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Mechanical Properties of Concrete Contained Recycled PVC Additives

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Abstract: This research is studied the possibility of reusing PVC pipes wastes as partial replacement of sand within concrete mixture. In this study, the fine aggregate is replaced with PVC at dosages 1.25%, 2.5%, 3.75% and 5% by weight of sand with superplasticizer (SP) admixture. The mechanical properties are evaluated, which included compressive strength, splitting tensile strength, and flexural strength, in which for each one, 60 specimens are tested for water to cement ratios 0.41 and 0.53. Also, the effect of these wastes on the strengths and serviceability of concrete beams are investigated by testing three simply supported reinforced concrete beams of dimensions 150×200×1400 mm. It is concluded that w/c ratio of 41% of the replacement of fine aggregates with 1.25% PVC particles showed the optimum results for compressive, tensile and flexural strengths, namely 31.66 %, 6.45%, and 31.23%, respectively, more than control mixture. The beam specimen that contain on 1.25% of PVC particles showed an increase in ultimate load by about 6.06% compared to the reference beam. While the hybrid cross section beam showed a relatively small reduction in ultimate load compared to reference beam, i.e, 14.5%. Thus with hybrid sections considerable amount of plastic wastes could be recycled with relatively small reduction in ultimate capacity of beams.

Keywords: Recycled concrete, PVC wastes, plastic wastes, sand replacement, hybrid beams.

1. Introduction

Plastic waste is one of main environmental problems facing Misan province (southern Iraq) nowadays, due to its exposed to the elements of the environment such as soil, water and air. These wastes consequently lead to the depletion of natural resources, in the same time the absence of correct ways for collection, transmission and processing of the plastic waste led to complicate this problem [1]. Despite the absence of a previous study discussing the recycling of plastic waste type (PVC) and its use within the components of the concrete mix by replacing it with certain percentages of sand weight, one of the previous studies dealt with the recycling of plastic boxes as a partial alternative to gravel. Hussein et al. [2] studied and tested the waste plastic box particles within the mixture as a partial substitute by weight of coarse aggregate in different percentages (0%, 20%, 40%, 60%, and 80%). Fresh and hardened concrete tested. The results proved that the properties of the concrete mixture such as slump, density, compressive strength, and split tensile strength decrease with increasing proportion of these particles. There are many previous studies on the recycling of other plastic waste, such as a polyethylene terephthalate (PET) bottle as a partial alternative to fine aggregate. Ismail and AL-Hashmi [3] utilized PET within the mix as a partial substitute by weight of fine aggregate in percentages of (0%, 10%, 15%, and 20%) with length of 0.15-12 mm and width of 0.15-4 mm. Each concrete mixture consisted of 1020 kg/m^3 coarse aggregate, 715 kg/m^3 fine aggregate, 380 kg/m^3 cement, and a water/cement ratio of 0.53. And Rahmani et al. [4] utilized PET within the concrete mixture as a partial substitute by weight of sand in percentages of (5%, 10%, 15%) by volume with a maximum size of 7 mm and two w/c ratios (0.42 and 0.54). Azhdarpour et al. [5] utilized PET within the mixture as a partial substitute by weight of fine aggregate in percentages of 0%, 15%, 10%, 15%, 20%, 25%, and 30% with two sizes of 2-4.9 mm coarse plastic and width of 0.05-2 mm fine plastic. In 2020, Gopi et al. [6] used PET within the concrete mixture as a partial substitute of sand in percentages of 5%, 10%, 15%, 20%, 25% by weight with a maximum size of 3 mm. The outcomes detected that the suitable addition of the waste into the concrete mixture reduce the slump with increasing of plastic waste particles. This outcome is confirmed by Ismail and AL-Hashmi [3] and Rahmani et al. [4]. In addition, the partial replacement ratio of 5% of fine aggregate was optimal, while 10% achieved the same result as the control samples in terms of compressive strength.

These results are proven by Ismael and Al-Hashimi [3], who showed that the compressive and flexural strength of hardened concrete decreased when the percentage of plastic waste used increased. Azdarpur et al. [5] demonstrated that the compressive strength was increased by 39% and 7.6% by replacing 5% and 10% of the PET particles.

Kalaivani et al. [7] used PET within the concrete mixture as a partial substitute by weight of fine aggregate in percentages of 5%, 10%, 15%, 20% by adding jute fiber with percentages of 0.25%, 0.5%, 0.75%, and 1% to the volume of optimized plastic waste concrete. The finding proved that the reinforced concrete containing 0.25% volume fraction of jute fiber and 10% weight fraction of PET aggregate, were the optimum replacement percentages for the compressive strength, while 0.5% volume fraction of jute fiber were the optimum replacement percentages for split tensile strength.

