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Compressive Strength and Bulk Density of Concrete Hollow Blocks (CHB) with Polypropylene (PP) Pellets as Partial Replacement for Sand

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Abstract

Plastics are non-biodegradable and the increasing generation of plastics creates a problem of disposal. One promising approach to address this problem is to find other uses for plastics after they are used. While studies on the incorporation of waste materials in concrete abound, little attention has been given to the incorporation of plastic wastes in concrete. Also, these few studies have focused on cylindrical concrete specimens – none in online published articles, to the authors' knowledge, has focused on concrete hollow blocks. The present study narrowed that gap by shifting the focus of research from the conventional cylindrical specimen to concrete hollow block. Thus, the main objective of the study was to assess the potential of concrete hollow blocks with PP pellets as partial replacement for sand. Polypropylene (PP), which is a subset of these plastics, were pelletized and incorporated in concrete hollow blocks as partial replacement for sand. Five batches of specimens, each with 0%, 10%, 20%, 30%, 40% PP replacement (by volume) were molded and cured for 28 days. The compressive strength and bulk density of the specimens from these batches were determined and compared. Results showed that, generally, compressive strength and bulk density decrease as percent replacement increases; however, it was observed that the compressive strength of the specimens from batch with 10% PP replacement were higher compared to batches with 0% PP replacement.

Keywords: Polypropylene Pellets; Compressive Strength; Bulk Density; Concrete Hollow Block.

1. Introduction

While Republic Act 9003, or the Ecological Solid Waste Management Act of 2000, has set the basis for managing solid wastes in the Philippines, it is not yet fully implemented in the country and the problems associated with solid wastes still persist [1].

Because population increases and the economy expands, solid waste generation has increased rapidly in the Philippines. For example, the national population increased from 86 million in 2005 to 100 million in 2015. It is reported by the National Solid Waste Management Commission (NSWMC) that total annual solid waste generation rate of the country is 30,000 tons/day with 26.6% from Metro Manila mostly from commercial and residential establishments [2]. This is projected to increase by 40% in the next decade. In addition, about 500 to 700 grams of solid waste per day on the average is generated by each person living in an urban area and 300 grams in rural areas. Furthermore, plastics account for 17% of the total solid waste generated in the country [3].

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As a consequence, a greater landfill area is required to dispose the wastes generated. Because the problem of solid waste disposal is exacerbated with higher population density, the problem is especially acute in urban areas [4]. One solution to this problem is recycling; however, not all solid wastes are recycled. For instance, only 8.4 percent of plastic waste is recycled in the Philippines [5]. As the quantity of waste generated increases yearly, it is therefore vital to find ways to recycle these wastes. This study offers a method of recycling plastic waste in the form of sand-substitution aggregate to masonry structures.

In recent decades, literature on the incorporation of waste materials to concrete and CHBs has been gaining popularity as waste management became more challenging. For example, a feasibility study was undertaken by Kumar on the production of fly ash–lime–gypsum (FaL-G) bricks and hollow blocks to solve the problems of housing shortage [6]. His objective was to build low-cost houses by utilizing industrial wastes. It was observed that these bricks and hollow blocks have sufficient strength for their use in low cost housing development and have potential as a replacement for conventional hollow burnt clay bricks and concrete hollow blocks. Moreover, FaL-G also reduces the dead weight and handling cost of materials in multi-storied constructions. The viability of sugar cane bagasse ash (SBA) in the construction of brick materials has also been studied [7]. It was reported that compressive and density decreases as the mix proportion of SBA increases. Ceramic waste, marble dust, granite dust, fly ash, rice husk ash, silica fume, born powder, ground-granulated blast-furnace slag, foundry waste, quarry dust, alkofile, pond ash, glass powder, palm oil fuel ash, and saw dust can also be used as partial replacement for cement, as summarized in one article [8].

