as reduced dead weight. This type of concrete is lighter than the conventional concrete and is thus widely used in many countries. Lightweight concrete was initially manufactured using lightweight aggregates as a replacement for conventional aggregates (Ducman and Breda, 2009).

METHOD OF PREPARATION OF PLASTIC AGGREGATES

This study focuses on three different types of plastic aggregates as replacements for normal aggregates (NAs). Recyclable plastic bags measuring 30 mm were gathered then heated in an oven at approximately 150 °C for nearly 10 min. They were then cooled at room temperature for roughly 1 min. This process ensured that the desired densities were obtained. The shape of the resulting plastic aggregates resembled a small ball. Before heating, the diameter of the compacted plastic bag aggregates (PBAs) was approximately 30 mm. The heating process then reduced the diameter to 10–20 mm. For the first type of PBA (PB1), the plastic material was directly heated in the oven. For the second type of PBA (PB2), Rynite 530 NC010, which is 30% glass-reinforced

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modified polyethylene terephthalate, was used. The material was covered with a plastic bag (see Figure-1) then heated in a container at 150 °C for roughly 5 min. For the third type of plastic bag aggregate (PB3), the plastic material was encapsulated with glass after sieving with a 2.36 mm sieve.

Figure-1. Different types of lightweight plastic aggregates.

RESULT AND DISCUSSIONS

Aggregate impact value

The study on the effect of the three different types of plastic aggregates (PB1, PB2, and PB3) and the NA was extended to analyze the aggregate impact value (AIV). The AIV is the percentage loss of weight particles passing through a 2.36 mm sieve via the application of 15 blows of a standard hammer. The test was conducted in accordance with BS 812: Part 122:1990. The results of the AIV test on the plastic aggregates and NA are presented in Table-1. The weight of the plastic aggregates (PB1, PB2, and PB3) after sieving with a 2.36 mm sieve was 0 g, whereas that of the NA was 83.8g. The AIV of the NA was higher than that of the three types of plastic aggregates.

Table-1. Aggregate impact values of the three different plastic aggregates and the normal aggregate.

Weight	PB1	PB2	PB3	NA
(W1 g)	121.4	272.6	260.4	333
(W2 g)	0	0	0	83.8
AIV = (W2/W1) 100	0	0	0	25.2

Aggregate crushing value (ACV)

The strength of aggregates is an important element in determining concrete strength. Thus, determining the strength of the three types of plastic aggregates and NA is crucial because of their indefinite strength. Aggregate crushing value (ACV) is used to identify aggregate crushing strength. The ACV test was conducted in this study according to BS 812: Part 110:1990. The plastic aggregates and NA that passed through a 14.0 mm sieve and then through a 10.0 mm sieve were used. Then, a measuring cylinder was filled with three layers of aggregate. Each layer was tamped 25 times with a tamping rod, and the volume was weighted to the nearest 0.1 g. A sample obtained from the measuring cylinder was then placed in the test cylinder in three layers and then tamped 25 times with the rod. The depth of the sample was roughly 100 mm. Then, the plunger was lowered onto the sample and rotated gently so that it was at the same level as the cylinder. The sample was then placed in a compressive testing machine. The load was applied at a uniform rate so that a force of 400 kN was reached in 10 min, after which the load was released. The whole sample was sieved in a 2.36 mm test sieve tray with the expectation that no considerable amount passes through in approximately 1 min. The material that passed through the sieve tray was weighed (W1) and expressed as a percentage of the original mass (W2). The results of the ACV conducted on the aggregates are presented in Table-2. The ACV of the NA was larger than the ACVs of the three types of plastic aggregates. This result indicated that the NA was weaker than its plastic counterparts because a large ACV essentially equates to a weak material. Thus, the types of plastic aggregates used in this study were considered a feasible replacement for NAs.

Table-2. Aggregate crushing value of the three types of plastic aggregates and the normal aggregate.

