Concrete Hollow Block Production Using Fine Aggregates of Polyvinyl Chloride and Polystyrene

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Abstract

Population concurrently grows with demand for food and infrastructure, which are associated with plastic waste mismanagement and concrete hollow block (CHB) consumption, respectively. However, there is a dearth in the utilization of plastic pellets using polyvinyl chloride (PVC) and polystyrene (PS) in CHBs. Hence, this study aimed to characterize PVC and PS pellets, and evaluate and compare their potentials when incorporated as fine aggregates in CHBs in terms of workability and compressive strength. The pellets were characterized and used as a substitute to sand resulting in four batches of CHB specimen with 0, 10, 20, and 30% by volume of each pellet. Results revealed that PVC absorbed more and sank in the water while PS absorbed less and floated in water. The workability of both experimental groups increased as the substitution of pellets was increased. The compressive strengths of the PVC group dropped linearly with increasing pellet substitution and less than the minimum acceptable value. The batch with 30% PS pellets resulted in the highest compressive strength of 3.66 MPa among the experimental groups and greater than the minimum acceptable value of 3.45 MPa. Results implied that the incorporation of PS pellets in CHBs can be a promising solution to the plastic waste mismanagement and demand for stronger CHBs.

***Keywords**:* plastic utensil, wire cable insulation, slump value, compressive load, mass concrete

1. Introduction

The effects brought about by exponential population growth have been ubiquitous worldwide. One effect is the growing statistics in the demand and consumption of the fundamental needs of human beings such as food and shelter. However, the processes underlying food production and materials for infrastructure as well as their preservation greatly contribute to a multifold and alarming increase in waste products.

The utilization of plastic materials in manufacturing, storing, and preserving foods are evident. Plastic materials are present in these processes in various forms and types. The benefits of using plastic in these processes come with the alarming effects on the environment (Sharma and Bansal, 2015). One of which is the staggering report on plastic debris in the ocean which was recorded to be 5.25 trillion pieces already (Parker, 2015) with a rate of 8 million trashes from 192 coastal countries (Dunham, 2015; Parker, 2015).

The Philippines ranked third in the list of coastal countries intensely contributing to plastic pollution around the globe (Dunham, 2015; Ocean Crusaders, 2020). The country dumps 125, 000 bags of plastics each day (Arkin, 2015) aggregating to 1.88 million tons of plastic wastes each year (Agence France-Presse, 2017). This was represented by the weekly Greenpeace Coastal Clean Up in September 2017 at the Manila Bay wherein 54, 200 pieces of plastic waste – materials from products sold by conglomerates like bags, bottle labels, sachet, and straws which were relevant to three identified companies – were recovered (Agence France-Presse, 2017). The country's current battle with plastic mismanagement urged various organizations and local government units (LGUs) to set forth policies and projects to put this to an end (Arkin, 2015). Some LGUs act by implementing policies in partnership with different companies and organizations (R. D. L. Peneyra, personal communication, November 3, 2018).

Aside from food, the exponential demand for shelter and infrastructure entails the rise in the need for construction materials with sufficient fresh and strength parameters to withstand any topographical and environmental risks and disasters such as typhoons and earthquakes. According to Reddy and Kolasani (2015), water and concrete hollow blocks (CHB) are the top two of the most consumed substances on earth. These materials are in great demand particularly in the industrial sector for infrastructural projects.

Innovations have been established to replace the aggregates of different materials and improve the parameters of CHB such as compressive strength, workability, tensile strength, and flexural strength among others (Gardner *et al.*, 2015; Senhadji *et al.*, 2015; Manjunath, 2016; Pešić *et al.*, 2016;

Gregorova *et al*., 2017; Hama and Hilal, 2017; Khalil and Khalaf, 2017; Lasco *et al*., 2017; Patel and Dala, 2017; De Jesus *et al*., 2018; Nguyen *et al*., 2018; Hameed and Ahmed, 2019). Generally, fresh and strength parameters of concrete increase almost linearly as the percentage of replacement increases (Sharma and Bansal, 2015; Babafemi *et al*., 2018). The studies have established the fact that the replacement of concrete constituents affects the concrete's fresh and strength parameters.