Crumb rubber has also been suggested as aggregate for rubberized long hollow blocks. It was reported that it automated production of the blocks with crumb rubber is better than factory-manufactured long hollow blocks; however, one must be wary in using the blocks with crumb rubber as the addition of crumb rubber causes significant deformation and drastic reduction in compressive strength [9-11]. Another study investigated the use of copper slag and discarded rubber tire as partial replacement for aggregates where the results showed that the concrete strength and durability increased due to the presence of copper slag. Furthermore, it was suggested that concrete mix with 40% copper slag and 10% rubber tire may be suitable for construction [12]. While addition of tire rubber can cause reduction in compressive strength and tensile strength, it can improve abrasion resistance as a recent study shows [13].

There are also studies dedicated to investigating the effect of admixtures on the properties of concrete. One common admixture to concrete is fly ash. Dodson and Roberts, who patented the use of fly ash as admixture to concrete, claimed that concretes containing Portland cement, fly ash, and aggregates can attain high compressive strengths with a high proportion of fly ash compared to cement [14]. These concretes, when formulated to have a high density, may be utilized for buildings, bridges, dams, and other infrastructures similar to the conventional structural concrete. Furthermore, when the concretes are formulated to be low in density, they can be used as a lightweight thermally-insulated concrete which may be specifically suited for use as thermal insulating components of roofs and as protective coatings for a variety of substrates. In a recent study, however, it was claimed that silica fume is superior to fly ash in terms of reducing lime content and increasing C-S-H and concrete's structural compacting [15]. Another study tested another probable admixture to concrete in the form of waste latex paint [16]. Conducted in New Zealand, where a considerable volume of waste latex paint exists, it was concluded that waste latex paint was a suitable substitute for common admixtures in concrete masonry blockfill, resulting in maintained strength and improved workability. In another study, paper waste was considered as an additive to produce porous and lightweight hollow clay bricks with reduced thermal conductivity and acceptable compressive strength [17].

Concretes mixed with plastic wastes have become the subject of many studies due to their significance in helping alleviate solid waste problems and producing lightweight and low-cost concretes. A study of the pulverized PET bottles, injection molded plastics, and polythene bags as partial replacement for sand was done in the past to prove its viability [18]. The 28-day compressive strength results revealed that when sand is replaced to the extent of up to 10%, strength reduction up to 13.5% was observed. Rebeiz and Craft [19] investigated the use of resins based on recycled polyethylene terephthalate (PET) plastic waste for the production of a high performance composite material, called polyester concrete (PC). Their results showed that resins using recycled PET offer the possibility of a lower cost of materials for forming good quality PC. PC products also allow the long-term disposal of PET waste, an important advantage in recycling applications.

Another study was done to investigate the use of waste plastic (80% polyethylene and 20% polystyrene) as aggregate replacement in concrete mixtures [20]. The study concluded that the incorporation of waste plastic in concrete arrests the propagation of micro-cracks ensuring the feasibility of waste plastic as a low-cost substitute for sand aggregates. A similar study was also conducted to determine the potential of using plastic bottle waste (made of polyethylene terephthalate) as a partial aggregate substitute to sand [21]. It was concluded that plastic bottles shredded into small particles may be successfully incorporated into concrete mixes as a sand-substitution aggregate. Moreover, it was pointed out that these resulting composites would help alleviate some solid waste problems in addition to being low cost. Frigione [22] studied substituting waste unwashed PET bottles (WPET) to an equal 5% by weight of natural sand as fine aggregate. He found that the WPET concretes display similar workability characteristics, slightly lower compressive strength and splitting tensile strength than that of the reference concrete and a moderately higher ductility.

To a lesser extent, some studies on the incorporation of other types of plastic have been done as well. For a comprehensive review of the use of different forms of plastic in concrete, the reader is directed to the article by Sharma and Bansal [23].

While the above literature investigated the feasibility of integrating waste materials in concrete, much still needs to be studied. First, almost all the studies investigated only one type of waste plastic (PET) [18, 21, 22, 24], and other types of plastic such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polystyrene (PS), polypropylene (PP), were hardly investigated [23]. Moreover, most studies involving plastic wastes used cylindrical or prismatic specimens, and none has focused on actual hollow blocks. This study narrowed that gap by shifting the focus of research from the conventional cylindrical specimen to concrete hollow block, which is the most commonly used building material.

The study was conducted to answer the following research question: Can PP pellets be incorporated in hollow blocks to make them lighter without compromising their compressive strength?