Albano et al. [8] used irregularly shaped PET particles with lengths approximately between 2.6 and 11.4 mm in alternate amounts of 10% and 20% in two different w/c ratios (0.50 and 0.60). The results showed that the compressive strength decreased with the increase in the proportion of waste plastic particles, which means that these particles act as defects within the internal structure of the concrete. Also, concluded through this study that the concrete mixture containing only the large size plastic particles is much weaker compared to the mixture containing the small size plastic particles only. Therefore, concrete compaction is affected by low workability due to honeycomb formation of cavities and pores

Frigione [9] used PET granules, which were categorized by their similarity to siliceous sand and replaced in the mixture. Through the study observed that the use of a replacement ratio of 5% leads to a decrease in the compressive strength of the mixture by approximately 2%.

Granular waste plastic was used to partially replace the fine aggregate by weight (quarry dust) of 0%, 5%, 10%, 15%, and 20%. The study proved that granular plastic can partially replace the fine aggregate in concrete by up to 20% of its weight and recommended the mixture to be used for lightweight concrete based on specific criteria [10].

In 2019, Kore et al. [11] focused in the study on recycling and crushing solid plastic waste and using it as fine aggregate by weight in concrete mixtures in different percentages 5%, 10%, 15%, 20% and 25% for conventional fine aggregates. Akiniele et al. [10] and Lukor et al. [11] through the study showed that the strength of the concrete mixture decreases as the percentage of plastic waste particles in the concrete mixture increases, through conducting several tests on the mixture such as compression, tensile and flexural tests. In 2020, Bag et al. [12] used plastic waste within the concrete mixture as a partial substitute of fine aggregate in percentages of 10%, 15%, 20%, and 25% by weight. The outcomes proved that the concrete mixture containing 15% of plastic particles was the optimum replacement percentage and the concrete mixture prepared containing plastic waste can be used for mass concrete and structures with low bearing of loads. Shanmukish et al. [13] the study focused on the use of plastic waste as a partial substitute for fine aggregate in the concrete mixture in varying proportions (10%, 20%, 30%, 50%) by comparing six concrete mixtures. Through the study observed that the use of a replacement ratio of 10% leads to a decrease in the compressive strength at 21 days of the mixture compared with the control mixture by approximately 15%. Despite the drop in the compressive strength in the mixture with a ratio of 10% plastic waste, the inclusion of the particles inside the mixture improved the tensile strength of the specimens compared with the reference mixture.

Many other researchers used more than one type of plastic waste within the mixture, such as electronic plastic waste (E-plastic waste) used as a partial replacement of coarse aggregate [14,15] and polypropylene (PP) [16, 17] and PET used as a coarse aggregate in the concrete mixture. Yang et al. [18] added plastic waste (PP) particles after cutting into short columns as a fine aggregate by volume into the concrete mixture and shredded into 1.5 mm to 4 mm length. The findings proved that the inclusion of the particles inside the mixture improved the compressive strength of the specimens in addition to a prominent effect on the flexural strength and the hardness.

In the present research, the mechanical properties (compressive, splitting tensile, and modulus of rupture) of concrete mixtures, which included four percentages of PVC waste with two w/c ratios added as a partial replacement of fine aggregate in the concrete mixture were estimated. Moreover, the deflection and failure load of RCBs containing different percentages of PVC waste were investigated on the basis of the success of the mechanical properties of the concrete mixture containing the waste in the first part of the study.

2 Experimental Work

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (Type 1) produced is used in this study. The chemical composition and physical properties of the cement are shown in Tables 1 and 2, respectively. The tests were done in the laboratory of Material and Construction – Technical Institute/Misan University according to the Iraqi Specification No.5/1984[19].

Table 1 Chemical components of cement

Oxide composition	Abbreviation	Content (percent) By weight	Limit of Iraqi specification No.5/1984 [19]
Lime	CaO	63.96	–
Silica	SiO_2	21.32	–
Alumina	AL_2O_3	4.58	–
Iron Oxide	Fe_2O_3	3.25	–
Sulphate	SO_3	2.48	<2.8%
Magnesia	MgO	2.75	≤5%
Loss on Ignition	L.O.I I.R	3.46	≤4%
Insoluble residue Lime saturation factor	L.S.F	1.07	≤1.5%
		0.97	0.66- 1.02
Main compounds (Bogue's equations)			
Tricalcium Silicate	C_3S	50.69	–
Di Calcium Silicate	C_2S	18.28	–
Tri-Calcium Aluminate	C_3A	8.14	–
Tetra Calcium Alumina Ferrite	C_4AF	9.89	–

Table 2 Physical and mechanical properties of cement

Physical properties	Test Result	Limits of Iraqi Specification No.5/1984[19]
Fineness Using Blain Air Permeability Apparatus (m^2/kg)	384	≥230
Setting time Using Victa's Method		
Initial (hrs: min.)	2:00	≥ 0:45 min
Final (hrs: min.)	3:45	≤ 10 hrs
Soundness Using Autoclave Method	0.22	< 0.8
The compressive strength of mortar		
3Days, MPa	20.8	≥15
7Days, MPa	27.4	≥23
28 Days, MPa	34.7	

2.1.2 Aggregates

In this work, the fine aggregate is supplied from Basra region in the south of Iraq, while the coarse aggregate is naturally available in Chilat region eastern Misan province close to Iraq-Iran borders. The maximum size of the fine and coarse aggregates used in this work are 4.75 mm and 20 mm, respectively. The properties of aggregates are determined according to the Iraqi Specification No.45/1984 [20] are shown in Tables (3,4, and 5) and Fig. 1.

