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Evaluation the Properties of Mortar Containing Plastic Boxes Waste

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Abstract

Countries generate vast numbers of plastic boxes waste used to hold fruits and vegetables. When the waste resulting from this type of plastic is discarded, it threatens the environment. This work studied the utilization of this type of waste to produce green cementitious materials. The influence of Plastic Boxes Waste (PBW) on the characteristics of mortar is presented. The PBW was utilized as particles which was used as a replacement for fine aggregate. In addition to the reference mixture, ten mixtures containing different volumetric percentages of PBW particles as replacement of sand volume (10, 20, 30, 40, 50, 60, 70, 80, 90-100%) were prepared. The effect of PBW particles on the mortar properties were evaluated by measuring slump flow, density, compressive, flexural, and splitting tensile strengths. The results show that there is a possibility of producing cement mortar containing high quantity of PBW, resulting in lightweight and ultra-lightweight mortar with a density less than 1200 kg/m^3. Additionally, the possibility of producing normal weight concrete mortar having a strength of 20 MPa using waste plastic boxes (PBW) particles is well established with a substitution ratio of up to 20%, and obtaining light weight concrete mortar having a strength of about 10 MPa using PBW particles with a substitution ratio of 60%.

Keywords: Plastic boxes waste, mechanical properties, compressive strength, flexural strength.

1- Introduction

Worldwide, large amounts of plastic waste are discarded, as plastic is used on a large scale. Because it is not biodegradable and harmful to the environment, the challenge presented by plastic waste must be faced [1,2]. In order to reduce the depletion of energy sources in manufacturing and minimize waste added to landfills, plastic recycling must be considered a targeted solution [3].

The utilization of plastic waste in concrete is an interesting solution that has been proposed to dispose of such materials. This solution introduces many advantages, such as producing sustainable concrete, reducing the environmental impact, and achieving economic advantage. Because of the features resulting from the use of plastic waste in concrete, researchers have studied the use of plastic waste in concrete as fibers or as alternatives to sand or gravel [4, 5, 6, 7].

A few researchers have discussed the influence of waste plastic boxes (WPB) on concrete [8, 9]. Hamsa and Abbas [8] have focused on the effect of PBW on the properties of concrete. Their method used PBW materials as a replacement fine aggregate. The water/cement ratio was 0.41 for all mixtures, which contained 0, 2.5, 5-10% PBW. The results showed that adding this material affected the strength of concrete. In the study by Hussien et. al. [9], waste plastic boxes particles were utilized as a gravels in concrete. The quantities were 0, 20, 40, 60-80% ratioed to gravel. The effects were assessed by hardened and physical properties in terms of both compressive and tensile strengths as well as density, and fresh properties. The physical and mechanical characteristics of mixtures containing PBW were reduced compared to samples without PBW.

Jameel G.S and et.al [10], Evaluated the physical and mechanical properties of mortar made from different amounts of PVC waste (5, 10, 15, 20, 25- 30%) by sand volume. Substituting materials for fine aggregate have been obtained from waste plastic pipes. These wastes were collected, crushed and then ground into particles. The findings revealed that PVC waste adversely affected the properties of cement mortar.

Kore [11] has incorporated recycled plastics into concrete mixtures by using theme as a sand substitution. This research examined the concrete characteristics like flowability, compression strength, flexural, and tensile strengths of mixes with fraction substitution of sand by fine aggregate produced from plastic waste. The plastic waste had different sizes; it varied from 0.15 mm to 12 mm in length and between 0.15 and 4 mm in thickness. Sand was substituted by 5-25% plastic waste. Using plastic as a substitution substance instead of sand up to 10% replacement levels led to improved fresh properties and density mixtures, while the hardened characteristics, such as compressive, flexural, and tensile strengths, were marginal reduced. Mohammed et al.[12] have investigated the properties of self-compacting concrete containing waste plastic. The waste plastic was used as the fine aggregate in concrete at different percentages (2, 4, 6-8%). Their findings revealed that the incorporation of waste plastic had a negative effect on compressive strength.

The current study examines the fresh and hardened characteristics of mortar manufactured with PBW; to our knowledge, A few studies has been performed on the characteristics of concrete containing PBW particles. Thus, the modernity of this research is to introduce information to assist fill up this lack by inclusion this kind of waste in the mortar. To meet this goal, ten volumetric percentages (10, 20, 30, 40, 50, 60, 70, 80, 90-100%) of PBW were utilized, and density, absorption, compressive, splitting tensile, and flexure strengths were measured. Using PBW particles obtained from boxes may improve some properties of concrete and decrease the impact of waste materials on the environment.

