University of Thi -Qar Journal for Engineering Sciences
https://doi.org/10.31663/tqujes13.1.463(2023)
Vol 13.1(January2023)

ISSN :2664- 5572 (online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@utq.edu.iq

Production and Properties of Plastic Boxes Waste Concrete

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Abstract

Waste residues from plastic crates used to transport fruit pose a serious environmental threat. In this paper, we investigated the use of this kind of waste in the production of green concrete. This study showed the effect of plastic boxes waste (PBW) on concrete properties. PBW was used as aggregate instead of fine aggregate (sand). Six mixtures containing varying amounts of PBW particles (5%, 10%, 15%, 20%, 25%, and 30%) were prepared in addition to a control mixture. The effects of PBW on concrete properties were evaluated using compressive strength, flexural strength, splitting tensile strength, density, water absorption, and ultrasonic pulse velocity (UPV). The use of plastic trash cans has a negative impact on the strength of concrete. Although the addition of plastic waste aggregates reduces the mechanical properties of concrete, using such wastes reduces the environmental impact of plastic waste and preserves natural aggregates for the future. Environmentally friendly concrete can be manufactured. However, a significant decrease in density was observed. Ultrasonic velocities were declined, indicating that this type of concrete is suitable for structural insulation. In addition, the study showed relationships between concrete properties. In this study, an upper limit for PBW content was proposed. The inclusion of this type of aggregate is a potential solution to the plastic waste problem and may improve concrete properties.

Keywords: Plastic box waste, mechanical properties, replacement ratio, compressive strength, flexural strength

1. Introduction

Engineering materials exhibiting desirable characteristics and adaptations for special purposes or use cases tend to be commonly used **[1]**. Annually, huge amounts of plastics are discarded. Moreover, plastics are difficult to dispose of, and large quantities of plastics cause an environmental problem **[2]**. In 2016, 335 million tons of plastic were manufactured globally, and 31.1% of the plastic produced was recycled **[3]**. There are many methods to reduce the impact of this problem, including the use of plastic waste as a building material **[4]** or in concrete technology**[5, 6]**. Plastic waste aggregates were utilized in production of sustainable concrete by replacement of coarse or fine aggregate. The use of plastic waste as aggregate in concrete affected concrete properties. Kore **[7]** has blended recycled plastics with concrete as a fine aggregate substitution. The flowability, compression, splitting tensile, and flexural strengths of concrete mixtures were investigated. The fragments of the plastics came in a wide variety of configurations and dimensions, with lengths ranging between 0.15-12 mm and thicknesses ranging between 0.15-4 mm. The fine aggregate was replaced by 5, 10, 15, 20 and 25% by weight of waste particles. Using plastic aggregate as a replacement material for sand reach to 10% substitution levels produce progress in fresh property and density while the mechanical characteristics, such as compression, tensile, and flexural strengths, were slightly lowered. Sexana et al. [8] reported that the use of plastic aggregates (small and large) from PET (polyethylene terephthalate) bottles increased the ductility of concrete and improved its impact resistance. Moreover, the higher plastic energy of plastic aggregates increased the energy absorption capacity of concrete. However, even though the addition of aggregates from plastic waste reduces the mechanical properties of concrete, the use of these wastes can reduce the environmental impact of plastic waste and replace natural bone. It is possible to produce environmentally friendly concrete that preserves the material for the future. [9].

Plastic box waste (PBW) has been considered by a few researchers in relation to concrete [4, 10]. Adnan and Dawood **[4]** investigated the effect of PBW on concrete characteristics. The fine aggregate was replaced with PBW material during the manufacturing process. The PBW percentages were chosen to be 0%, 2.5%, 5% and 10% of the sand weight. The results showed that the addition of this substance affected the properties of fresh and hardened concrete. Compressive strength, modulus of rupture, and ductility were all improved by including 5% PBW, despite the low tensile strength of the concrete.

Hussain et al. [10], Plastic boxes particles (PBP) are used as coarse aggregate in concrete production. The amount of PBP was 0%, 20%, 40%, 60%, and 80% of the gravel volume. Effects were evaluated on hardness and physical properties in terms of compressive strength, tensile strength, density, and fresh properties. Despite the decline in the strength of concrete, research has shown that this type of recycled aggregate could be used to produce sustainable concrete.