The main objective of the study was to assess the potential of concrete hollow blocks with PP pellets as partial replacement for sand. Specifically, this study aimed to:

1. Determine and analyze the effect of incorporating PP pellets on the compressive strength of concrete hollow blocks,
2. Determine and analyze the effect of incorporating PP pellets on the bulk density of concrete hollow blocks, and
3. Determine the optimum percent replacement of PP pellets.

By directly confronting the challenge of what to do with the millions of tons of plastics that are generated (and wasted) in the country annually, this study is a basic and preliminary step in solid waste engineering, which is essential in attaining economic and ecological sustainability in infrastructure, industry, and development.

2. Materials and Methods

2.1. Research Design

Figure 1. summarizes the methods of the experiment. Two tests were performed before mixing the hollow blocks: determination of specific gravity test and sieve analyses of aggregates. The specific gravity of each material was determined and became the basis for mixing. Sieve analysis was performed for the sand and PP pellets to assess the gradation of these materials. These tests were performed in the Civil Engineering Department laboratory of the University of the Philippines Los Banos. After performing the preliminary tests, forty (40) specimens of 4”x8”x16” nominal size CHB were prepared and tested for compressive strength and dry density tests. Eight specimens per batch were prepared for compressive strength tests and three specimens per batch were prepared for dry density tests. Each batch was composed of specimens having a specific mix proportion. Five mix proportions (0%, 10%, 20%, 30%, and 40%) by volume were designed. Each specimen was cured and air-dried for 28 days, stored in a place where it can be monitored frequently, and then transported to the laboratory for testing. From the results, discussions focused on the effect of PP pellets to the compressive strength and dry density of the hollow blocks. Conclusions were stated to assess whether the objectives are met.

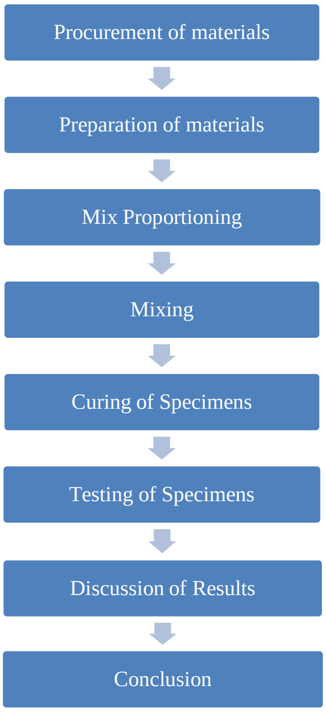

Figure 1. Research Design

2.2. Materials

The main materials used in this study were as follows: water, cement, white sand, and PP pellets. This study uses apparently clean tap water from the laboratory for mixing and curing. The specific gravity of water was taken to be 1.00. Type I Portland cement was sourced from a local hardware. Sand as aggregate was used and dried before determining the specific gravity and before mixing until saturated surface dry (SSD) condition was achieved. The PP pellets that was derived from waste plastics were sourced from a manufacturing company in Metro Manila. Figure 2 shows the PP pellets used in this study.