Among the innovations in CHB production, replacing fine aggregates with plastic waste materials abound in the scientific society to solve both the need for stronger CHB and solutions for recycling plastic wastes. The replacement of fine aggregate with polypropylene pellets (PP) is the only local study that maximized pellet materials in the Philippines using nominal size CHB 4" x 8" x 16" and following the standards for CHB in the country (Lasco *et al.*, 2017). However, studies that maximize the use of other types of plastic materials like low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and polystyrene (PS) (Lasco *et al.*, 2017) are scant. As recommended by Lasco *et al.* (2017), extensive investigation on the use of different types of plastic wastes aside from PP and measurement of other strength parameters should be carried out. Thus, the present study characterized PVC and PS pellets as CHB reinforcement; determined the effects of varying percentage replacement of fine aggregate with PVC and PS pellets on the fresh and strength parameters of CHB such as workability and compressive strength; and compared the PVC- and PS-blended CHBs' fresh and strength parameters.

2. Methodology

The study used an experimental research design. Materials were acquired from the local hardware in Silang, Cavite, Philippines. The materials were prepared based on the characterization and computed amount of each material before mixing. The mixing of each material for each batch was done in a construction site in Silang, Cavite. The fresh parameter of each batch was tested in situ after acquiring a wet mixture. The specimens were then cured in preparation for the measurement of strength parameter done at the laboratories of the College of Engineering, Architecture, and Technology (CEAT) of De La Salle University – Dasmariñas (DLSU-D).

2.1 Materials Preparation

The raw materials used were water, cement, white sand, PVC pellets, and PS pellets. Commonly used for mixing and curing, the clean tap water was from the CHB manufacturing site in Silang, Cavite. The specific gravity was taken as 1.00. The cement used was Type 1 Portland cement purchased from a local supplier. White sand as the fine aggregate was characterized and prepared until a saturated surface dry condition was achieved. The PVC pellets were thermoplastic pellets previously used as wire cable insulation obtained from a junk shop in Silang, Cavite, wherein ground residual wastes from electronics companies in the place are received. The PS pellets were in the form of plastic cutlery wastes from the same junk shop. These cutleries were ground in a grinding machine to achieve pellet size. These pellets in Figure 1 underwent sieve analysis using American Society for Testing and Materials (ASTM) E11-20 (2020) sieve plate number 04 with an aperture of 4.75 mm (Milano, Italy). Pellets with sizes larger than 4.75 mm (> 4.75 mm) were excluded as it may affect the strength parameters of the specimen (Lasco *et al.*, 2017). These materials were characterized in terms of density and specific gravity using Archimedes' Principle (Lasco *et al.*, 2017), bulk density following ASTM D1895-17 (2017), and absorption for 24 h following ASTM D570-98 (2018), which became the bases for mixing. The fluid used in the characterization of PVC pellets was distilled water while isopropyl alcohol was utilized for PS pellets due to the difference in specific gravity.

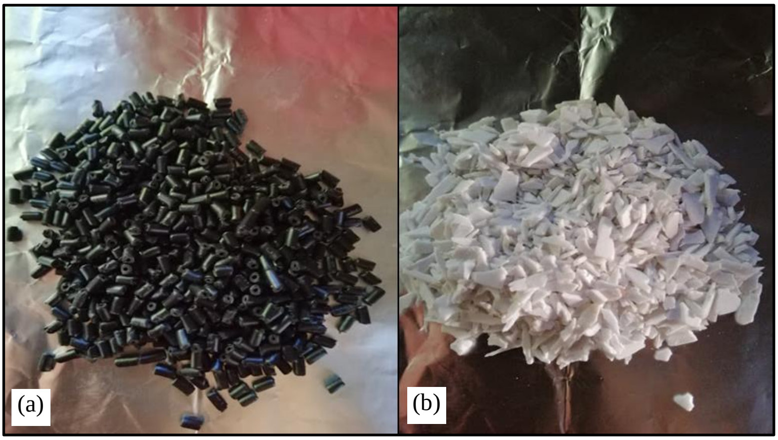

Figure 1. PVC pellets from wire cable insulation (a) and PS pellets from plastic utensils (b) ground using grinding machineries

The materials were mixed to form the test specimens. Four batches each were prepared for PVC- and PS-blended CHBs: batch 1 (0%), batch 2 (10%), batch 3 (20%), and batch 4 (30%) (Lasco *et al.*, 2017). Batch 1 served as the reference group wherein all other batches were compared with. The distribution and measurement of each raw material based on the characterization for each batch are shown in Table 1.