In this study, different proportions of plastic boxes waste (PBW) were used to prepare concrete mixes. Different percentages of PBW were considered as replace of fine aggregate volume. The effects of PBW on mechanical properties were evaluated in terms of compressive strength, tensile strength, and flexural strength. In addition, the physical properties were investigated. Relationships between these mechanical properties are also shown.

2. Experimental Work

2.1 Materials

In this study Cubais standard Portland cement was used to produce all concrete mixes with and without PWB. The physical properties of cement were measured according to IQS5/2019 [11] and are listed in Table 1. The concrete is made using natural sand (from Ramadi city) with a maximum particle size of 4.75 mm and natural coarse aggregates (produced in Samara city) with a size of 10 mm or less. Physical property and sieve analyzes were performed according to ASTM C136 [12]. To obtain PWB particles, a vegetable and fruit storage box was broken (Fig. 1) and these plastic particles were passed through a No. 4.75 sieve to separate fine particles used as a sand substitute. The PBW used has a specific gravity of 1.34 and a maximum grain size of 4.75 mm. The sieving analysis of coarse and fine aggregates and PWB is shown in the figure. 2. Physical properties are shown in Table 2.

Table 1 physical properties of cement

Test	Result	Limitations
Initial setting (min)	125	Not less than 45 min
Final setting (min)	235	Not greater than 600 min
Compressive strength at 3 days (N/mm^2)	21	Not less than 15 N/mm^2
Compressive strength at 7 days (N/mm^2)	27	Not less than 23 N/mm^2

Fig. 1 Production of plastic box waste aggregate (PBW)

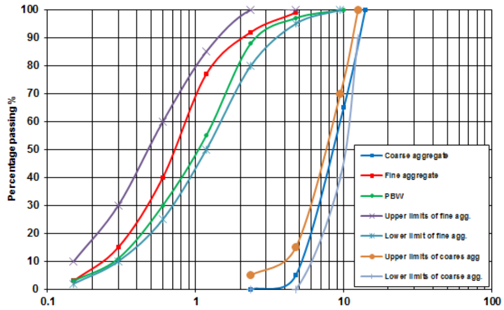

Fig.2 Particle size distribution of aggregates

Table 2 Physical properties of aggregates and (PBW).

Physical properties	Coarse aggregate	Fine aggregate	PBW
Fineness modulus	-	3.77	3.6
Water absorption %	1.1	2.37	0
Specific gravity	2.68	2.65	1.34

2.2 Mix proportions

In this study, seven concrete mixtures were prepared and cast to measure the hardened properties. The reference mixtures without PBW, consisted of cement, sand, coarse aggregate (gravel), and water, while the other six mixtures contained PBW. PBW particles were used as a substitute to replace fine aggregate (% by volume). The ratios of sand substitute to PWB were 5%, 10%, 15%, 20%, 25% and 30%, corresponding to blends 2, 3, 4, 5, 6 and 7, respectively. As shown in Table 3, the mixtures are coded according to the percentage of PBW particles they contain. For example, the mix code PB25C refers to a concrete containing 25% PBW instead of sand.

To achieve homogeneity in concrete, sand, gravel and cement with PBW particles (dry ingredients) were mixed for about one minute. After that, to prevent segregation, water was added (divided in two parts), all ingredients were mixed again for a total of three minutes. An additional 2 minutes of mixing time was allowed to ensure good mixing of the concrete components. To determine the mechanical properties, cubic samples of size 100 × 100 × 100 mm were used to measure compressive strength, water absorption, and density. Furthermore, for tensile and bending tests, a cylindrical concrete specimen with a size of 100 × 200 mm and a prismatic specimen with a size of 100 × 100 × 500 mm were fabricated [13]. After 24 hours, all concrete samples were placed in water for treatment until reaching the 7th and 28th days of the test period.

Table 3 Mix proportions of concrete (kg/m^3).