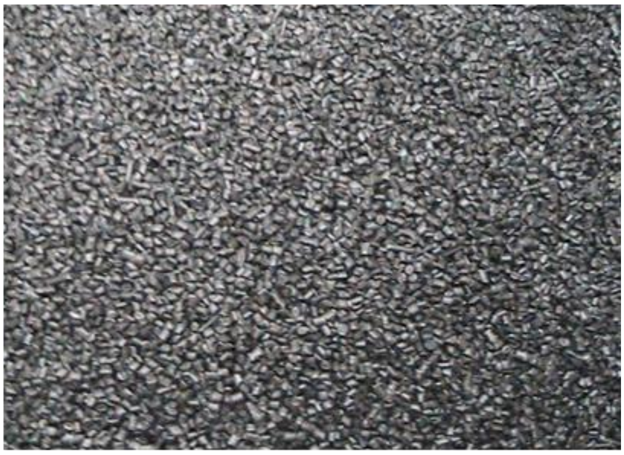

Figure 2. Polypropylene Pellets

Pellets larger than $4.75\,mm$ were excluded because such large size may affect the strength of the specimen considerably. The particle size distribution of the pellets (Figure 3) was determined by sieve analysis and the finest modulus was determined to be 4.86. The specific gravity of the pellets was determined by volume displacement method, based on Archimedes' Principle. The density of the object was then obtained by dividing the mass of the fluid with its volume. The specific gravity was computed by dividing the density (in g/mL) of the fluid with the density of a standard, which is water, and since the density of water is just $1\ g/mL$, the specific gravity of the object is just numerically equal to its density. The fluid used was alcohol because the pellets float on water. Three trials were performed and the average was taken as the specific gravity of the pellets. The value obtained was 0.89.

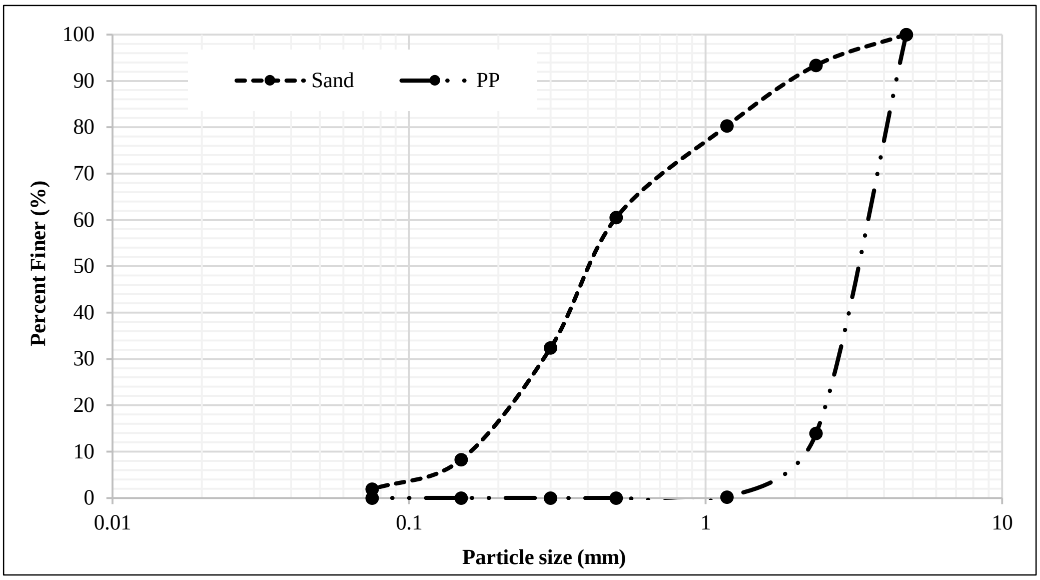

Figure 3. Gradation curve of aggregates

2.3. Experimental Treatments

In general, the study compared hollow blocks with four different levels of PP added (in place of sand) to that of conventional hollow blocks. For the control hollow blocks, the water-cement ratio was set at 0.50, and the cement to sand ratio was set at 1: 5 (by volume). For the experimental hollow blocks, 10%, 20%, 30% and 40% by volume of PP were added as shown in Table 1.

Table 1. Masses (in kg) of each material per m^3 of mortar corresponding to a mix proportion

Material	Mix proportioning by volume				
	A (0%)	B (10%)	C (20%)	D (30%)	E (40%)
Water	207.9	193.7	178.5	162.1	144.4
Cement	415.8	387.4	356.9	324.1	288.8
Sand	1610.6	1500.5	1382.4	1255.4	1118.4
PP	0.0	60.8	126.1	196.3	272.0
Total	2234.3	2142.5	2043.9	1937.9	1823.5

2.4. Preparation of specimens

After designing the mix proportion of the materials, the materials were mixed in a concrete mixer. The masses of each material were overestimated to account for spillage during mixing. Forty (40) specimens of $100 \times 200 \times 400\ mm$ nominal size hollow blocks were molded and cured for 28 days. Twenty-five (25) of these blocks were tested for compressive strength and 15 were tested for bulk density. The number of specimens for each test was divided equally into five batches with different mix proportions according to percent replacement of PP. A sample specimen is shown in Figure 4.