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2- Experimental Work

2.1 Materials

Ordinary Portland Cement (Type 1) with a fineness of 326 m^2/kg was used in this study to prepare all the mortar mixtures. Physical characteristics of cement are measured and listed in Table 1 according to IQS5/2019 [13]. The maximum size of the sand used was 4.75 mm. The PBW used had a specific gravity of (1.34) and a maximum grain size of 4.75 mm. The physical properties were measured, and sieve analysis was performed according to the Iraqi standards (IQS) [14] as shown in Table 2. In order to obtain PBW particles, the boxes used for storing vegetables were broken (Figure 1), then these plastic particles were passed through a No 4.75 sieve to separate the fine particles used as a sand substitution material.

Table 1. physical characteristics of cement

Test	Result	Limitation according (IQS5/2019)
Initial setting (min)	125	Not lower than 45 min
Final setting (min)	235	Not more than 600 min
Compression strength at three days (N/mm^2)	21	Not lower than 15 N/mm^2
Compression strength at seven days (N/mm^2)	27	Not lower than 23 N/mm^2

Table 2. Physical properties and grading of fine aggregate and PBW

Sieve size mm	Sand %	PBW %	Limitations (zone 2)
4.75	94	100	90-100
2.36	80	47	75-100
1.18	68	16	55-90
0.6	52	7	35-59
0.3	18	3	8-30
0.15	2	1.8	0-10
Fineness modulus	3.77	4.25	
Water Absorption %	2.37	0	
Specific gravity	2.65	1.34	

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Figure 1. Plastic boxes waste used to produce PBW particles

2.2 Mix Design and Casting

Eleven mortar mixes were designed and were cast in order to measure the fresh and hardened properties. The first one, which is reference mixture (0PBW), consisted of cement, fine aggregate, and water, whereas the others ten contained PBW particles in addition to the ingredients of the reference mixture. The PBW particles were added as a percentage of the sand volume. PBW particles were added to the mortar at percentages of 10, 20, 30, 40, 50, 60, 70, 80, 90-100%, corresponding to the mixtures 10, 20, 30, 40, 50, 60, 70, 80, 90-100PBW. As can be seen in Table 3, the mixtures were titled regarding to the percentage of PBW particles. For instance, the mix titled 100PBW refers to the mixture containing 100% PBW.

Table 3. Mix design of mortar (kg/m^3).

Mix code	Cement	Fine aggregate	Plastic boxes waste	water
0PBW	550	1600	0	272
10PBW	550	1440	81	272
20PBW	550	1280	162	272
30PBW	550	1120	243	272
40PBW	550	960	324	272
50PBW	550	800	405	272
60PBW	550	640	486	272
70PBW	550	480	567	272
80PBW	550	320	647	272
90PBW	550	160	728	272
100PBW	550	0	809	272

To attain perfect uniformity, the concrete casting started by blending the sand, and cement with or without PBW particles for 1 minute. The water was added in smaller amounts to limit segregation, and the ingredients were blended for 3 minutes. The mixture then was left to rest for 2 minutes, then blended again for 2 minutes. In order to evaluate the mechanical properties, 50 × 50 × 50 mm cubic specimens were prepared to examine the compressive strength, density, and absorption. Additionally, 75 × 150 mm cylindrical concrete samples were cast to measure the splitting tensile strength. Finally, For the flexural strength test, a 160 × 40 × 40 mm prism was prepared [15]. All samples were de-molded and stored in curing water until the ages of 3, 7, 28 days were reached. Figure 2 shows the splitting and flexural tests machines.

Figure 2. Splitting and flexural tests machine

2.3 Test procedures

To assess the effect of the PBW particles on mortar quality and the possibility of manufacturing cementitious materials utilizing this substance, the fresh and hardened characteristics were measured, taking into account the volumetric substitution of fine aggregate by PBW.

A compression test was performed according to Specifications BS 1881-116 [16]. The outcomes were calculated by averaging the findings from three specimens for each mixture at 3, 7 and 28 days. The splitting tensile strength was evaluated following the ASTM C496 standard [17]. The density was calculated in agreement with BS 1981: Part 114 [18]. Moreover, water absorption was also examined according to ASTM C642 [19]. The testing procedures involved drying the specimens for 24 hours until equal weights were obtained in sequential measurements. It's the weight of absorbed water divided by the dry weight that determines water absorption.