Mix	Cement	Fine aggregate	PBW%	Coarse aggregate	W
PB0C	321	716	0	1000	163
PB5C	321	680	5	1000	163
PB10C	321	642	10	1000	163
PB15C	321	606	15	1000	163

PB20C	321	570	20	1000	163
PB25C	321	535	25	1000	163
PB30C	321	500	30	1000	163

2.3 Test Procedures

In order to evaluate the influence of PBW particles on the concrete properties and the feasibility of obtaining concrete using this material, the mechanical and physical properties were analyzed considering the partial replacement of fine aggregates by PWB aggregates.

Density was calculated from a 100 mm side cube according to BS 1981: Part 114 [14]. In addition, water absorption was also tested according to ASTM C642 [15] using the same cubes. The test procedure included drying the samples for 24 hours until consecutive measurements yielded the same weight. Water absorption is determined by the ratio of the weight of water absorbed to the dry weight. Ultrasonic pulse velocity measurements were performed on a cube of size 100 mm^3 according to ASTM C597 [16].

Therefore, the compressive strength of concrete was tested according to BS 1881-116 [17]. Results were evaluated by averaging the results of her three cube samples of each mixture after 7 and 28 days. Tensile and flexural strengths were calculated using the average of three samples and tested according to ASTM C496 and ASTM C78 [18,19].

3. Results and Discussion

3.1 Density and Absorption

on the diagram. Figure 3 shows the density test results for all mixtures. The inclusion of PBW reduces the density, and this reduction is proportional to the PBW content. The lowest density is observed at 30% PBW (2115 kg/m^3).

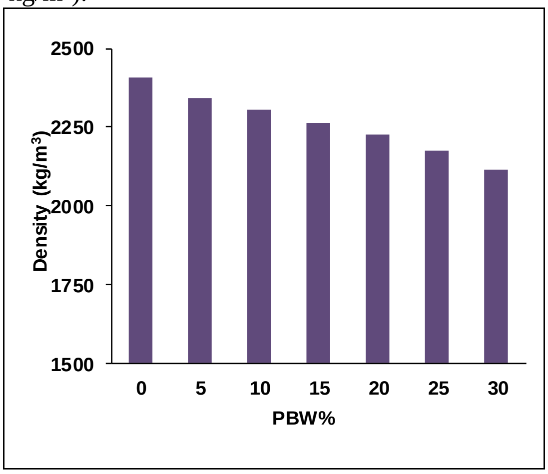

Fig.3 Results of density with respect to PBW content

Concrete density reduction values were 2.7%, 4.3%, 6.0%, 7.6%, 9.7% and 12.2%, at PBW contents were 5%, 10%, 15%, 20%, 25% and 30%. The low density of this concrete is due to the high content of PBW particles. There is a close relationship between PBW particle content and concrete density. Concrete is less dense because the PBW particles are less dense than sand.

Table 4 shows the results of density and water absorption of concrete mixes.

Table 4 Density and water absorption of concrete mixes.

Mix	Density kg/m^3	% reduction	Water absorption %
PB0C	2410	-	4.3
PB5C	2345	2.7	4.7
PB10C	2305	4.3	5.1
PB15C	2265	6.0	5.4
PB20C	2225	7.6	5.7
PB25C	2175	9.7	5.9
PB30C	2115	12.2	6.7

on the diagram. FIG. 4 shows the water sorption results of the reference mixture and the mixture containing PBW particles.