Figure 4. CHB with 40% PP replacement

2.5. Test of Specimens

The preliminary tests done before mixing were specific gravity determination, fineness modulus determination, and sieve analyses. The bulk densities of three specimens per batch were determined according to ASTM C127 (American Society for Testing and Materials, 2006) [25]. Figure 5. shows the set-up for determining the mass of the specimen in water: a specimen is suspended in a weighing scale and dipped into a basin filled with water. The representative bulk density of each batch was taken as the average of the bulk densities of the three specimens in the batch.

Figure 5. Set-up for density measurement

The compressive strengths of five specimens per batch were determined in accordance with ASTM C140 (American Society for Testing and Materials, 2006) [26]. Shown in Figure 6 is one specimen undergoing testing in a Universal Testing Machine (UTM).

Figure 6. Set-up for compressive strength test

The representative compressive strength of each batch was taken as the average of the compressive strengths of the five specimens in the batch. Figure 7. shows the concrete hollow block specimens tested for compressive strength at failure.

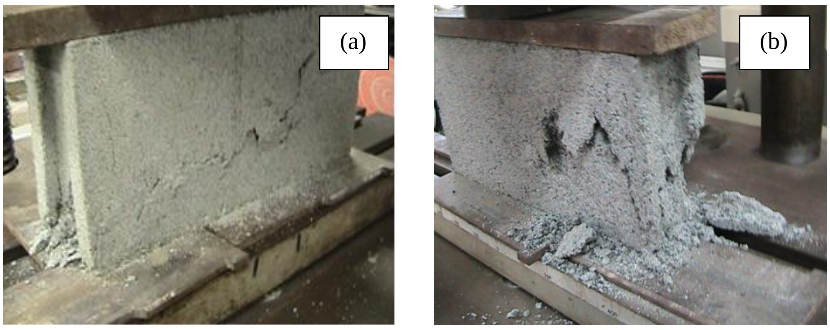

Figure 7. Concrete hollow blocks at failure: (a) 0% replacement, (b) 30% replacement.

To further evaluate data obtained from measuring the bulk density and compressive strength test, statistical analysis was performed. F Test Using One Way ANOVA technique was used to determine if at least one batch differs from the control. Pairwise Mean Comparison was also employed to determine which pairs of data are different.

3. Results and Discussion

3.1. Specific Gravity and Fineness Modulus

Before mixing the different materials used for concrete hollow block making, the specific gravity of water, sand, cement, and PP pellets were first determined. Likewise, the fineness moduli for sand and PP pellets were also determined prior to mixing. Table 2 summarizes the result of the specific gravities and fineness moduli of the materials for this study.

Table 2. Specific gravities and fineness moduli of the materials

Material	Specific Gravity	Fineness Modulus
Water	1.00	
Cement	3.15	
Sand	2.44	2.25
PP	0.89	4.86

3.2. Compressive Strength

Compressive strength generally decreases almost linearly as percent replacement of PP increases (Figure 8). The decrease in strength is expected and can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste [20]. Plastic is considered hydrophobic, which restricts the flow of water necessary for hydration of cement. This restriction makes the curing process less effective. Furthermore, increase in PP pellets also increases the probability of localized cracking. The trend of decreasing compressive strength has also been observed in other studies [18, 20, 22, 23]. Nonetheless, the compressive strength increased at 10% PP replacement. This increase can be attributed to the pellets which also contributed in resisting the compressive load. Moreover, the pellets must have been distributed evenly so localized failure was not observed.