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3- Results and Discussions

3.1- Fresh properties

Figure 3 shows the fresh mortar properties of all mixtures studied. These values were obtained from the slump flow test. The slump values ranged from 105 to 190 mm for mixture containing 100% PBW and 0% PBW, respectively. Thus, the inclusion of PBW particles significantly affects the workability of fresh concrete. This result is conform with Safi results [20]. Decreased slump was associated with many factors, such as the texture of waste materials is generally strong-edged and uneven, increasing the surface area of the particles, which, in turn, leads to more water being consumed by the mixture [20]. Figure 4 shows the samples of slump flow examinations of mixture 2, mixture 6 , and mixture 11.

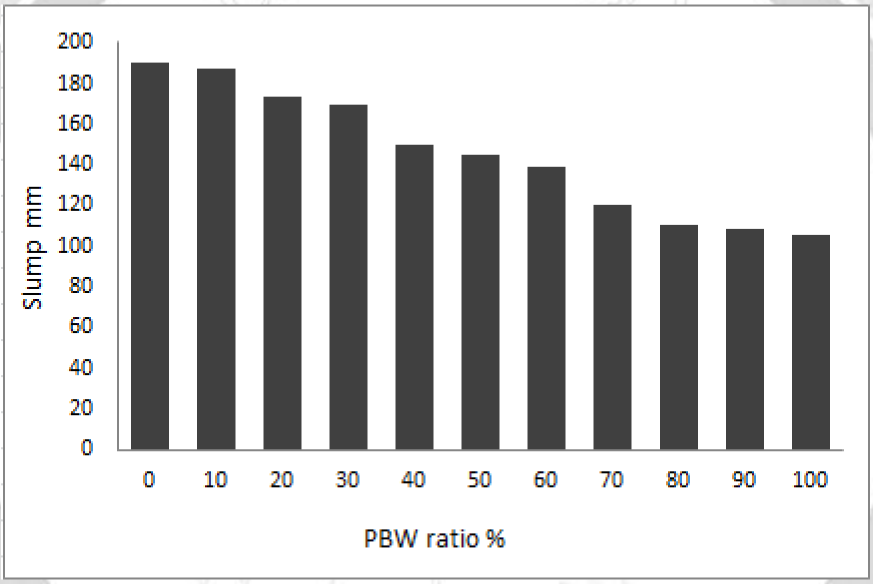

Figure 3. Slump flow of mixtures

Figure 4. Samples from slump flow examination

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3.2- Density

The importance of the properties of cementitious materials depends on the function that it will perform. Sometimes the most important feature of cementitious materials is the lower density when such materials used as non-bearing members (partitions), thus reducing dead load on foundations and lowering construction costs. Figure 5 represents of fresh density while figure 6 shows the results of hardened density tests at 7 days for all mixtures. The inclusion of PBW led to decreased density and this reduction is proportional to the PBW content. The reduction values of hardened density of concrete were 6.45, 10.5, 16.4, 19.7, 27.6, 30.7, 37.5, 41.3, 44- 49% at 10, 20, 30, 40, 50, 60, 70, 80, 90-100% PBW content, respectively. The decrease in the density of these materials is due to the higher content of PBW particles which have low density compared with density of fine aggregate. Furthermore, there was an excellent correlation between PBW particle contents and the density of samples. The lowest density was observed at 100% PBW (1170 kg/m^3). The high reduction in unit weight of mixture may be attributed to the fineness modulus of PBW particles which led to forms more voids inside the mixture.

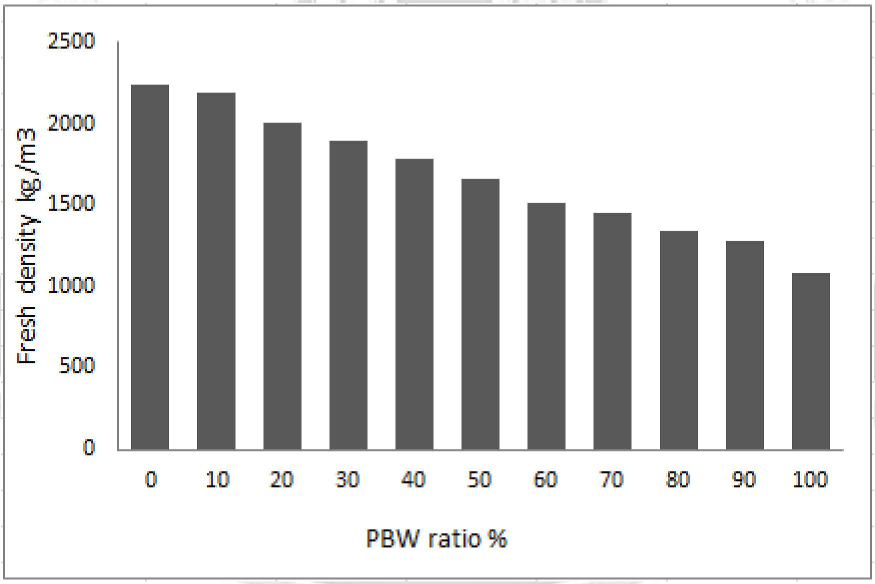

Figure 5. Fresh density of mixtures.