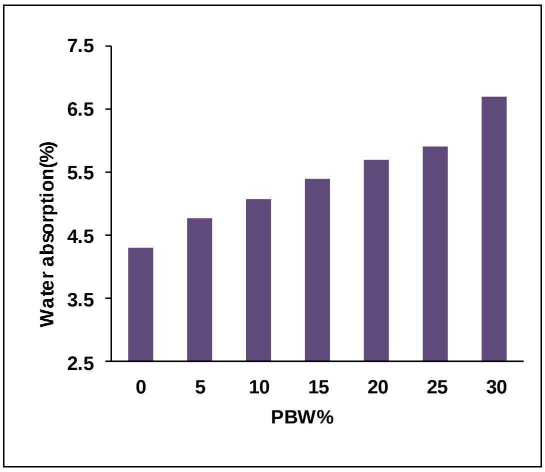

Fig.4 Results of water absorption with respect to PBW content

Water absorption is an important property of concrete as it affects the corrosion of reinforcing bars and the overall durability of the concrete. The water absorption of the concrete samples was investigated 28 days after casting. Sorption studies show that the introduction of PBW particles increases water absorption. The increased absorption is likely due to the increased porosity of the mixture containing the plastic waste particles. The lowest water absorption occurred in the reference mixture and the highest water absorption was 6.7% in the mixture containing 30% PBW particles. The absorption results are consistent with Ruiz Herrero's conclusions [20].

The relationship between density and water absorption is shown in the figure 5. It can be seen that there is a good relationship between the density and water absorption of concrete admixtures containing PBW.

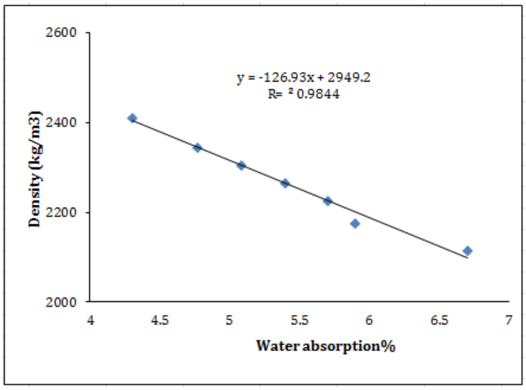

Fig.5 Relationship between Density and Water Absorption of Concrete Mixture Containing PMB

3.2 UPV

The UPV results are shown in Figure 6. It can be seen that the inclusion of PBW leads to a slight decrease in UPV and this decrease is proportional to the PBW content. In general, all mixes showed good quality (UPV > 3500 m/s) according to the Solis-Carcano and Moreno [21] classification, except for the mix with 30% PBW content.

The results showed that the percentages of decrease were 3.9%, 5.7%, 6.4%, 7.7%, 10.7%, and 12.4% at 5%, 10%, 15%, 20%, 25% and 30% PBW content, respectively. The reduction in UPV is attributed to the increase of entrapped air by PBW aggregate, and generation of micro cracks in the concrete matrix. The results are in accordance with **[22, 23]**. The relationship between density and UPV is presented in Figure 7, as shown, a good correlation was obtained between these hardened properties indicating the suitability of such type of concrete for insulation of building.

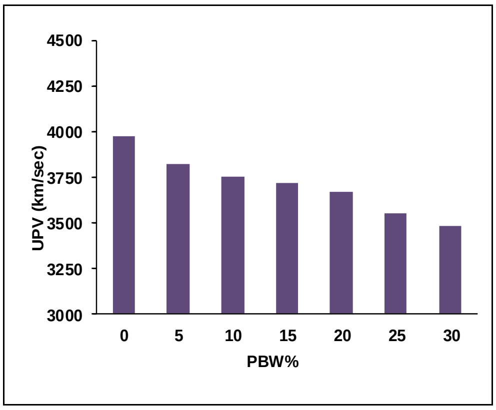

Fig.6 Effect of PBW on UPV of concrete

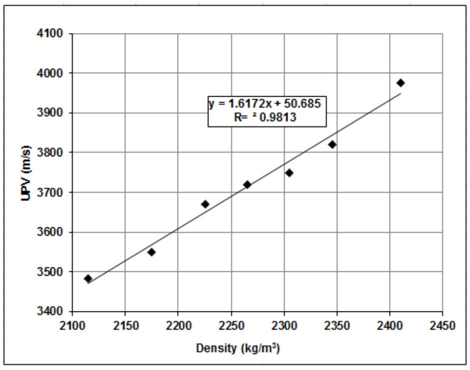

Fig.7 Relationship between density and UPV of concrete containing PBW aggregate

3.3 Compressive Strength

The findings from tests to determine a concrete's compressive strength after 7 and 28 days are shown in Figures 8 and 9, respectively. When PBW particles were utilized as a partial substitution for fine aggregate, there was a detrimental impact on the concrete compressive strength. Specimens contained PBW particles exhibited reduced compressive strength.