Table 1. Masses (kg) of each CHB constituent per cubic meter (m^3) corresponding to a mixed proportion (adapted from Lasco *et al*., 2017)

Material	Mix proportion by volume per batch of PVC and PS concretes			
	1 (0%)	2 (10%)	3 (20%)	4 (30%)
PVC Fine Aggregates				
Water	91.65	82.50	73.30	64.15
Cement	197.61	177.88	158.05	138.32
Sand	1132.91	1019.68	906.33	793.10
PVC	0	123.31	246.61	369.99
PS Fine Aggregates				
Water	91.65	82.50	73.30	64.15
Cement	197.61	177.88	158.05	138.32
Sand	1132.91	1019.68	906.33	793.10
PS	0	95.72	191.44	287.22

For each batch, five test specimens were made to maintain objectivity and attain precision. This resulted in a total of 35 test specimens. The materials were mixed with the cement to the sand ratio of 1:5 by volume and water-cement ratio of 0.50 by volume. The test specimen mixtures were molded into a 4” x 8” x 16” nominal size of CHBs (Lasco *et al.*, 2017) using a molder. Overestimation of materials was done with the help of the owner and expert in CHB manufacturing from Silang, Cavite to account for spillage during the mixing process.

2.2 Test of Specimens

The workability was tested following standard test method for slump of hydraulic cement concrete conforming to ASTM C143/C143M-20 (2020). Compressive strength was tested using the universal testing machine (UTM) for the standard test for sampling and testing concrete masonry units and related units following ASTM C140/C140M-20a (2020). The compressive strength test was done under the supervision of the technical support personnel and laboratory technician of CEAT in DLSU-D. The results were reviewed and certified by a civil engineer specializing in structural engineering.

The data gathered for the parameters from batches 2 to 4 were compared with batch 1. The data analyses were focused on determining if at least one batch was different from the reference group using one-way analysis of variance (ANOVA). Pairwise mean comparison was then utilized to determine which pairs of data were significantly different. All statistical analyses were done at a 5% probability level.

3. Results and Discussion

3.1 Characterization of Fine Aggregates

The sand and plastic concrete reinforcements in CHBs were compared in terms of their physical characteristics (density, specific gravity, bulk density, and absorption rate). Table 2 shows the result of the characterization of the fine aggregate. These values were used in the mixing of the constituents of CHBs and bases for the justifications in the workability and compressive strength.

Table 2. Physical properties characterization of sand and plastic concrete reinforcements

Material	Density (g/cm^3)	Specific Gravity	Bulk Density (kg/m^3)	Absorption (%)
Sand	2.43	2.43	1236.13	1.00*
PVC	1.35	1.35	1345.40	0.91
PS	0.96	0.96	958.23	0.09

*characterization of average water absorption of white sand from (Mishra, 2020)

As shown in Table 2, white sand and PVC aggregates sank in the water while PS aggregates floated otherwise. Moreover, the PVC had a greater absorption ability than PS which were both lower than that of the white sand. This means that when the pellets were mixed with two different concrete mixtures, there was more water available in the PS mixture than the PVC mixture for hydration. Furthermore, the specific gravity of the PVC and PS pellets was higher than that of the cited literature which used PP pellets with 0.89 (Lasco *et al*., 2017). Meanwhile, the same as the sand, PVC pellets sank in the water. These, in turn, justified the fact that whether the plastic pellet sinks or floats in water, it can be a fine aggregate substitute for CHB mixture.