Table 3 Physical Properties of Fine Aggregate

Physical properties	Test results	Limits of Iraqi specification No.45/1984[20]
Specific gravity	2.56	-
Sulfate content %	0.13	≤ 0.5%
Absorption %	0.75	-

Table 4 Grading of the Fine aggregate

Sieve size (mm)	Percent passing %	Cumulative passing % Limits of Iraqi specification No.45/1984[20]
10	100	100
4.75	95.6	90-100
2.36	87.73	75-100
1.18	76.04	55-90
0.60	50.25	35-59
0.3	11.75	8-30
0.15	2.4	0-10

Table 5 Grading of Coarse Aggregate

No.	Sieve size	%Passing	
		% Coarse Aggregate	Iraqi specification No. 45/1984 [20]
1	37.5 mm	100	100
2	20 mm	95	95-100
3	10 mm	39.83	30-60
4	5 mm	1.145	0-10

2.1.3 Admixture

Superplasticizer is utilized in this study to increase the workability of the fresh concrete, which negatively influenced by presence of plastic waste within mixture. The liquid Type Hyperplast PC260 is used and it's complies with ASTM C494-99 Types A and G [21]. The technical specification according to supplier is shown in Table 6.

2.1.4 PVC particles

Polyvinyl chloride (PVC) waste is collected from Plastic Factory in Misan province southern Iraq as by product. The maximum size waste pieces are 9.5 mm as shown in Fig. 1. The waste has irregular shape not spherical and its color is white, the grading of PVC and the properties are shown in Tables 7 and 8, respectively.

Table 6 Technical Description of Flocrete PC 260

Chemical Base	Modified polycarxylates based polymer
Appearance/colors	Light yellow liquid
Freezing point	-7^{o} C approximately
Specific gravity @ 25^{o} C	1.1±0.02
Air entrainment	Typically less than 2 % additional air is entrained above control mix at normal dosages
Dosage	0.5 to 4.0 liter per 100 kg of binder
Storage condition/Shelf Life	12 months if stored at temperatures between 2^{o} C and 50^{o} C

Fig. 1 Sample of plastic waste used

Table 7 Grading of plastic waste (PVC) used

Sieve size	Cumulative % passing
12.7 mm	100
9.5mm	94.74
4.75 mm	52.63
1.18 mm	32.105
0.6 mm	26.654
0.3 mm	22.331
Pan	11.8

2.2 Mixture proportioning

Two mixtures with two w/c ratios are designed, casted and cured for 7 and 28 days. The first mixture with w/c equal to 0.41 consisted of 649.644 kg/m^3 sand, 1024 kg/m^3 gravel, 495.12 kg/m^3 cement with adding 3.961 kg/m^3 of superplasticizer. While the second mixture with w/c equal to 0.53 consisted of 741.8 kg/m^3 sand, 1024 kg/m^3 gravel, 383.02 kg/m^3 cement with adding 3.064 kg/m^3 of superplasticizer. Concrete mixtures with PVC wastes are presented in Table 9 with dosages of plastic wastes of 1.25%, 2.5 %, 3.75%, and 5% as sand replacement (by weight of sand).

Table 8 Properties of plastic waste (PVC)

Properties	Value
Density (g/cm^3)	1.41
Water Absorption, 24 hrs (%)	0
Tensile Strength (psi)	7500
Tensile Modulus	411000
Tensile Elongation at Break (%)	----
Flexural Strength (psi)	12800
Flexural Modulus (psi)	481000
Hardness	115

Table 9 Concrete mixture proportion with PVC

	Case I		W/C = 0.41		
Material (Kg/m^3)	0%	1.25%	2.5%	3.75%	5%
Cement	495.12	495.12	495.12	495.12	495.12
Sand	649.644	641.523	633.403	625.282	617.164
Gravel	1024	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38	201.38
PVC	-	8.121	16.2411	24.352	32.48
SP	3.961	3.961	3.961	3.961	3.961
Case II		W/C = 0.53			
Material (Kg/m^3)	0%	1.25%	2.5%	3.75%	5%
Cement	383.02	383.02	383.02	383.02	383.02
Sand	741.804	732.53	723.259	713.98	704.7138
Gravel	1024	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38	201.38
PVC	-	9.272	18.545	27.817	37.0902
SP	3.064	3.064	3.064	3.064	3.064