At 30% PBW, mixture strength decreased by 43% and 49% at 7 and 28 days of age, respectively. For mixtures containing PBW, the compressive strength at 28 days decreased by 14.8%, 16.9%, 30.4%, 40.9%, and 45.3% at 5%, 10%, 15%, 20%, and 25% PBW. This reduction in compressive strength is explained by the weakness of the PBW particles and the weak bonding between these particles and the cement paste [24-26].

To evaluate the quality of concrete admixtures containing PBW, the relationship between compressive strength and UPV was introduced in this study, as shown in Figure 10. A decrease in UPV resulted in a decrease in the compressive strength of concrete admixtures. Concrete types are declined by including PBW.

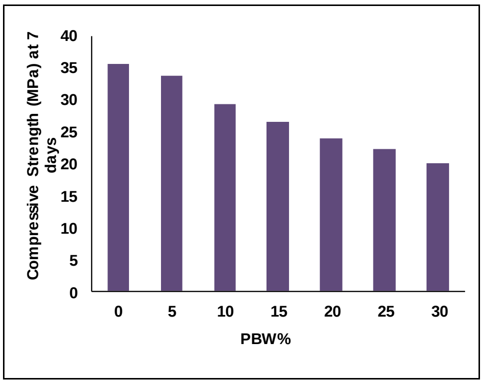

Fig.8 Compressive strength at 7 days

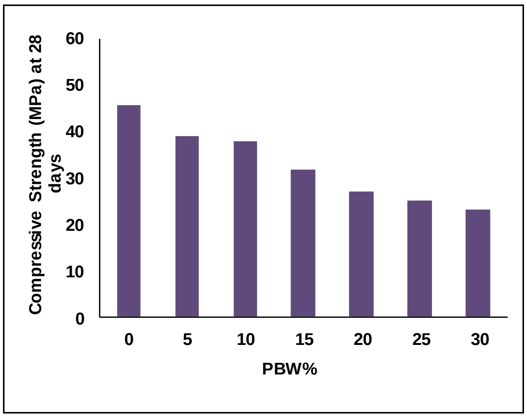

Fig.9 Compressive strength at 28 day

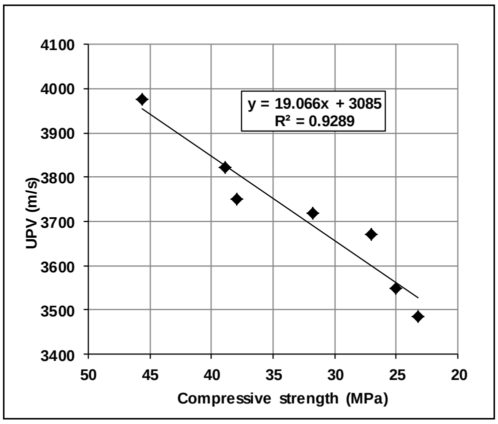

Fig.10 Relationship between compressive strength and UPV of concrete mixes

3.4 Splitting Tensile Strength

Figure 11 shows the results of testing the tensile split strength of 28-day-old PBW concrete. Similar to the compressive strength test results, the addition of PBW particles decreased the tensile split strength. The tensile strength of concrete decreases as the number of PBW particles increases. The maximum reduction in tensile strength was 32.45% at 30% PBW. The reference mixture had the highest tensile strength and the concrete containing 30% PWB the lowest. The decrease in this strength was explained by the formation of microcracks under the applied load, which adversely affected the tensile strength of PBW mixtures. Furthermore, the introduction of PBW particles increased the porosity of concrete, resulting in a decrease in tensile split strength. The tensile strength results are consistent with several studies showing that the mechanical properties of concrete are adversely affected by the introduction of PBW [4, 27]. Conversely, the failure mode in mixtures containing plastic particles is different from that in mixtures without.
The control concrete sample was split into two parts and the concrete sample containing PBW was left intact (Figure 12). This behavior indicates that the inclusion of PBW particles improved ductility.