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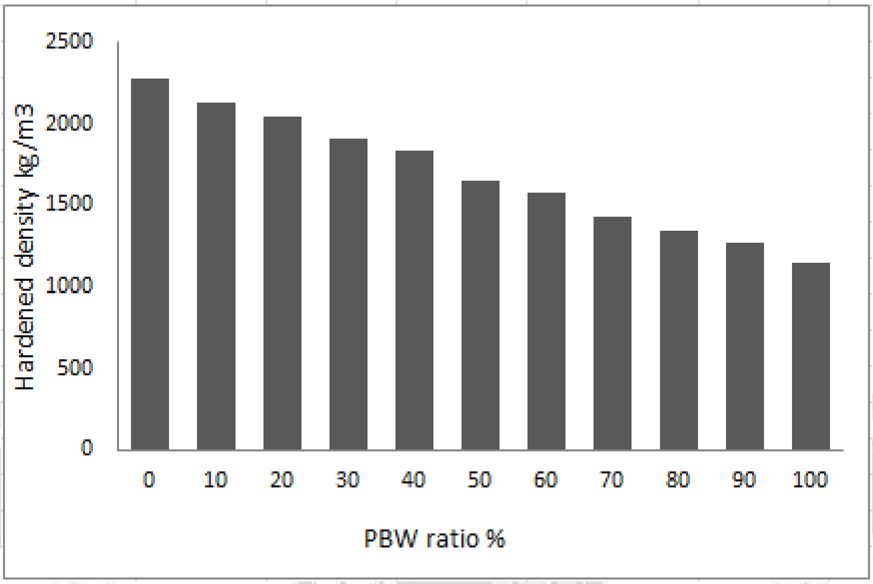

Figure 6. Hardened density of mortar

3.3- Compressive Strength

The results of the compressive strength test, which is considered the major criterion for evaluating the strength of concrete, are presented in Figure 7. The compressive strength is specified at 3 and 7 days and compared with the reference mixture.

Compared to the reference mix (0PBW), the decrease of compression strength was noticed while the percentage of PBW particles was increased.

For all mixtures including the mixtures containing high volume of PBW reach to 100%, the recorded compressive strength refers to the ability of this construction materials to withstand the applied load.

The compressive strength ranged from 3.56 to 15.54 MPa and 4.13 to 27.94 MPa at 3 and 7 days ages, respectively. This recorded strength refers to possibility to producing concrete mortar with high ratio of PBW particles and considering as construction materials. Additionally, from the figures below it is noted that the strength gains with age for all mixtures. This is, generally, attributed to the continuous formation of hydration products during the curing period.

Additionally, monitoring the behavior of failure mode showed brittle failure for the samples cast from reference mixture. In contrast, the samples of concrete containing PBW particles underwent ductile failure. As evident from Figure 8, the reference sample broken under compression test while the samples containing PBW particles remained as one piece, demonstrating the advantage of using PBW in terms of failure mode.

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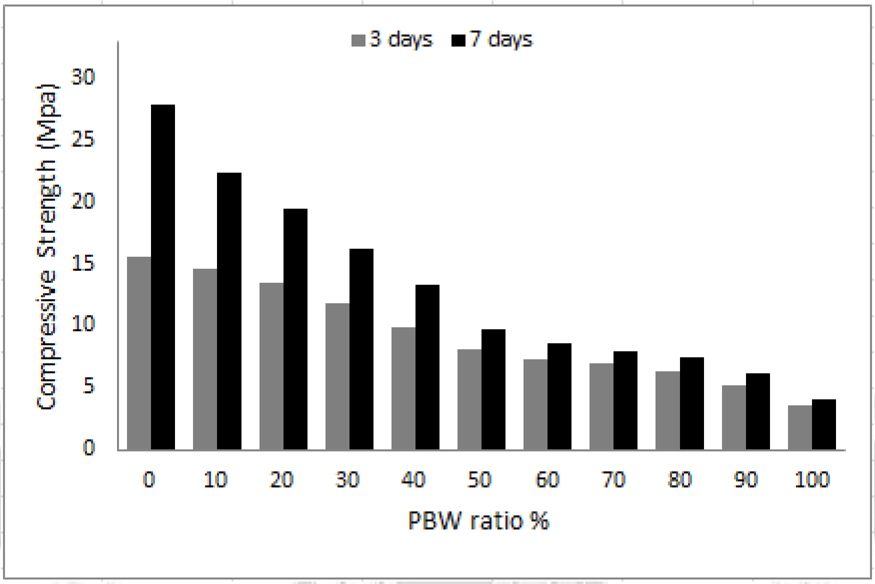