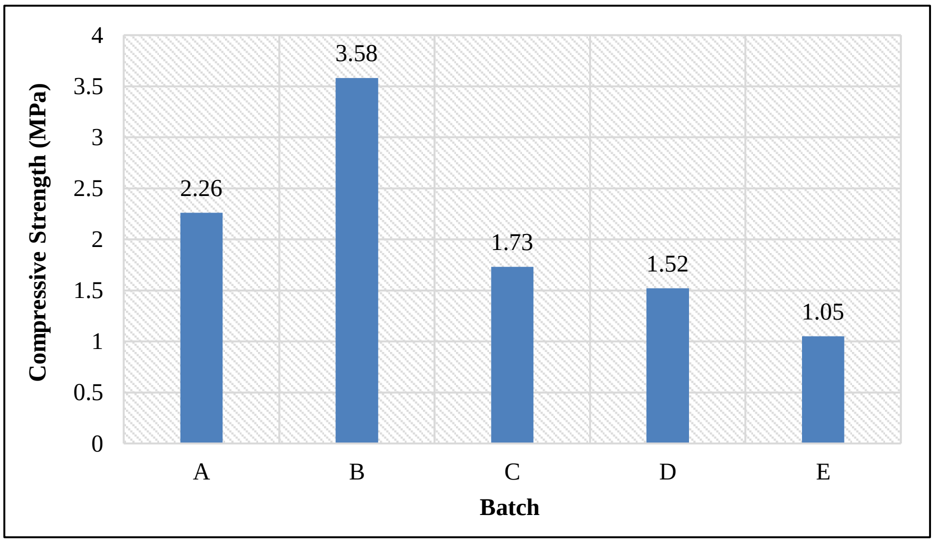

Figure 8. Compressive Strength of Hollow Blocks per Batch

3.3. Density

The values indicate the bulk density of the specimens and not the dry density because the specimens were not oven-dried during testing. However, the bulk densities may approximate the dry densities because the specimens were air-dried for more than 48 hours before testing.

Results showed that unit weight decreases as percent replacement of PP is increased (Figure 9). The decrease in weight can be explained by Law of Mixtures. The properties and composites are influenced by a confluence of factors, one of which is the proportions of the matrix and reinforcement making the composite [27].

When the Law of Mixtures is applied to this study, the addition of the PP, which is the lightest component in the mix, naturally made the resulting hollow block lighter. This result is also consistent with the findings of previous study [20], albeit the waste plastic used is PET and not PP.

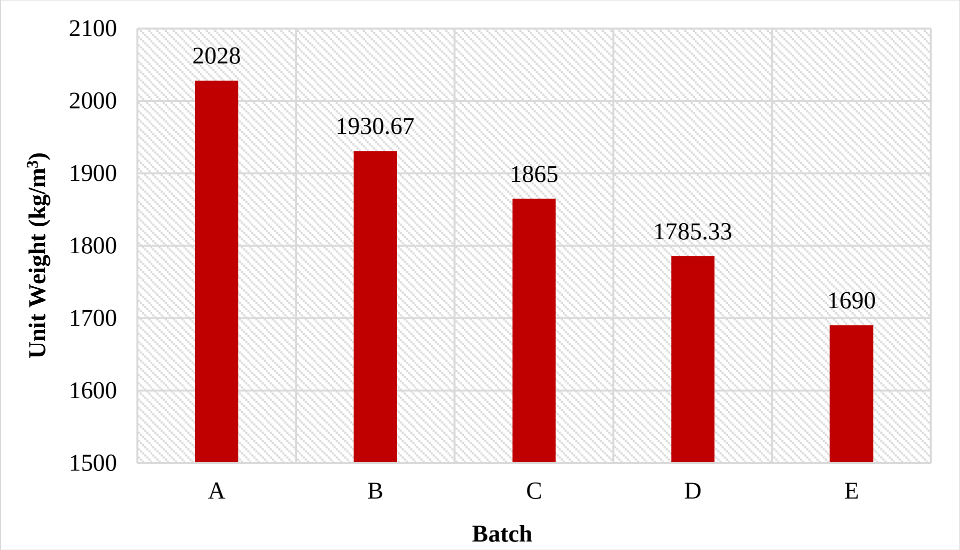

Figure 9. Bulk density of hollow blocks per batch

4. Statistical Analysis

To further evaluate data obtained from measuring the bulk density and compressive strength test, statistical analysis was performed. F Test Using One Way ANOVA technique was used to determine if at least one batch differs from the control. Pairwise Mean Comparison using Duncan's Multiple Range Test (DMRT) was also employed to determine which pairs of data are different.

