BJES Basrah Journal for Engineering Sciences

Basrah Journal for Engineering Sciences, Vol. 23, No. 2, (2023), 126-138

Original Article

Journal homepage: www.bjes.edu.iq
ISSN (Online): 23118385, ISSN (Print): 18146120

OPEN ACCESS

Improving Behavior of Reinforced Concrete Members Containing Waste Plastic by Adding Shredded Paper

Daoud S. Manshad [1, *], Fareed H. Majeed [2], Majed A. Khalaf [3]

[1,2,3] *Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq*
E-mail addresses: arceng.d@gmail.com , fareed.majeed@uobasrah.edu.iq , majed.khalaf@uobasrah.edu.iq

Received: 16 June 2023; Revised: 29 July 2023; Accepted: 10 August 2023; Published: 30 December 2023

Abstract

This study is to investigate the effect of partially replacement of coarse aggregate by waste plastic and using the paper sludge as additive material at concrete, on the hardened concrete properties and its impact on structural behavior of the reinforced concrete members (slab, column, and beam). Plastics and paper are widely used in daily life in huge amounts. Both incineration and landfilling are options for disposing of plastic and paper waste, but either one could be harmful to the environment. Therefore, reducing waste or increasing its value can reduce pollution and reduce disposal costs. The variables of the experimental program include the ratio of waste plastic and paper sludge, the used ratios for plastic and paper were (5%, 10%, and 15%) by volume. Hardened concrete properties were investigated for concrete include: flexural strength, modulus of elasticity, and splitting tensile strength. For each structural reinforced member, the (Load – Deflection) curve has been extracted. The study shows that the plastic waste negatively affects most of concrete properties. The research indicates that using waste plastic in reinforced concrete members with percentage of (5% and 10%) by volume as a partially replacement of coarse aggregate giving acceptable results. However, when adding (5%) by mixture volume of waste paper in reinforced concrete members, the load-deflection behavior and ultimate load-bearing capacity have been improved. In general, using waste plastic and paper sludge in concrete mixtures lead to reduction in ultimate load ranging between (4.62%-10.82%) for slab under point load, (4.85-18.99%) slab under distributed load, (3.72%-12.21%) column, and (1.78%-7.16%) beam specimens respectively.

Keywords: waste plastic, shredded paper, paper sludge, structural members.