3.2 Workability

Table 3 shows the average measured workability or slump values (mm) of wet concrete mixtures with PVC and PS plastic as fine aggregates. Based on the results, the control group obtained the lowest slump value, and batch 4 of both plastic-blended concretes attained the highest slump values. It can also be observed that workability increased as the percentage of plastic pellets was increased (Figure 2). Moreover, the mean slump values of the concretes with PS pellets were slower than that of the PVC pellets.

Table 3. Workability (mm) of PVC- and PS- blended CHBs following the slump test (ASTM C143/C143M-20, 2020)

Batches	Workability (mm) PVC	Workability (mm) PS	Degree of Workability
1 (0%)	10.30^{A}	10.30^{A}	Very low (0 – 25 mm)
2 (10%)	14.60^{BX}	12.60^{BY}	
3 (20%)	16.30^{CX}	14.70^{BY}	
4 (30%)	21.90^{DX}	21.10^{CY}	

^{ABCD} – Treatment within each type of plastic (batches); ^{XY} – the type of plastic pellets (PVC versus PS). Different letters indicate a significant difference at the 0.05 level.

This set of data and observations confirmed the study of Choi *et al*. (2009) as cited by Khalil and Khalaf (2017), Patel and Dala (2017) and Babafemi *et al*. (2018). This trend was attributed to the lower absorption of the pellets (Table 2) resulting in a greater amount of water for the hydration of the mixture when the amount of the natural fine aggregates was reduced (Babafemi *et al*., 2018). Conversely, this result contradicts the study of Rai *et al*. (2012) as cited by Babafemi *et al*. (2018). It can be inferred that concrete mixtures with PVC pellets had greater slump values than that of the concrete mixtures with PS pellets. Such result is in contrast with the idea that if the supplement has low absorption (Babafemi *et al*., 2018), there is more amount of water available for hydration since PVC had greater absorption than PS. This can be attributed to the fact that the absorption test of PS pellets was done using isopropyl alcohol compared with PVC pellets which were immersed in distilled water.

The values from batch 1 to 4 were within the very dry mixture classification between 0 to 25 mm (The Constructor, 2018). This implies that the types of concrete formed were suitable for the roads vibrated by power-operated machines and can be compacted by hand-operated machines. Moreover, batch 4 of both plastic-blended concretes with PVC and PS pellets were in the range of 20 to 40 mm for a mixture that can be maximized for road construction. The same batch for plastic-blended concretes can be classified as a mixture for mass concrete with a workability value ranged from 20 to 50 mm (The

Constructor, 2018). Hence, the mixtures can be utilized in various massive structures such as dams, bridge piers, and canal locks among others (Kulkarni and Oluwafisayo, 2017).

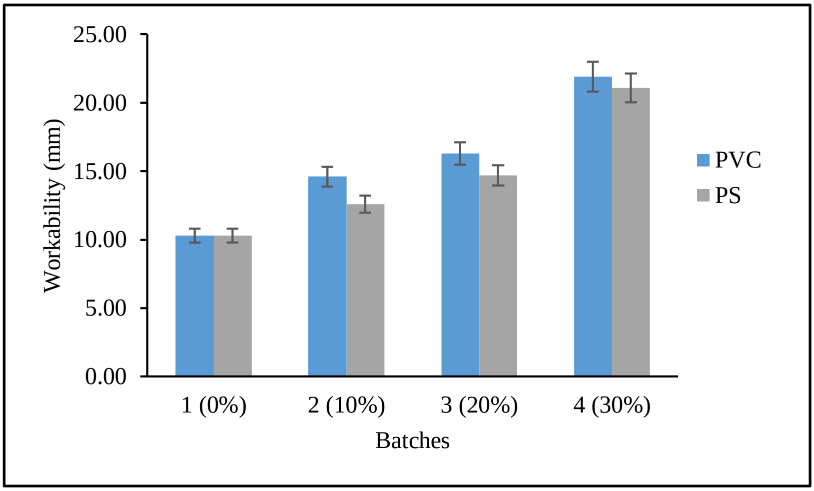

Figure 2. Workability of plastic-blended concrete with PVC and PS pellet aggregates

3.3 Compressive Strength

The compressive strength values (MPa) of plastic-blended CHBs are presented in Table 4 following ASTM C140/C140M-20a (2020). These values show the maximum pressure or strength that the test specimen can withstand.