Result of the F Test using One Way ANOVA shows that at least one batch is different from the rest with a p-value of < 0.0001. Likewise the results of the pairwise mean comparison using DMRT are shown in Table 3 and 4. Results show that for compressive strength, batch B is different from the rest; batches A and E are different (Table 3). For bulk density, results showed that batch A is different from the rest; batch B is different from D and E; batches C and D are different from batch E (Table 4).

Table 3. Grouping of batches using DMRT with compressive strength as response variable

Batch	Replacement (%)	Mean (MPa)	DMRT
A	0	2.26	B
B	10	3.58	A
C	20	1.73	BC
D	30	1.52	BC
E	40	1.05	C

Table 4. Grouping of batches using DMRT with bulk density as response variable

Batch	Replacement (%)	Mean (kg/m^3)	DMRT
A	0	2028.00	A
B	10	1930.67	B
C	20	1865.00	BC
D	30	1785.33	C
E	40	1690.00	D

5. Selection of the Best Mix

From the results, batch B can be considered as the best mix from the standpoint of compressive strength and batch E can be considered as the best mix from the standpoint of bulk density.

To choose which of the two batches B and E is better, batch B should be assessed for bulk density and batch E should be assessed for compressive strength. Results showed that among the batches, batch E has the lowest compressive strength. Statistical analysis has also shown that the compressive strength of batch E is different from batch A, and the compressive strength of A is different from B. The compressive strength of B is therefore different from E on two levels; thus, its higher compressive strength gives it a large advantage over E. For bulk density, results showed that batch A, not batch B, is the worst mix. Moreover, statistical analysis has shown that batch B is different from batch A. Therefore, the 10% replacement of waste plastic made the bulk density of the hollow blocks different from the control. Statistical analysis has also shown that the bulk densities of batch B and E are different on two levels; however, compressive strength tests have shown that the compressive strength of batch E is also the weakest and well below the minimum allowable compressive strength of 3.45 MPa set by ASTM C140 [26]. Since compressive strength is compromised, the advantage of batch E being low cost is not enough for it to be considered in structural applications. Therefore the advantage of batch B having the higher compressive strength than batch E outweighs the advantage of the latter having the lower bulk density than the former. Thus, batch B can be concluded as the better mix.

It is also necessary to compare batch C with batch B because while batch B has the higher compressive strength than batch C, batch C has the lower unit weight. Statistical analysis has shown that the compressive strength of batch B is different from the rest, including batch C. In contrast, the bulk densities of batches B and C are not significantly different. Therefore, the benefits of batch C being the lighter are marginal, but the benefits of batch B, being the material with higher compressive strength is significant.

Another consideration in the selection of materials is its environmental implications. Obviously, a higher percent replacement of PP to the CHB will be more beneficial to the environment. However, it was determined from the tests that the compressive strength will be significantly compromised when shifting from batch B to C.

From the above discussions, we can conclude that batch B is the best mix because it has the highest compressive strength. It has even yield a much higher compressive strength (58.4% higher) compared to the control specimen. Additionally, the bulk density of Batch B is less than that of the control which makes it lighter and more beneficial to the environment, particularly the problem of waste disposal.

6. Conclusion

The study aimed to investigate on the compressive strength and bulk density of concrete hollow blocks with PP pellets as partial replacement for sand. From the tests, it can be concluded that waste plastic to the extent of 10% can be incorporated in hollow blocks to make them lighter and even increase its compressive strength.

The study also concluded that batch B is the best mix because it has the highest compressive strength. It has even yield a much higher compressive strength (58.4% higher) compared to the control specimen. The study also found out that the bulk density of Batch B is less than that of the control which makes it lighter and more beneficial to the environment, particularly the problem of waste disposal.

In general, the study concluded that as the % replacement of sand with PP pellets increases, the compressive strength and the bulk density of hollow block decreases, thus it would suffice to say, that the % replacement of PP pellets is inversely proportional to the compressive strength and the bulk density of the concrete hollow block.

Based from the above findings, the authors recommend for further investigation focusing on testing other mechanical properties of concrete hollow blocks and testing hollow blocks mixed with other waste materials.

7. Acknowledgment

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