https://doi.org/10.33971/bjes.23.2.15

1. Introduction

Currently, either burning or burying these plastic wastes are the methods used to get rid of them. However, these cycles are pricey, if thermosetting plastic waste can be reused, both the consumption system's environmental impact and the cost of these waste management cycles can be reduced [2]. In this study, the first kind will be used. In concrete mixtures, plastic aggregate is added as a partial replacement for coarse aggregate (CA) or fine aggregate (FA). Plastic aggregates are preferred for the production of lightweight concrete because they generally have a lower bulk density than natural aggregates [3]. In addition, numerous studies have reported that plastic aggregates have a significant impact on a variety of concrete properties, including fresh, physical, mechanical, thermal, acoustic, and others. [4]. Al- Hadithi and Mustafa[5] studied the effect of waste plastic fibers (PET) on the shear behavior of seven reinforced concrete beams with that were designed to fail in shear, the fibers percentages that were used in this study are (0.25, 0.5, 0.75, 1,1.25 and 1.5)%. The shear strength and absorbed energy of reinforced concrete beams were increased with incorporating the plastic fibers in concrete until the fibers percentage of (1%) that recorded increase in the applied load about (8.54%). K.B. Osifala et al [6] investigated the effect of waste plastic shreds on steel-concrete bond. From the test results and analysis, the waste plastic shreds material was found not to improve the bond resistance between concrete and steel. However, though lower than normal concrete, there was an increase in the bond resistance with increase in the percent of plastic shreds. Batayneh et al. [7] investigated how grinded plastic affected concrete slump. With an increase in the proportion of plastic particles, the slump decreased, and the slump dropped to 25% of the original slump value with 0% plastic particle content for a replacement of 20%. Choi et al. [8] studied the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the compressive strength of concrete. It can be seen that compressive strength of concrete mixtures decreased with the increase in PET aggregates. Soroushian et al. [9] Reported that the incorporation of discrete reinforcement into concrete resulted in a decrease in air permeability. S. B. Kim et al. [10] investigated the deflection behavior of a reinforced concrete beam containing varying amounts of PET fibers. Compared to concrete specimens lacking fiber, specimens with fiber volume fractions of 0.5 percent, 0.75%, and 1.0 percent experienced increases in ultimate strength of 25 percent, 31 percent, and 32 percent, respectively, as well as increases in deflection of seven, eight, and ten times, respectively. Al-Hadithi et al. [11] investigated the impact resistance of concrete slabs using a variety of volume percentage replacement ratios for waste plastic fibers (originally derived from soft drink bottles). The results revealed that all mixes containing waste plastic fibers had significantly improved low-velocity impact resistance. K.B. Osifala et al [12] studied the effect of plastic waste on the bond between steel and concrete. The waste plastic shreds material did not improve the bond resistance between concrete and steel, according to the test results and analysis. Omar K. A. et al (2021) [13] investigated how the flexural behavior of reinforced concrete beams was affected by Polyethylene terephthalate (PET) fibers. They discovered: When compared to the reference beam, an increase in the ultimate load and ultimate deflection was achieved by adding the plastic fibers to the beams in a ratio of (0.5%). Fuller.B et al. [14] made research to determine whether paper-crete is suitable for use as a home construction material based on its mechanical and physical properties. The Young's Modulus (E), thermal conductivity (K), thermal resistance (R), bond characteristics, and creep behavior were the parameters he investigated. According to the Stress - Strain curves, paper-crete is a ductile material that can withstand significant deformations. H.Jung, et al. [15] conducted an experiment on bricks to determine the mechanical properties of waste paper, and the results showed that an increase in the paper-to-cement ratio led to a decrease in the density of concrete and an increase in the shrinkage of concrete. M. S. Suganya [32-16] reported that, Paper-crete bricks, are lighter and more flexible. Paper-crete bricks might be a good choice for earthquake-prone regions. Shatha R. A. et al. [17] prepared study to examining utilizing wastepaper as additive material to the concrete mixture to be used in construction purposes. At (28) days of curing age, the addition of wastepaper via volume resulted in a (0.24) percent decrease in density while simultaneously increasing compressive strength, splitting strength, flexural tensile strength, and water absorption by (22.56) percent, (17.63) percent, (4.8) percent, and (44.19) percent, respectively. Fareed H. Majeed [18] investigated the concrete's resistance to chloride attacks. The plastic fine aggregate (PFA)'s effects on concrete's mechanical and physical properties were investigated. Up until a PFA-to-concrete ratio of 20 percent, the unit weight and mechanical properties of concrete decreased slightly. However, when compared to concrete protected by reliable methods, the results demonstrated significant improvements in PFA concrete's resistance to chloride attack under normal, cyclic, and aggressive chloride attack conditions. Ahmad K. Jassim [19] investigated the possibility of producing plastic cement from polyethylene waste mixing with Portland cement using different percentages. According to the findings, the concrete mix design's percentage of waste polyethylene affected the density of the produced plastic cement. It gets higher as the percentage of waste gets higher—up to 30 percent—then gradually gets lower. Decreasing in density was (15%) compared to conventional concrete.

According to the previous researches the following can be concluded:

1. Plastic aggregates can be successfully and effectively utilized to replace conventional aggregates.
2. The use of the recycled plastic in the concrete reduced the overall concrete bulk density.
3. Splitting tensile strength of concrete made with plastic aggregates was found to decrease with increase in the percentage of plastic aggregates.
4. Results showed a significant improvement in low-velocity impact resistance of mixes containing waste plastic fibers.
5. The studies indicate that waste paper can be used as additional material in reinforced concrete members to improve load-deflection behavior and ultimate load-bearing capacity.