2.3 Fresh concrete test

To assess the workability of fresh concrete, it was tested by one of the most important and common tests, namely the slump test. If the concrete is found to be cohesive and properly installed without being subjected to separating its parts, even if it was poured without losing its homogeneity and pressure with minimal effort, this means that the concrete is workable and therefore usable. This test was performed according to ASTM C143 [22]. It was noticed that the densities of concrete mixtures decrease as PVC particles percentage increases within the mixtures. The explanation for this decrease is that PVC particles usually have a specific gravity (1.35-1.45) lower than natural fine aggregates (2.67), and the density of concrete depends on the density of its formations. Therefore, the density decreased as the level of substitution increased.

2.4 Reinforced concrete beams

Wooden molds are utilized for casting all concrete beams, as shown in Fig. 2. The beams are simply supported with span length 1400 mm and the cross section is rectangular (b×h=150×200 mm). Three concrete beams are casted in this study, with different percentages of PVC wastes. The beams are reinforced with deformed rebar, as shown in Fig. 3, which include two bars #13 (12.7 mm diameter) as tension reinforcement, stirrups reinforcement #10 (9.5 mm diameter) at 60 mm c/c and two top bars #10 mm as anchorage bars to fix the stirrups.

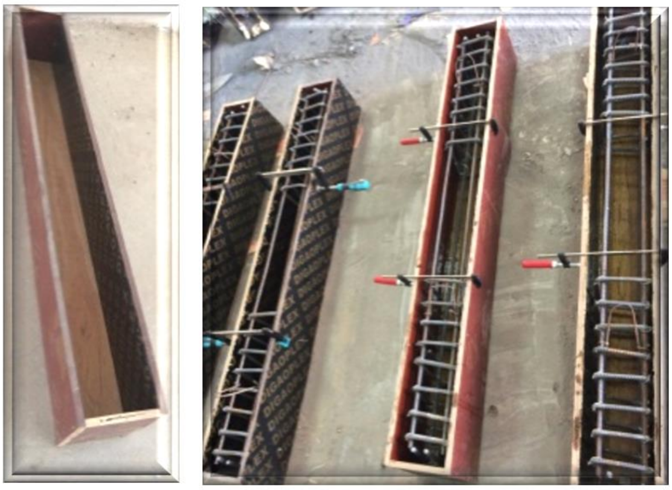

Fig. 2 Beam molds and reinforcement

3 Results and discussion

3.1 The fresh concrete properties

Concrete is said to be workable when it had appropriate consistency, handled without segregation, casted without loss in homogeneity and compacted with less effort. Slump test (according to the European Standards [23]) is used to investigate the effect of PVC wastes on concrete workability. From Table 10, its observed that the slump with different w/c decreases as PVC percentage increases. A similar outcome was exhibited by another review [24] where the workability of concrete mixture decreased by increasing the metallic plastic waste fibers in the mixture. The same decrease in the workability of mixtures containing PET particles as a partial replacement for sand and gravel was also observed with the same results in other researches [3,4,5,25]. The decreasing of slump was estimated for percentages of 2.5%, 5%, and 10% as 5%, 10%, and 15%, respectively. The results are consistent with those of Hussein et al. [2] which observed that slump dropped by 33.33%, 50%, 66.67% and 83.33% with 20%, 40%, 60% and 80% substitutions for plastic box particles, respectively. The decrease in slump has been associated with many factors, such as the overall texture of the waste material being sharply edged and uneven, which leads to an increase in the surface area of the particles, which in turn causes more water to be consumed by the mixture.

Table 10 Result of slump test for plastic (PVC) waste

Plastic Percentage (%)	Slump Test (mm)	Workability classification	Limit of ENV 206 [23]	Reduction in Slump (%)
0	200	S4: High workability	>160 mm	----
1.25	180	S4: High workability	>160 mm	10
2.5	150	S3: Medium workability	100-150 mm	25
3.75	100	S3: Medium workability	100-150 mm	50
5	50	S2: Low workability	50-90 mm	75