Weight	PB1	PB2	PB3	NA
(W1 g)	1000	1200	1140	2688
(W2 g)	0	0	0	481
ACV = (W2 / W1) 100	0	0	0	17.89

Specific gravity and water absorption test

The water absorption of the different types of PBAs and NAs is indicative of the proportions of water used in the concrete production process. However, in the present study, water absorption was utilized as an indicator of the water permeability of the PBAs and NA in hardened concrete. The water absorption percentage of aggregates can be determined through a test conducted according to BS EN 1097-6: 2000.

The results of the water absorption test conducted on the PBAs and NA are presented in Table-3. The water absorption of NA was higher than those of the PBAs.

Specific gravity is defined as the mass ratio (i.e., weight in air) of a unit volume of a material to the mass of the same volume of water at a stated temperature. In this study, the specific gravity test on the aggregates was conducted according to ASTM C127. The plastic bag aggregate and NA were sieved using a standard sieving

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apparatus. The samples were thoroughly washed, drained, and immersed in water. They were then soaked in water for not less than 15 h. Subsequently, the samples were removed from the water, towel dried to surface dry conditions, and then weighed in water. The samples were thoroughly dried in an oven and then weighed. The specific gravities of the PBAs and NA are presented in Table-3. The specific gravities of the three plastic aggregates (PB1, PB2, and PB3) were 60%, 55%, and 50% lower than that of NA, respectively, under the same condition.

Table-3. Specific gravity and water absorption.

Property	PB1	PB2	PB3	NA
Specific gravity (%)	1.02	1.12	1.14	2.58
Apparent specific gravity (%)	1.02	1.12	1.15	2.89
Water absorption (%)	0.89	1.6	1.25	2.79

Mix design of concrete

Raw materials such as water, Portland cement, sand, and coarse aggregates were mixed. The mix design aimed at achieving a compressive strength of 25 N/mm² within 28 days involved a mix proportion ratio of 1:2:3, which is in accordance with the recommendation of the Department of Environment of Malaysia. As shown in Table-4, the same water–cement ratio was used for the three PBAs (3%, 6%, and 9%) and the NA. The mixing process was homogeneous and carefully conducted to ensure the proper coating of cement on the aggregates. During the mixture of the raw materials, small amounts of water were added.

Compressive strength test

Compressive strength tests were performed using 150 × 150 × 150 mm concrete cubes according to the B.S. 1881: Part 116: 1983. The compressive strength of the normal concrete and those of the concrete containing 0%, 3%, 6%, and 9% plastic aggregates were determined after 7 and 28 days. The result of the compressive strength test on the three different types of concrete in comparison with the result for the normal concrete is presented in Table-5.

The result for the first type of concrete mix with PB1 (CPB1) is illustrated in Figure-2. The highest compressive strength was observed for the concrete mix with 6% plastic aggregates, and such value exceeded that of the normal concrete by 10%. The lowest compressive strength was observed for the concrete mix with 9% plastic aggregates, in which case the strength of the concrete decreased to 60%. The low strength observed for the latter may be attributed to the weak bond between the artificial aggregates and the cement paste.

Table-4. Mix design of concrete.

Parameter	PBA 3%	PBA 6%	PBA 9%	NA
W/C %	0.5	0.5	0.5	0.5
Cement (kg/m^3)	360	360	360	360
Water (kg/m^3)	180	180	180	180
FA (kg/m^3)	680.8	680.8	680	680.8
CA (kg/m^3)	1,124.4	1,089.6	1,054.9	1,159.2
PBA (kg/m^3)	34.8	69.55	104.3	0

* FA=Fine Aggregate, CA=Coarse Aggregate, PBA=Plastic Bag Aggregate, NA=Normal Aggregate

Table-5. Compressive strengths of concrete mixes with different percentages of artificial lightweight aggregates.

Percentage %	7 days	28 days
0% NA	20.71	32.37
3% PB1	16.8	29.73
6% PB1	24.12	35.7
9% PB1	13.63	22.37
3% PB2	17.3	23.7
6% PB2	20.1	30.25
9% PB2	15.9	28.1
3% PB3	20.3	25.3
6% PB3	21.5	33.8
9% PB3	22.8	34.93

The compressive strength of the concrete mix containing 3%, 6%, and 9% PB2 (CPB2) is presented in Figure-3. This concrete is considerably weaker than the control concrete. Such weakness is attributable to the high water absorption of the plastic aggregate as shown in Table-3.