2. Experimental Program

2.1. Materials

All of the specimens were cast using ordinary Portland cement (Mabroka), which was available on the local market. Sand and gravel from AlZubair region was utilized for concrete mixes in this research as shown in Tables 1 to 4, and Figures 1 and 2. Different deformed reinforcement bar sizes were used in this study as detailed in Table 5. An irregular shape, waste plastic from a local plastic recycling area in Basra have used as a partial replacement of coarse aggregate in three different ratios (5%, 10%, and 15%) by volume. A waste plastic sample and properties are illustrated in Figure 1 and Table 6, respectively. In this study, wastepaper (ordinary printing paper) were used as the additive material to the mixture in three different ratios (5%, 10%, and 15%) by total volume. Table 7 indicates shredded paper physical properties. Waste paper was first of all decreased into little pieces by using a paper cutter. Then, the shredded paper was soaked in water for 48 hours as shown in Figure 2. Then the papers were weighed and immersed in water. After that, the papers were blended in a mixer to get the paper sludge.

Fig. 1 Waste plastic.

Fig. 2 Paper sludge.

Table.1 Sand grading.

Sieve Size (mm)	Passing (%)	Limitations (%)
4.75	96	90-100
2.36	88	85-100
1.18	76	75-100
0.6	62	60-79
0.3	18	12- 40
0.15	4.5	0-10

Table 2. Physical properties of sand.

No.	Property	Test Results
1	Fineness Modulus	2.62
2	Bulk Density (kg/m^3)	1680
3	Moisture Content (%)	0.31
4	Specific gravity	2.56

Table 3. Physical properties of gravel.

No.	Property	Test Results
1	Specific gravity	2.67
2	Absorption	0.6 %
3	Bulk density Kg/m^3	1480

Table 4. Gravel grading.

No.	Sieve size (mm)	%Passing	
		test result (%)	Limitations (%)
1	20	100	100
2	14	96	90-100
3	10	76.6	50-85
4	5	3.5	0-10
5	2.36	0	---

Table 5. Reinforcement bars properties.

Bar dia. (mm)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
8	460	529	12
10	467	624	13
12	590	720	14
16	500	710	16

Table 6. Physical Properties of Plastic.

Property	Values
Dimensions (mm)	Variable (5 - 20)
Density (kg/m^3)	378

Table 7. Physical Properties of Shredded Paper.

Property	Values
Density (kg/m^3)	45
Specific Gravity *	0.98
Absorption (%) *	0.90

*Shatha et al. (2020) [35].

2.2. Mix Design

Sixteen trial mixtures have been designed according to (ACI 211.1-91) [20] to find the best mixing ratios for waste plastic and paper sludge. Five mixing ratios have been chosen to study behavior of structural reinforced concrete members as shown in Table 8.

Table 8. Chosen mixing ratio.

Mixing Ratio	Identification	Cement Kg/m^3	Gravel Kg/m^3	Sand Kg/m^3	Plastic Kg/m^3	Paper Kg/m^3	Water L/m^3
Reference	R	466	1042	626	0	0	210
5 % pl	PL5%	466	968	626	18.9	0	210
10 % pl	PL10%	466	858	626	37.8	0	210
5 % pp + 5 % pl	PPL5%	466	968	626	18.9	2.25	210
5 % pp + 10 % pl	PPL10%	466	858	626	37.8	2.25	210

3. Structural member's specimens

As mentioned recently, five mixing ratios have been chosen to study behavior of structural reinforced concrete members, and accordingly, five specimens of each structural member were casted.