Figure 7. Compressive strength of mixtures

Figure 8. Plate represent the mode of failure of cubes sample under compression test

3.4- Classification of Mortar

Eleven mixtures have been manufactured in this study. Table 5 represent the results of compressive strength and hardened density at 28 days. According to Zongjin Li [21], concrete can be sorted depending on its compressive strength and weight. Light weight structural concrete which have density less than 1850 kg/m^3 and 17 MPa compressive strength while structural normal weight concrete that have density more than 1850 kg/m^3 and compressive strength 20MPa.

Zongjin Li [21] mentioned another more comprehension classification depending on unit weight and strength of concrete. Concrete can be divided into four classes depending on its density, as explained in Table 4. Ultra-lightweight, lightweight, ordinary-weight, and heavyweight concrete. The aggregate is the major ingredient that effect on mortar density. The types of mortar differentiated by density according to change replacement ratio of PBW particle. Depending on to the compression property, concrete may be divided to 4 types, as

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clear from Table 4 [21]. ultra-high-strength, high-strength, moderate-strength and Low-strength concretes.

From the results of the compressive strength and density at the age of 28 days, the produced mortar can be divided into several series (Table 5). The first series is represented by the three mixtures containing (0PBW, 10PBW, 20PBW%) classified as normal weight mortar with normal strength. The second series is the mixture containing (30%PBW) classified as normal weight low strength mortar. The third series is represented by the six mixtures containing (40PBW, 50PBW, 60PBW, 70PBW, 80PBW, 90PBW) classified as lightweight concrete with low strength. As for the fourth and important series, it was represented by the mixture containing (100%) PBW and classified as ultra-low density and low strength.

Table 4 Classification of Concrete [21]

Classification in accordance with unit weight	Limitations of Unit weight (kg/m^3)	Classification in accordance with compressive strength	Limitations of compressive strength (N/mm^2)
Ultra-lightweight	<1200	Low -strength	<20
Lightweight	1200-1800	Moderate strength	20-50
Normal-weight	~2400	High strength	50-150
Heavyweight	>3200	Ultra high strength	>150

Table 5. Classification of mortar

Mix code	Compressive strength MPa (28 days)	Density	Type of mortar
0PBW	34.13	2280	Moderate strength normal weight
10PBW	30.006	2147	Moderate strength normal weight
20PBW	20.713	2040	Moderate strength normal weight
30PBW	18.53	1906.6	Low strength normal weight
40PBW	14.563	1800	Low strength lightweight
50PBW	10.38	1640	Low strength lightweight
60PBW	9.98	1560	Low strength lightweight
70PBW	9.38	1466	Low strength lightweight
80PBW	8.1	1413	Low strength lightweight
90PBW	5.91	1307	Low strength lightweight
100PBW	5.03	1174	Low strength Ultra-lightweight

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3.5- Splitting Tensile Strength

The splitting test is an indirect procedure of calculating the tension strength of concrete using a cylindrical sample, which is split toward the sample diameter.

PBW cement mortar aged of 28 days was tested, and the outcomes are presented in Figure 9. Similar to the findings of the compressive strength tests, adding PBW particles resulted in reduced splitting tensile strength. The tension strength of mortar was reduced when the amount of PBW particles was increased. The values of splitting tensile strength ranged from 0.75 to 2.94 Mpa for mixture containing 100% PBW particles and reference, respectively. The decrease in splitting tensile strength was ascribed to the forming of micro-cracks under applied load, which affected the tensile strength PBW mixture negatively. Moreover, incorporating PBW particles increased the porosity inside the concrete, leading to diminished splitting tensile strength. The tensile strength results agreed with many studies that showed concrete's mechanical characteristics are adversely affected by inclusion of PBW [3,10,22]. In contrast, the failure mode in mixtures containing plastic particles differed from that in mixtures having no plastic particles. The reference mortar sample was divided into two parts while the sample containing PBW remained as a single piece (see Figure 10); this behavior shows improved ductility due to the inclusion of PBW particle.