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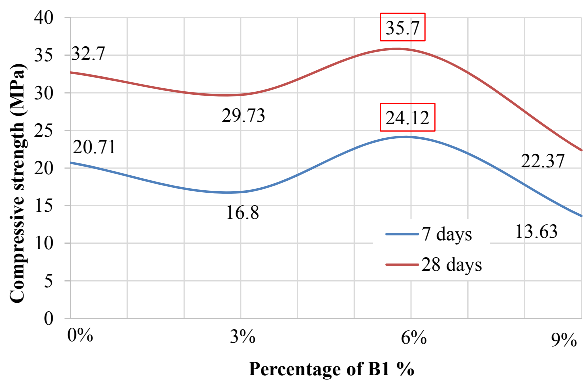

Figure-2. Compressive strengths of concrete mixes with different percentages of PB1.

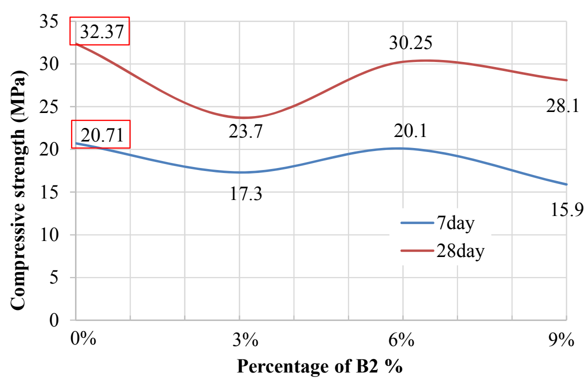

Figure-3. Compressive strengths of concrete mixes with different percentages of PB2.

The third type of concrete mix containing 6% and 9% PB3 (CPB3) achieved the highest compressive strengths and even exceeded that of the normal aggregate after 7 and 28 days (Figure-4). Such result can be attributed to the type of aggregate in this concrete mix, which was the type encapsulated with glass. This material type affected the mechanical properties of the concrete, and the result was the strong bond between the cement paste and the artificial aggregate. Clearly, the rough surface of PB3 resulted in its strong bond with cement.

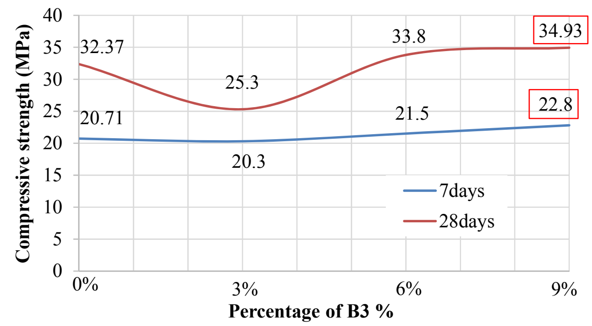

Figure-4. Compressive strengths of concrete mixes with different percentages of PB3.

Regardless of the results of the compressive strength tests, differences in the products were observed because concrete is a composite material whose behavior depends on the behavior of its constituent materials. As expected, the test specimens with the same percentages of replacement materials yielded different results.

CONCLUSIONS

The compressive strength tests revealed that the concrete mixes with 6% PB1 and 6% and 9% PB3 as coarse aggregate replacements achieved the highest compressive strengths. However, the compressive strengths decreased by 22% when 3% of the coarse aggregates were replaced with PB1 and PB3. Meanwhile, the compressive strength of the concrete mixes with 3%, 6%, and 9% PB2 was lower than that of the control mix.

Lightweight plastic aggregates decrease the unit weight of concrete by reducing the dead load. Moreover, lightweight plastic aggregates have weaker thermal conductivity than normal aggregates. Therefore, concrete with lightweight plastic aggregates has excellent thermal dielectric properties with respect to normal concrete.

Using lightweight plastic aggregates is an environmentally friendly means to dispose non-recyclable plastic. In addition, changing the surface properties of plastic materials can increase concrete strength.

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