3.1 Specimens Details and Reinforcement

3.1.1 Two Way Slabs

Ten slabs were cast, with half of them designed to fail under concentrated load and the other half designed to fail under uniform load. With dimensions of (800mm x 800mm) and a thickness of (100mm), each slab was cast. The slabs were cast with the same reinforcement ratio, and five mixes based on the ratios of paper sludge and plastic aggregate were used, as shown in Table 8. Steel mesh (Ø8 mm) square opening of size (200 mm c/c) were used to reinforce the slabs. Figure 4 displays reinforcement and details of the slabs.

3.1.2 Rectangular cross section beams

Five cast beams were designed to fail in flexure when subjected to a concentrated load. The dimensions of each cast beam were (900 mm x 300 mm x 150 mm) in length, width, and height, respectively. Five mixes based on the ratios of plastic aggregate and paper sludge were used to cast the beams, as shown in the Table 8. The beams were reinforced with (4Ø12mm) in the longitudinal direction and (6Ø10 mm) closed stirrups in the transverse direction. Figure 5 shows reinforcement and details of the beams.

3.1.2 Square cross section columns

The capacity and deformation of five casted columns under load were evaluated. The cast columns had a square section of (200mm x 200mm) and a height of (800mm). As can be seen in Table 8, five mixes based on the ratios of plastic aggregate and paper sludge were used to cast the columns. The beams were reinforced with (4Ø16mm) in the longitudinal direction and (6Ø12 mm) closed stirrups in the transverse direction as shown Figure 6.

Fig. 3 Forms and Reinforcement of the Specimens.

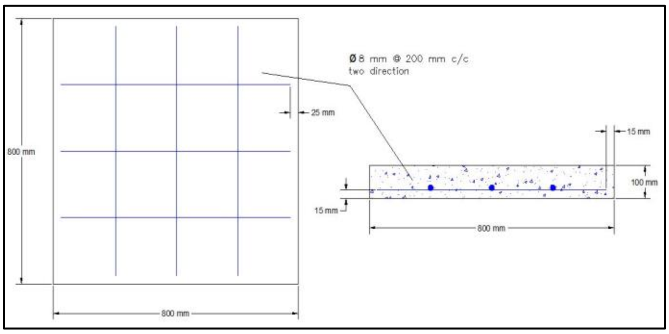

Fig. 4 Slabs reinforcement.

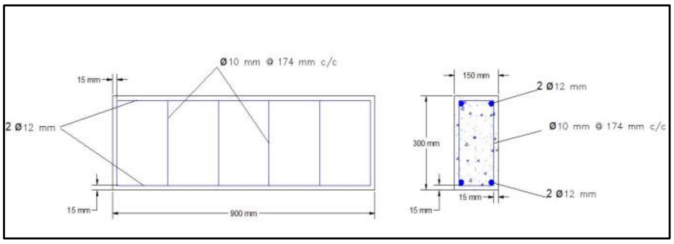

Fig. 5 Beams reinforcement.

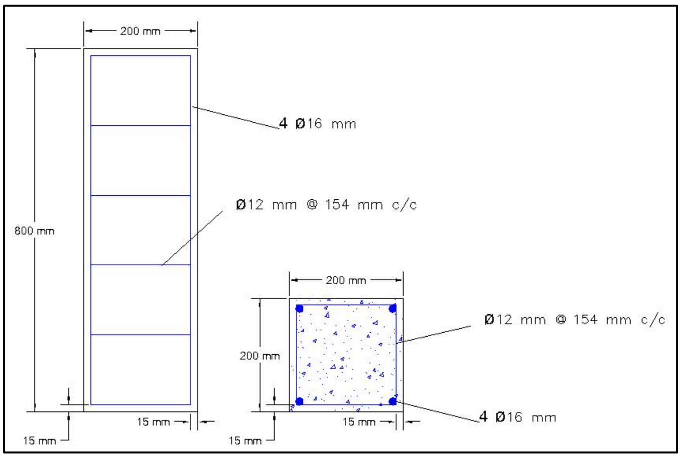

Fig. 6 Columns reinforcement.