Figure 11 show the relationships between the compressive and splitting tensile. As seen in this figure, there is an excellent correlation between the compressive and tensile strengths of PBW cement mortar. The high correlation factor (R^2) of about 97% indicates that both the compressive strength and flexural strength were strongly correlated regardless of the particles contents. Kou et al. [23] have reported the same relationship for this parameter. Moreover, equation 4-1 expresses the linear relationship between the compressive and tensile strength using regression analysis.

$$f_{st} = 0.0677 f_c + 0.496 \qquad (4\text{-}1)$$

Where, $\mathbf{f_{st}}$ and f_c are the tensile and compressive strength of PBW concrete, respectively.

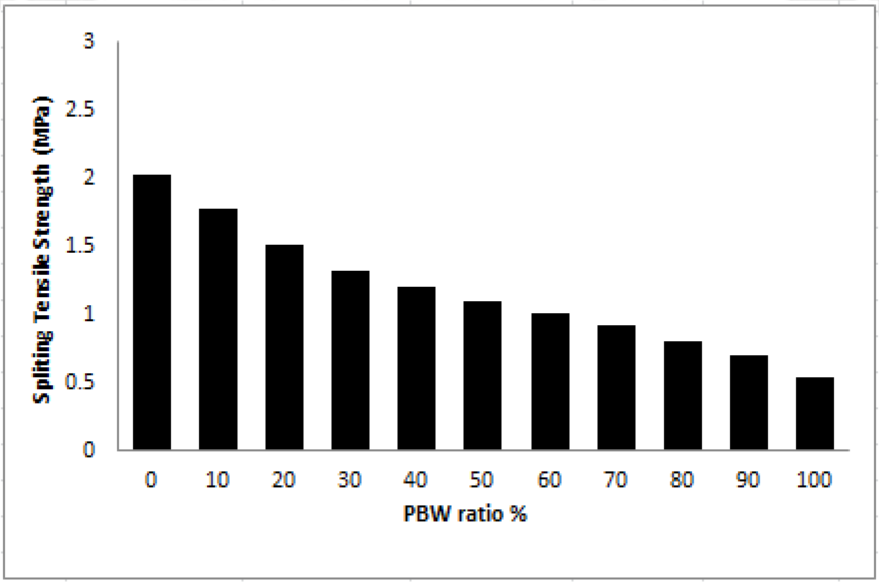

Figure 9. Splitting tensile strength of mixtures

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Figure 10. Plate represent the mode of failure of cylinders sample under tension test

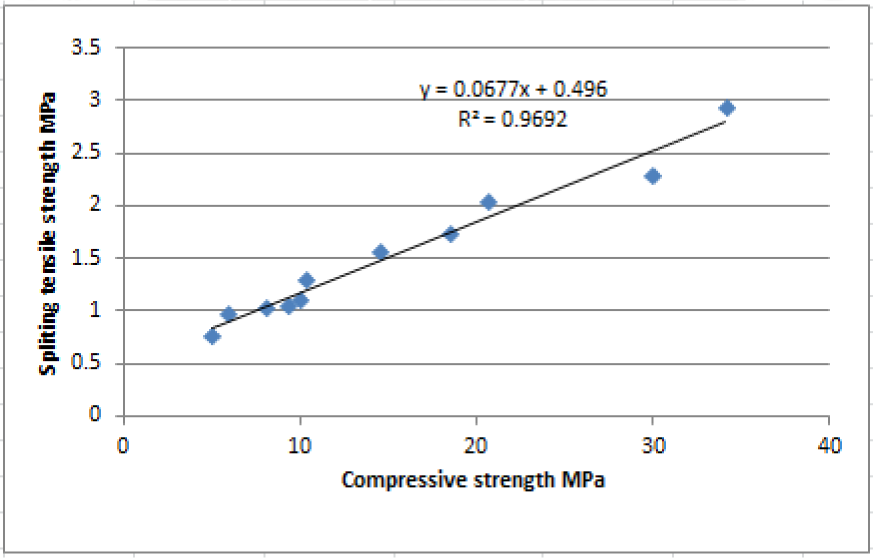

Figure 11. Relationship between compressive and splitting tensile strength

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3.6- Flexural strength

The flexural strength of mortar containing PBW was also evaluated, and the findings are offered in Figure 12, which displays the modulus of rupture according to the amount of PBW particles.

The incorporation of this material affected the flexural strength; the strength decreased with increased PBW. The flexural strength of concrete with and without PBW ranged from 0.54 MPa to 2.02 MPa. The weaker connection between the cement paste and the PBW particles may be the reason behind the flexural strength reduction [11][22].