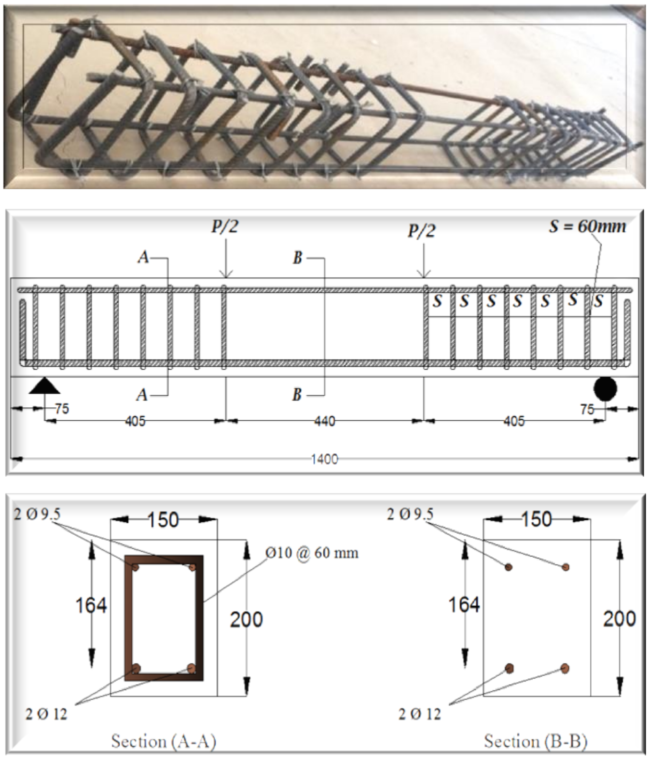

Fig. 3 Dimensions and details of beam specimen

3.2 Compressive strength

Cubic specimens of dimensions 100×100×100 mm, with different w/c ratios and PVC dosages are tested to evaluate the compressive strength of concrete. Details related to compressive strength are shown in Table 11. Generally, as the dosage of PVC wastes replaced the sand increases, the compressive strength increased up to optimum dosage of 1.25%, then vice versa (except for w/c ratio= 0.41 with 5% replacement at which the compressive strength increasing considerably) as shown in Fig. 4. For w/c ratio of 0.41, the dosages 1.25%, 2.5 %, 3.75 %, and 5 % of PVC wastes as sand replacement increased the compressive strength by 31.66 %, 10.67 %, 11.08 %, and 21.82 %, respectively, while for w/c ratio of 0.53 and for the same dosages the compressive strength increased by 31.19%, 30.06%, 7.25% and 1.89 % respectively. These results are consistent with the findings of Hussain et al. [2] who used plastic box particles by 20%, 40%, 60%, and 80%. Also this result is supported by Gopi [6] who used PET particles as a partial replacement of sand in the concrete mixture in different percentages (5%, 10%, 15%, 20%, 25%). He also observed that the 5% replacement of sand was the optimum percentage, but the 10% replacement of sand almost had the same result of control specimens for compressive strength. These results are consistent with the findings of Hussein et al. [2] who used plastic can particles in 20%, 40%, 60% and 80%. This result was also supported by Gopi [6] who used PET particles as a partial substitute for sand in the concrete mixture with various dosages (5%, 10%, 15%, 20%, 25%). He also noted that 5% sand replacement was optimal, but about 10% sand replacement had the same result as the pressure resistance control samples. The utilization of plastic particles by 10% minimized the compressive strength. This decreasing is steady with the discoveries of Hussain et al. [2] who utilized PBPs by 20%, 40%, 60%, and 80%, and these rates brought about a lessening in compressive strength by 7.37%, 17.68%, 38.6%, and 45.65%, separately. This outcome is upheld by Gopi [6] who involved PET jug particles as a fractional substitution of fine total in the substantial blend in various rates (5%, 10%, 15%, 20%, 25%). He additionally saw that the 5% substitution of sand was the ideal rate, yet the 10% substitution of sand nearly had similar aftereffect of control examples for compressive strength. The failure modes of all cubes that contain different types of PVC wastes, in which the cubes are not crushed suddenly as for reference mix, but kept its shape with surface cracks, this show the ductility provided by presence of plastic waste.