Table 4. Compressive strength (MPa) of PVC- and PS-blended CHBs following C140/C140M-20a (2020)

Batches	Compressive Strength (MPa)	
	PVC	PS
1 (0%)	3.78^{A}	3.78^{A}
2 (10%)	3.08^{BX}	3.46^{AY}
3 (20%)	2.58^{BCX}	3.28^{AY}
4 (30%)	2.20^{CX}	3.66^{AY}

^{ABCD} – Treatment within each type of plastic (batches); ^{XY} – the type of plastic pellets (PVC versus PS). Different letters indicate a significant difference at the 0.05 level.

Based on the results, it can be seen that batch 1 attained the maximum compressive strength. For CHBs with plastic pellets, batch 4 (30% PVC pellets) and batch 3 (20% PS pellets) attained the weakest compressive strengths within their respective experimental groups. Meanwhile, batch 2 (10% PVC pellets) and batch 4 (30% PS pellets) obtained the strongest compressive strength within their respective experimental groups. It can also be observed that the compressive strength dropped almost linearly from batch 1 to 4 of PVC-blended CHBs and minimal differences between the compressive strength of PS-blended CHBs compared with the control group (Figure 3). Thus, with these results, it is worth noting that the sets of data can be analyzed separately.

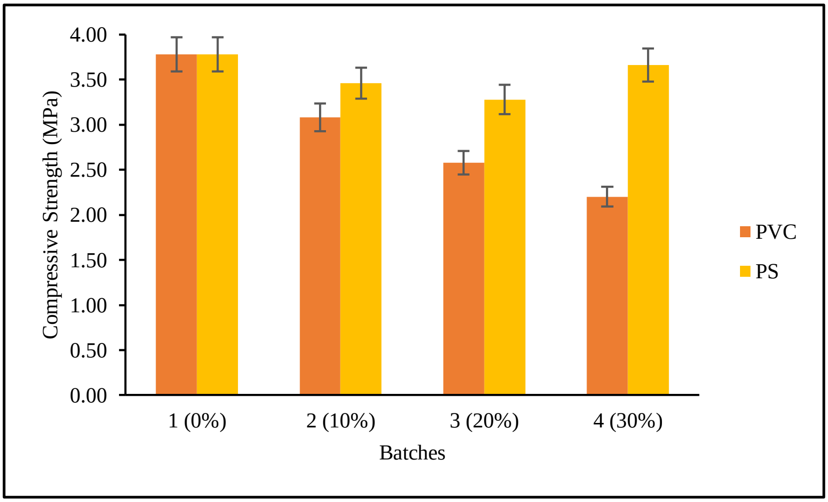

Figure 3. Compressive strength of plastic-blended concrete with PVC and PS pellet aggregates

Statistically, there was a significant difference (p < 0.05) between the compressive strengths of the treatments on the PVC-blended CHBs. Among the experimental group, batch 2 (10% PVC pellets) was able to withstand the maximum pressure which confirmed the work of Lasco *et al.* (2017). This is ascribed to the minimal amount of incorporated plastic which can still resist the compressive load.

The compressive strength of CHBs partially replaced with PVC pellets generally dropped from batch 1 to 4 nearly linear. This suggests that the probability of localized cracking of the specimens increased as the percentage replacement was increased up to 30%. This trend of findings is in agreement with Khalil and Khalaf (2017) and Patel and Dala (2017). Meanwhile, this result reversed the trend observed in other studies (Rahmani *et al*., 2013; Yang *et al*., 2015; Azhdarpour *et al*., 2016) in which it was contended that the increase of the compressive strength can only be observed if there is a small amount of partial replacement of plastic aggregate in the CHB mixture.

The dropped trend of the compressive strength or the localized cracking of the test specimens after being subjected to UTM was attributed to three common reasons. First, there is a decrease in the adhesive force between the surface of the waste plastic and cement paste (Lasco *et al*., 2017). Second, it is the nature of plastic to be hydrophobic which can restrict the flow of water which in turn made the curing period of the CHBs less effective. Third, the aforementioned reasons result in lower strength in the interfacial transition zone (ITZ) of the CHBs (Sharma and Bansal, 2015) and greater probability of having an increase in the matrix porosity; thus, decreasing the specimen density and compressive strength (Senhadji *et al*., 2015).