Figure 13 indicates that there is a correlation between compressive and flexural strengths of PBW mortar at 28 days age. As seen in this figure, there is an excellent correlation between the compressive and flexural strengths of PBW mortar. The correlation factor (R^2) of 0.96 indicates that the compressive strength is strongly correlated with the flexural strength regardless of the PBW particles substitution. Moreover, equation 4-2 expresses the linear relationship between these two properties using regression analysis.

$$f_{st} = 0.0459f_c + 0.4725 \qquad (4\text{-}2)$$

Where, $\mathbf{f_{st}}$ and f_c are the tensile and compressive strength of PBW concrete, respectively.

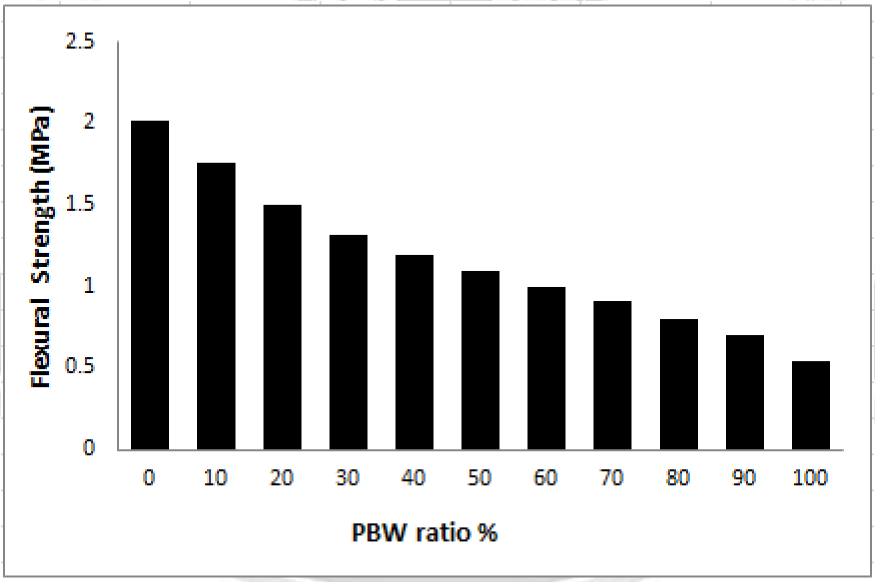

Figure 12. Flexural strength of mixtures

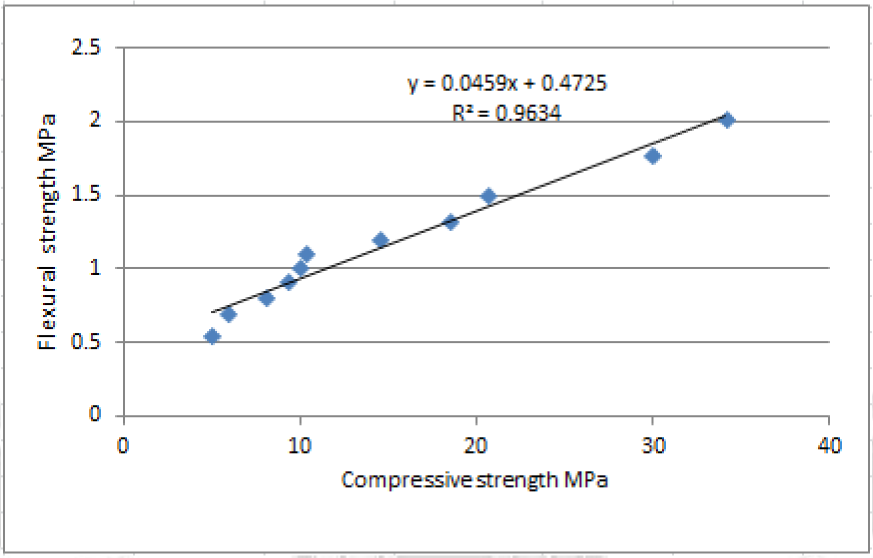

Figure 13 The relationship between compressive and flexural strength

3.7- Absorption

Figure 14 displays the results of water absorption of the control mixture and the mixtures incorporating PBW grains. Water absorption can be considered as an important property because of its possible negative effect on the steel reinforcement corrosion and concrete durability in general. The absorption of water by the specimens was examined 28 days after the date of casting. The absorption tests claimed that the inclusion of PBW grains caused an increase in water absorption. The lowest water absorption was in the control mixture, whereas the highest one was in the mixture containing 100% PBW particles. These results agreed with the findings of Ruiz-herrero [24].