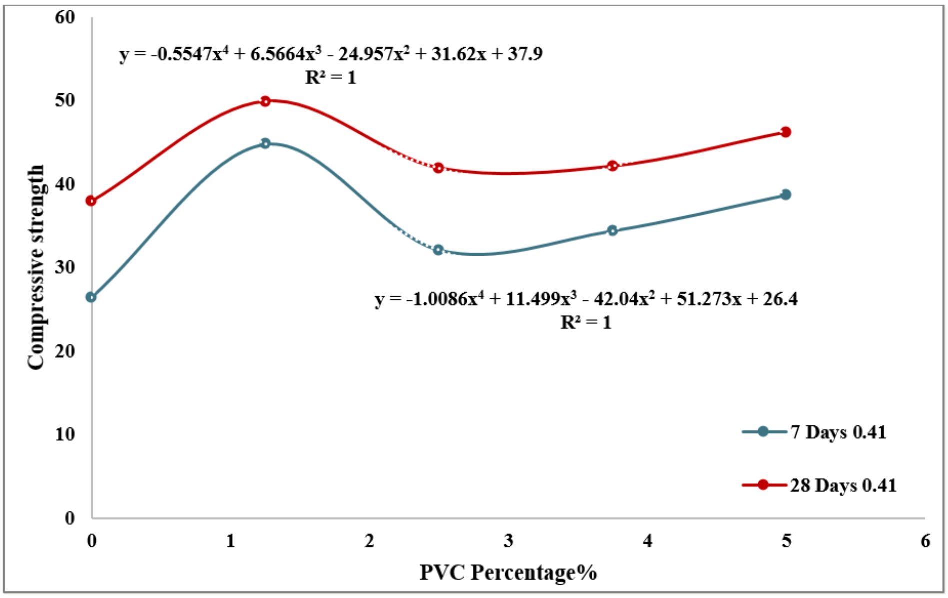

Fig. 4 Result of compressive strength of PVC

3.3 Splitting tensile strength

The effect of sand partially replaced with PVC wastes on the concrete tensile strength is presented in Table 11. Generally, the tensile strength is decreasing as the dosage of PVC wastes is increased beyond the optimum percentage of 1.25%. For w/c = 0.41, the splitting tensile strength for mixture with optimum percentage of PVC wastes, i.e., 1.25% is 6.45% (while increased by 5.77% for w/c=0.53), for higher dosages its drop by 1.61% and 0.967% for percentages of 2.5% and 3.75%, respectively. The failure mode of the reference mixture is suddenly crushed and completely divided into two parts, while there is no separation in the cylindrical samples that contain plastic wastes, but there are cracking development and spreading on the sample surface, which indicate that ductility provided by plastic wastes for concrete. Albano et al. [8] showed that the tensile strength decreased with the increase in the size of large waste particles and the high replacement rates as a result of the increase in the voids inside the concrete mixture. Another study [2] confirmed that the tensile strength decreased by 33.33%, 40%, 46.67%, and 53.33% with adding 20%, 40%, 60%, and 80% percentages, respectively, of plastic box particles. This reduction was also conclusion by Frigione [9] on using PET particles and added with percentage of 5% by volume, this percentage led to drop in the tensile strength by about 2%.

Table 11 Compressive, tensile, and flexural strengths of specimens at the age of 7 and 28 days (MPa)

W/C	Plastic Percentage (%)	Compressive strength (f_{cu}) MPa		Split tensile strength (f_s) MPa		Flexural strength (f_r) MPa		Changing in Compressive strength (%)	Decreasing in tensile strength (%)	Changing in flexural strength (%)
		7 Days	28 Days	7 Days	28 Days	7 Days	28 Days			
0.41	0	26.4	37.9	3.1	2.7	4.53	4	----	----	----
	1.25	44.8	49.9	3.3	3.2	5.945	5.6	+31.7	+18.52	+40
	2.5	31.1	41.9	3.05	2.7	5.56	3.97	+10.7	----	-0.75

	3.75	34.4	42.1	3.07	2.6	4.746	3.797	+11.1	-3.7	-5.075
	5	38.7	46.2	3.1	2.7	4.7	4.22	+21.82	----	+5.5
0.53	0	22.4	26.5	2.6	2.43	4.46	3.735	----	----	----
	1.25	32.6	34.7	2.75	2.3	4.723	3.82	+31.2	-5.35	+2.27
	2.5	26.33	34.4	2.3	2.25	3.401	2.63	+30.1	-7.41	-29.58
	3.75	23	28.37	2.2	2.1	3.797	3.137	+7.25	-13.58	-16.01
	5	28.45	26.95	2.4	2.3	3.935	3.031	+1.9	-5.35	-18.85
Number of specimens		3	3	3	3	3	3			

3.4 Flexural strength

The effect of PVC wastes as sand replacement with two w/c ratios on flexural strength is investigated by using 10×10×50 cm prism is shown in Table 11. Generally, the flexural strength is decreasing when the dosage of PVC particles increased beyond the optimum percentage of 1.25%. For 1.25% replacement of sand with PVC wastes with w/c ratios of 0.41 and 0.53, the flexural strength is increased by 31.23% and 5.9%, respectively. For w/c = 0.41, the flexural strength for dosages 2.5%, 3.75% and 5% of PVC wastes is 22.7 %, 4.77%, and 3.75%, respectively. As noticed after the modulus of rupture test, the specimens containing the ordinary mixture are divided into two parts after failure; while in the case of including PVCs in the mixture, these specimens did not fail immediately after the failure, but began to appear small cracks on the surface of the specimen without separating it into two parts and retained its shape, which shows that the integration of the concrete mixture with PVCPs leads to improving the ductility and performance of the concrete mixture. It was also concluded that PVCPs should be included and spread within the concrete mixture with a uniform and homogeneous distribution. At the same time, percentages must be accurately determined.