3. Testing setup

Deflection was measured using an LVDT (Linear Variable Differential Transformer). A load cell with a capacity of 75 tons was used to measure the applied load in the middle of the specimens. The loads were applied by using Universal Testing machine with a capacity of 200 ton. The load was applied at a different rate according to expected ultimate capacity, however, the minimum step value was 250N.Both of LVDT sensor and the load cell were connected to a computer equipped with an application that can record the applied load and the resulted deflection simultaneously as shown in Figure 7.

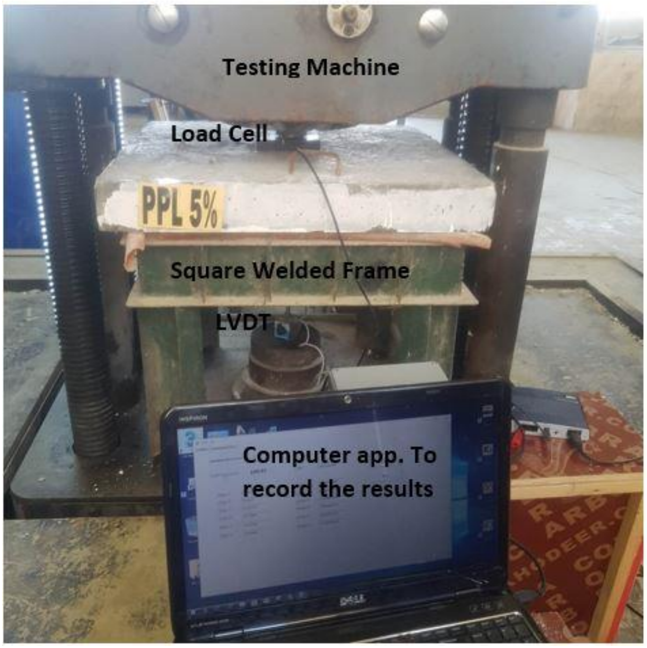

Fig. 7 Test Instruments.

3.1 Flexural test of two way slab

For point load test: The slabs were simply supported by a 700 x 700 mm square welded frame. Deflection at the span's center was measured using an LVDT. The load was applied in the middle of the slab. For distributed load test: Over the surface of the tested slab, a square welded frame with dimensions of (800 * 800) mm and a height of (100) mm was filled with fine sand to ensure uniform load distribution as displayed in Figures 8 and 9.

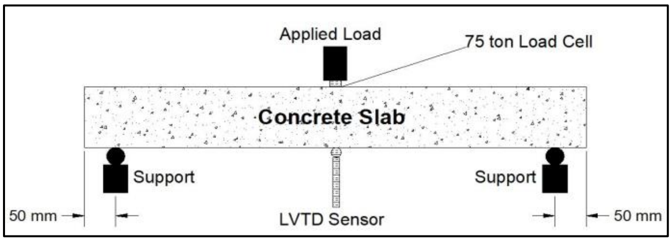

Fig. 8 Flexural test of two way Slab under Point Load.

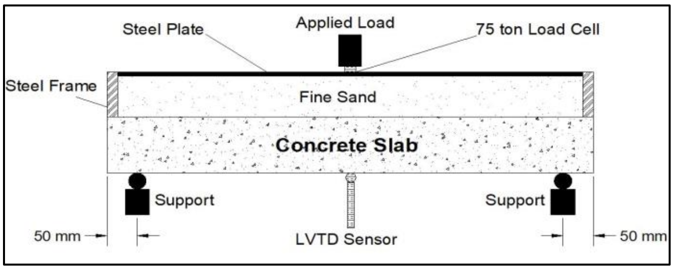

Fig. 9 Flexural test of two way slab under distributed load.

3.2 Column capacity and shortness test under axial load

The column was placed vertically under load center of the testing machine. The load was gradually applied. At every load increment, readings of load and resulted shortness have been recorded manually.