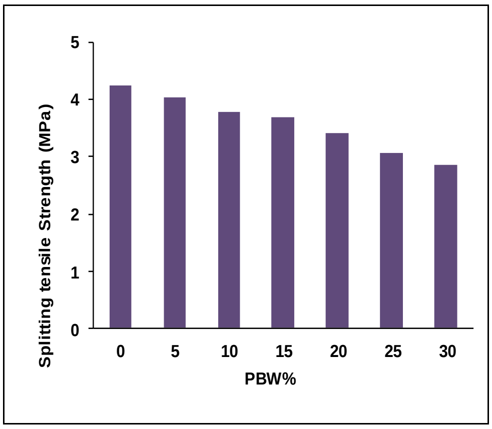

Fig.11 Splitting tensile strength at 28 day

Fig.12 Specimen after testing

3.5 Flexural strength

Figure 13 shows the effect of PBW on the flexural strength of concrete at various substitution rates.

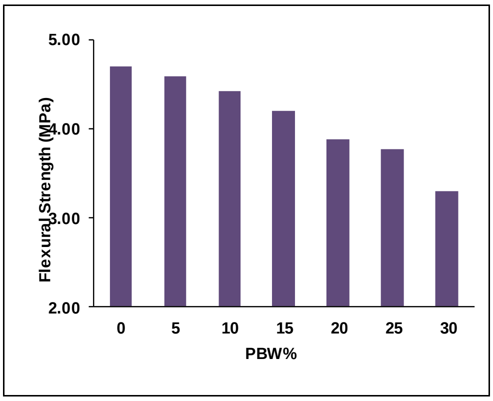

Fig.13 Flexural strength at 28 day

Including this material affected the flexural strength. The strength decreased with increasing PBW. The flexural strength of concrete containing 5%, 10%, 15%, 20%, 25%, and 30% plastic waste decreased by 2.38%, 5.9%, 10.6%, 17.4%, 19, 7% and 29.9% respectively.

Weak bonding between the slurry and PBW particles may be the reason for the lower flexural strength. The results of this study are consistent with previous studies [7-29]. Figure 14 shows the relationship between compressive strength and bending strength of 28-day-old PBW concrete.

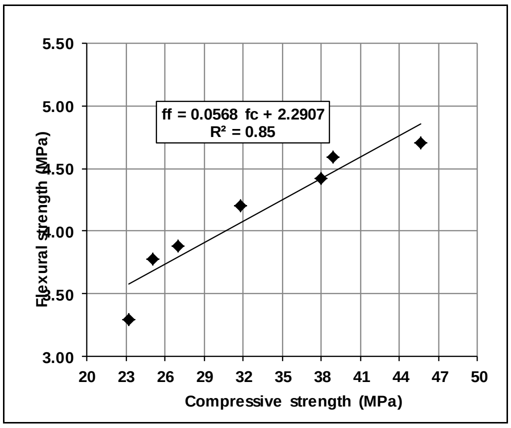

Fig. 14 Relationship between compressive and flexural strength at 28 day

Conclusions

According to this work, the following are reasonable inferences to make:

1. The density of hardened concrete was affected by the inclusion of plastic container waste particles. A decrease in density is observed with increasing content of PBW particles.
2. Water absorption, which affects corrosion of rebar and durability of concrete, increases with increasing PBW particle content.
3. Ultra-sonic pulse velocity, which is an indicator for concrete quality, showed reduced values when PBW was added to concrete. However, except mix with 30% PBW content, this type of concrete was in a “good” quality.
4. The ability of concrete to withstand compressive loads was adversely affected by using PBW particles instead of sand. Compressive strength decreased in direct proportion to the proportion of PBW particles present in the concrete.
5. Tensile strength of concrete shows a similar trend as compressive strength. Increasing PBW had a negative effect on concrete tensile strength at breakout. In addition, bending strength decreases as PBW increases. The reason for this decrease may be the weakened contact between slurry and PBW particles.
6. Correlations between mechanical properties of PBW concrete were obtained.
7. Based on the above results, as a result of the negative results obtained at 25% and 30% percentages, the upper limit of PBW content is in the fine aggregate volume range (15-20%). Suggested. However, the inclusion of this material into concrete may improve other properties such as toughness, and durability, which require further research.

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