Meanwhile, there was no significant difference ($p > 0.05$) between the compressive strengths of the PS-blended and the locally manufactured CHBs. Hence, it can be inferred that the PS-blended CHBs were at par with the control group in terms of strength. The CHBs with the maximum percentage of plastic pellets incorporated were able to resist the maximum load among the experimental group it belonged to. This result contradicted the findings from PVC pellets experimental group whose maximum load was withstood by batch 1 (10% PVC pellets). This is also in contrast with the results of Lasco *et al*. (2017). Thus, PS pellets from plastic utensils can be utilized in a greater percentage suggesting that a possible solution in solving problems in plastic waste mismanagement of PS type of plastic and the demand for stronger CHB in the infrastructure industry.

Lastly, the compressive strengths achieved by both experimental groups were less than the control group with a mean value of 3.78 MPa. Such value was greater than the minimum acceptable value of 3.45 MPa set by ASTM C140/C140M-20a (2020) (Lasco *et al*., 2017).

4. Conclusion and Recommendation

The fine aggregates used to partially replace the sand as natural aggregate were characterized in terms of density, specific gravity, bulk density, and absorption. PVC had a greater absorption ability than PS which both were lower than that of the white sand. PVC pellets absorbed more than PS pellets.

Hence, the PS-concrete mixture had more water for hydration than the PVC-concrete mixture.

The study also revealed that the workability in terms of slump values of fresh concrete mixtures increased linearly as the percentage replacements of both PVC and PS pellets increased. This observation is linked to the pellet absorption that resulted in more water for plastic-blended mixtures hydration. Both slump values of PVC- and PS-blended CHBs are qualified for roads vibrated by power-operated machines and can be compacted by hand-operated machines. Further, both batch 4 of plastic-blended CHBs are apt for massive structure utilization such as dams, bridge piers, and canal locks among others.

The experimental groups yielded different results in terms of compressive strength. The compressive strength in the experimental group with PVC pellets decreased as the percentage replacement of plastic aggregate increased. Meanwhile, the compressive strengths of CHBs incorporated with PS pellets were statistically equal to that of the control group. This implies that the PS-blended CHBs were at par with the locally manufactured CHBs in terms of maximum compressive strength. The maximum compressive strength in the experimental group with PS pellets was obtained by batch 4 (30% PS pellets). The said batch attained the maximum compressive strength among the experimental groups which was less than the compressive strength of the control group and greater than the minimum acceptable compressive strength for 4” x 8” x 16” nominal size of CHB in the country. This suggests that incorporation of PS pellets in greater percentage to concrete mixtures can suffice the need for a solution for plastic waste management of PS type of plastic in its cutlery form and the demand for stronger CHBs in the infrastructure industry.

Based on the results, the following recommendations were drawn. First, further investigation on the effect of small increment of percentage replacement of plastic aggregates can be done to identify whether the large leap from 0% is a factor to take into account. Additionally, increasing the amount of plastic to greater than 30% may also be considered. Second, effects of varying water to cement ratio and mix design using either PVC or PS pellets at their best mixes for workability and/or compressive strength can be examined to identify whether these affect such parameters. Third, it is recommended to test the absorption of PS pellets in distilled water using sinkers due to the difference in specific gravity of water and PS pellets. This will help in validating the contradicting results of the cited literature and the present study. Fourth, PVC and PS in other forms and grain sizes such as fiber and flakes can also be utilized to determine if there is a significant difference in the workability and compressive strength. Fifth, other types of plastic wastes or residual wastes can be further maximized to solve plastic waste management and provide potential solutions for the demand for stronger CHBs in the country. Lastly, the effects of using plastic as fine and/or coarse aggregates and investigating its effect on other physical and mechanical properties and fresh and strength parameters of the CHBs (bulk density, porosity, tensile strength, and flexural strength) may be carried out.

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