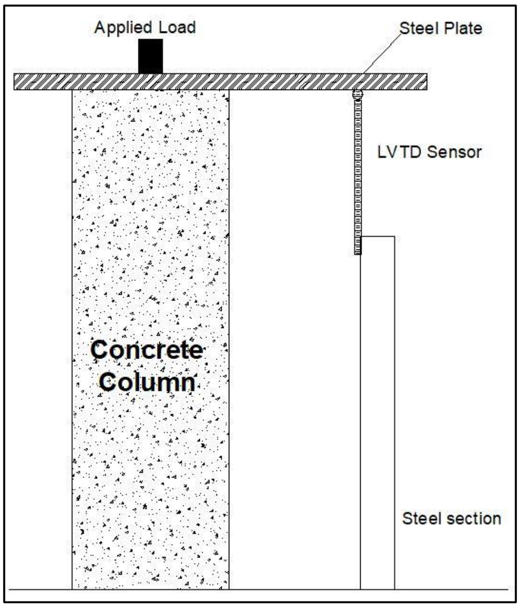

Fig. 10 Column test instruments.

3.3 Flexural Test of Beam under point Load

The beam was simply supported on welded steel supports with a clear span (700) mm. LVDT was used to measure deflection at center of span. Applied load and the resulted deflection were recorded by a computer application simultaneously.

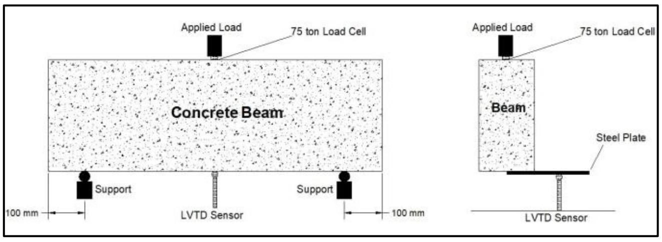

Fig. 11 Beam Test Instruments.

4. Hardened concrete test results

4.1 Compressive strength

The effects of partially replacing coarse aggregate with waste plastic and using paper sludge as an additive material in concrete were examined using sixteen trial mixtures. Compressive strength results for (7) days and (28) days ages reveal that increasing of waste plastic ratio decrease compressive strength for all mixtures types, opposite to that addition of paper sludge ratio to maximum (5%) improve compressive strength, the higher percentage (10% and 15%) will reduce the compressive strength as shown in Figure 12. According to the results, four mixtures as well as reference mixture were chosen for the next stages of test. As detailed in Table 9.

4.2 Splitting tensile and flexural Strengths

Both splitting tensile and flexural Strength are inversely proportional with waste plastic quantity, while adding paper sludge increase strength values for all mixtures as shown in Table 10. The splitting tensile strength and flexural Strength of all concrete mixtures is depicted in Figures 13 and 14 respectively.

4.3 Modulus of Elasticity and Poisson's Ratio

The waste plastic ratio had a significant impact on the modulus of elasticity. When compared to the reference mixture, the modulus of elasticity of the mixture that contains waste plastic was decreased. Modulus of elasticity value was increased when shredded paper added to concrete mixtures comparing to modulus of elasticity of reference mixture. Unlike other properties Poisson's ratio was increased for all waste plastic ratios compared to reference mixture, while decreased for concrete mixtures containing shredded paper. Modulus of elasticity and Poisson's ratios and for all concrete mixtures are depicted in Figure 14 and 15. Table 11 shows the variety in modulus of elasticity and Poisson's ratio for all mixtures comparing to reference mixture.

4. Structural Members Specimens test results

In order to investigate the behavior of structural reinforced concrete members, five specimens of each structural member were made, as previously mentioned. Figures (20 to 23) show specimens after testing.