4 Testing of concrete beams

The optimum percentage of PVC wastes, namely 1.25%, is used in casting beam specimens to study the effect of these wastes on beams behavior. The test variables include the percentage of plastic waste, and cross section of beams (homogenous or hybrid) as shown in Table 12 and Fig. 5. The water to cement ratio used of concrete mixture for all beams is 0.41.

A load frame facility in the structural laboratory of University of Misan is employed as the experimental loading system with manual hydraulic jack for load application as shown in Fig. 6. The three point loads test are used for all specimens with distance between these points are 440 mm. The loads are applied in successive increments of (5 kN) until failure. At each load increment, observations are recorded such as the deflection, first crack and draw crack patterns.

The flexural behavior of the concrete beams is investigated via ultimate load, the deflection at mid span and crack pattern. One reference beam and two samples with different percentages of plastic waste are tested. For each load increment, the deflection at mid span is measured and the crack pattern of beams is modified based on crack path growth.

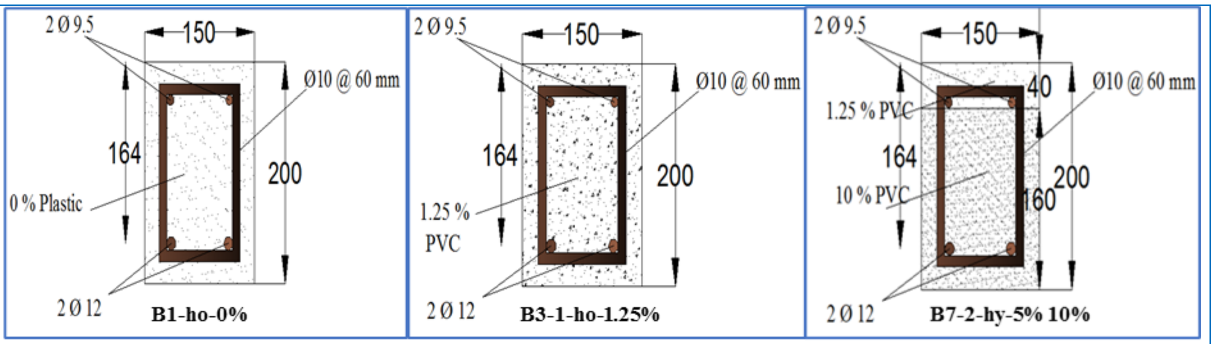

Fig. 5 Beams details

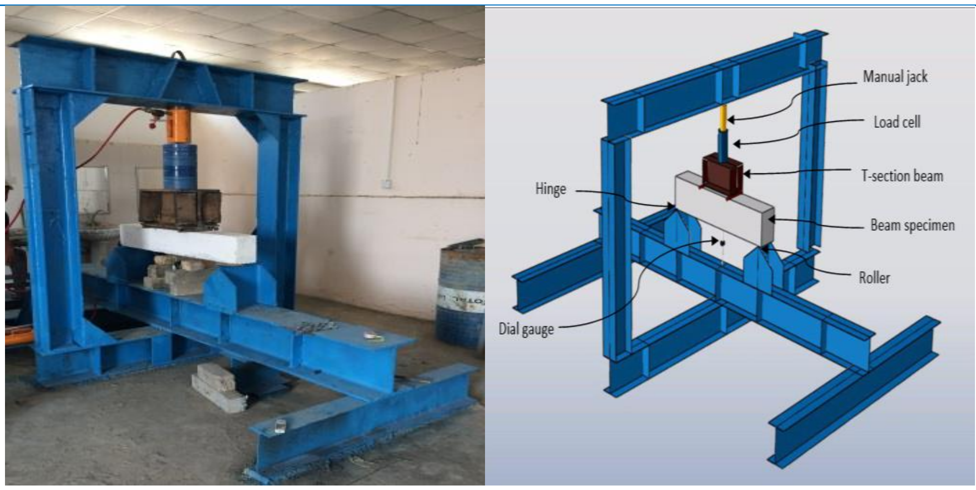

Fig. 6 Testing machine

Table 12 Beams details

No.	Beam Designation	Cross section	Percentage of plastic waste	Constituent	Waste replacement	A form of plastic used
1	B1-ho-0%	Homogenous	0 %	Reference beam with normal mixture	-	---
2	B3-1-ho-1.25%	Homogenous	1.25 %	Beam with optimum mixture of PVC that equal to 1.25 % by weight of sand and normal reinforcement	Sand replacement	
3	B7-2-hy-5% 10%	Hybrid	1.25 % in Compression zone 10 % in Tension zone	Beam with two mixtures (Hybrid PVC) one of them in the compression part that consists of 1.25 % PVC and the other in the tension part consists of 10 % PVC and normal reinforcement	Sand replacement	

4.1 Beam ultimate load

The ultimate loads for all concrete beams are recorded and presented in Table.13. The ultimate failure load of reference beam (B1-0-ho-0%) which had homogeneous cross section of normal concrete without wastes is 82.5 kN. The beam (B3-1-ho-1.25%) which have homogenous cross section with 1.25% PVC waste as sand replacement, showed higher ultimate failure load than reference beam by about 6.06%. this result coincides with trial mixes which showed that 1.25% PVC waste is the optimum percentage and gives higher compressive and tensile stresses.