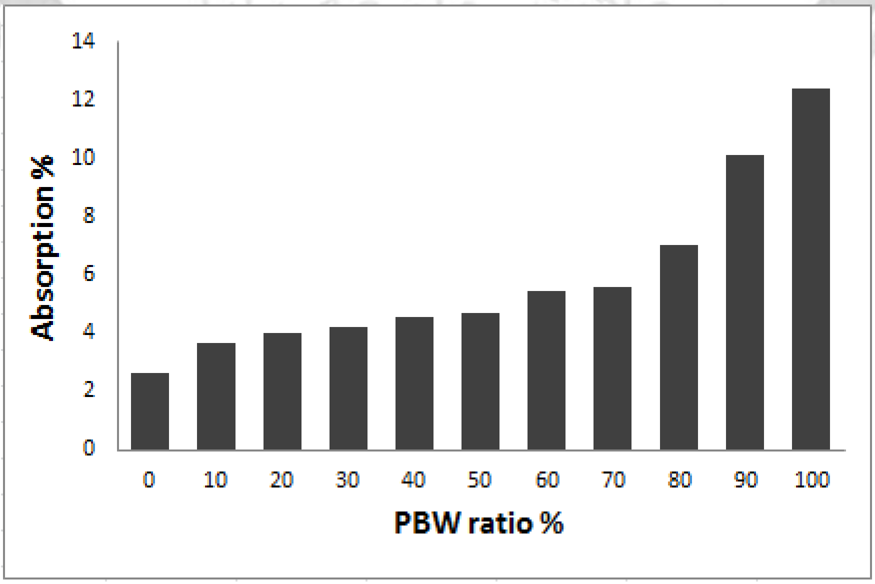

Figure 14. Absorption of mixtures

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4- Conclusions

The following conclusions are reached from this research:

1. It is possible to produce mortar containing PBW particles up to 100% (volumetric percent). The employment 100% of PBW particles instead of sand produced mortar with density (1170 kg/m^3) which classified as ultra-lightweight.

2- Incorporating of PBW particles (40% or more) by volume of sand led to produce lightweight concrete which reduce dead load of structures consequently reduce the applied load on foundation and cost of manufacturing.

3- Possibility of producing normal weight cementitious materials with good strength containing (20%) plastic boxes waste (PBW) particles and obtaining lightweight cementitious materials with acceptable strength containing (60%) PBW particles.

4- The density was affected by the incorporation of PBW particles. With increased PBW particles content, decreased density was observed.

5- The failure mode of specimens under compressive and splitting tensile strengths tests showed significant changes due to the addition of PBW particles: the failure mode changed from brittle to ductile behavior.

6- The addition of PBW in concrete mortar mixtures decreased the recorded slump flow; the minimum result at 100% PBW particles was 105 mm, and the maximum value was 190 mm, for the reference mixture.

7- The mechanical properties of mortar was adversely affected when PBW particles used to replace sand.

8- Water absorption, which possibly affect both steel reinforcement corrosion as well as the durability of concrete, increased with increased PBW particles content.

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تقييم خصائص الملاط المحتوي على نفايات الصناديق البلاستيكية

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الخلاصة

تنتج البلدان أعدادًا كبيرة من نفايات الصناديق البلاستيكية المستخدمة لحفظ الفواكه والخضروات. عندما يتم التخلص من النفايات الناتجة عن هذا النوع من البلاستيك ، فإنها تهدد البيئة. في هذا البحث تم استخدام هذا النوع من المخلفات لإنتاج الخرسانة الخضراء حيث تم دراسة تاثير نفايات الصناديق البلاستيكية (PBW) على خصائص الملاط. تم استخدام حبيبات ال PBW كبديل للركام الناعم. بالإضافة إلى الخلطة المرجعية، تم تحضير عشرة خلطات تحتوي على نسب حجمية مختلفة من مسحوق الPBW (10، 20، 30، 40، 50، 60، 70، 80، 90–100%). تم تقييم تأثير جزيئات PBWعلى خصائص الملاط عن طريق قياس الخواص الطرية ، الكثافة ، الانضغاط ، الانحناء ، والشد. أظهرت النتائج إمكانية إنتاج ملاط أسمنتي يحتوي على نسب عالية من PBW مما ينتج عنه خرسانة خفيفة الوزن و وخرسانة خفيفة الوزن للغاية بكثافة اقل من 1200كغم/م^3. بالإضافة إلى ذلك، امكانية انتاج ملاط خرساني بوزن اعتيادي ومقاومة (20) ميكاباسكال باستخدام فضلات الصناديق البلاستيكية تصل الى 20%, كما يمكن انتاج ملاط اسمنتي خفيف الوزن بمقاومة (10) ميكاباسكال باستخدام (60)% من فضلات الصناديق البلاستيكية.

الكلمات الدالة: نفايات الصناديق البلاستيكية ، الخواص الميكانيكية ، مقاومة الانضغاط ، قوة الانحناء.

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