In order to use as much as possible of PVC wastes within concrete beams, a hybrid-cross section concrete beams are presented, namely beam (B7-1-hy-1.25% 10%). The hybrid cross section is achieved by using concrete mix with optimum percentages of PVC wastes as sand replacement, namely 1.25% above the natural axis (compression zone). While in the lower part of beam's cross section below neutral axis (tension zone) the concrete mixes with 10% percentage of PVC wastes are used as sand replacement. The use of hybrid section yields ultimate loads of about 85% of reference beam (14.5% reduction in ultimate load) as shown in Table 13, namely acceptable results taking into account the amount plastic wastes that recycled into concrete beams.

4.2 Beams deflection

The maximum deflection for all concrete beams are presented in Table 13. The maximum deflection of reference beam (B1-0-ho-0%) is 12.65 mm, which is lower than all beams that included PVC waste. The beam that contain 1.25% PVC wastes with concrete mixture, namely (B3-1-ho-1.25%) showed maximum deflection of 25.55 mm, namely larger than reference beam by about (101.97%). While hybrid cross section beam (B7-1-hy-1.25% 10%) showed maximum deflection of 30.05 mm, namely larger than reference beam by about (137.55%). Thus, the inclusion of PVC wastes into concrete much improve the beam ductility.

4.4 Cracking

The cracking is development in concrete when applied tensile stress exceeding the tensile strength of concrete. The first crack loads for all concrete beams are presented in Table 13 and the cracking patterns for all beams at failure are shown in Fig. 7. As shown in Table 13, the reference beam (B1-0-ho-0%) and (B3-1-ho-1.25%) showed the same first crack load of 35 kN and the number of cracks at failure of eleven and eight respectively. While the first crack load for hybrid is 48 kN (namely more than reference beam by 37%) and the number of cracks at failure are six. Thus, the inclusion of PVC wastes into concrete mixture reduce the number of cracks and increase the cracking load, and as the amount of PVC in tension zone is increased as the number of cracks are decreased.

Table 13 Load and deflection values of reinforced concrete beams

Beam No.	F_{cu} (MPa)	P_{cr} (kN)	P_u (kN)	Δ_y (mm)	Δ_u (mm)	$P_u/P_{Ref.}$ (%)	Changing in ultimate load (%)
B1-0-ho-0%	35.8	35	82.5	4.23	12.65	100	----
B2-1-ho-1.25%	47.2	35	87.5	8.13	25.55	106.06	+ 6.06
B3-1-hy-1.25% 10%	29.9	48	70.5	5.3	30.05	85.45	- 14.5

(a) B1-0-ho-0%

(b) B2-1-ho-1.25%	
(c) B3-1-hy-1.25% 10%	

Fig. 7 Crack pattern for beams tested

5. Conclusions

The research draws the following conclusions:

- Considering the fresh concrete outcomes, the including of PVC particles within the concrete mixture decreased the workability for all mixtures.
- From the hardened concrete findings, the incorporation of PVC particles into the mixture decreased the tensile and flexural strength, and improved the compressive strength. All mixtures meet the increasing in compressive strength. The RPVC-1.25 was the only mixture, which caused enhancement the tensile strength by 18.52%. All mixtures showed the down in modulus of rupture by 0.75%, 5.08%, 29.58%, 16.01%, and 18.85% with the replacement of RPVC-2.5-0.41, RPVC-2.5-0.41 RPVC-3.75-0.41, RPVC-2.5-0.53, RPVC-3.75-0.53, and RPVC-5-0.53, respectively, except for the concrete mixtures of RPVC-1.25-0.41, RPVC-5-0.41.
- Despite the slight decrease in the bending strength with a percentage of 2.5% and 3.75% PVCPs, the presence of PVC particles within the mix prevents sudden division of the samples, which means that the two parts of the specimen remain attached to each other.
- The PVCPs of RCBs had a slight increase in final (Ultimate) failure load, but the hybrid-section beam had a small decrease compared to the control beam.
- In spite of the little decreasing in the ultimate load of the hybrid beam, the inclusion of recycled Polyvinyl chloride particles (RPVCPs) within the concrete mixture of beams had a positive effect on the deflection and ductility behaviour of them all. This behaviour much is observed in the hybrid beam. During the cracking stage, the hybrid beam containing 1.25-RPVC and 10-RPVC in the compression and tension zones, respectively, showed that the strength of the first crack improved compared with the control concrete beam. However, adding RPVCPs to the reinforced concrete produced significant results, particularly in the linear elastic region.

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