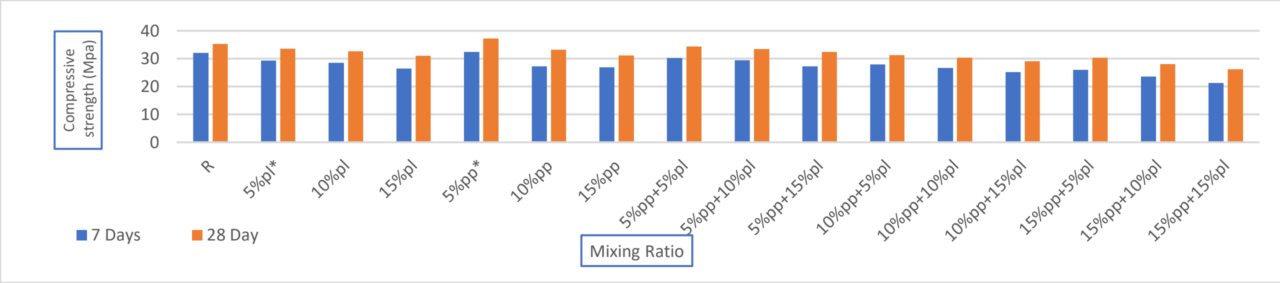

Fig. 12 Compressive strength results for 16 trial mixtures.

Table 9. Chosen mixtures compressive strength.

Mixing Ratio	Identification	7 days compressive strength (MPa)	Reduction Comparing to Reference %	28 days compressive strength (MPa)	Reduction Comparing to Reference %
Reference	R	32.12	0.00	35.31	0.00
5%pl	PL5%	29.32	8.72	33.60	4.84
10%pl	PL10%	28.50	11.27	32.70	7.39
5%pp+5%pl	PPL5%	30.20	5.98	34.33	2.78
5%pp+10%pl	PPL10%	29.40	8.47	33.45	5.27

Table 10. Splitting Tensile Strength and Flexural Strength.

Mixing Ratio	Identification	Splitting Tensile Strength (MPa)	Reduction Comparing to Reference %	Flexural Strength (MPa)	Reduction Comparing to Reference %
Reference	R	3.11	0.00	4.77	0.00
5%pl	PL5%	2.87	7.72	4.12	13.63
10%pl	PL10%	2.71	12.86	3.68	22.85
5%pp+5%pl	PPL5%	3.01	3.22	4.37	8.39
5%pp+10%pl	PPL10%	2.81	9.65	4.1	14.05

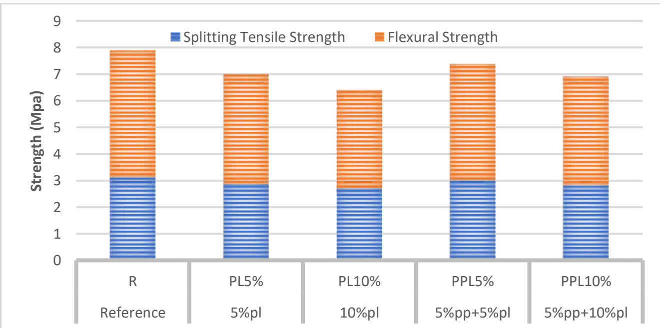

Fig. 13 Splitting & Flexural Strength.

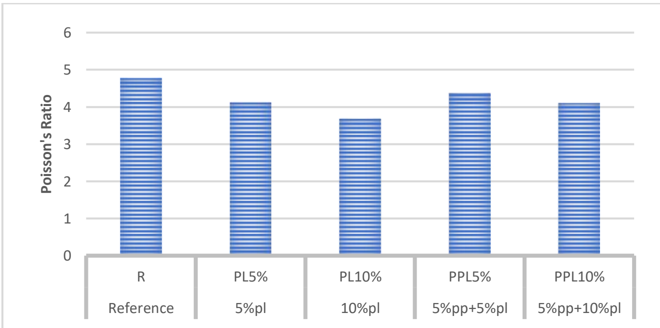

Fig. 15 Poisson's ratio.

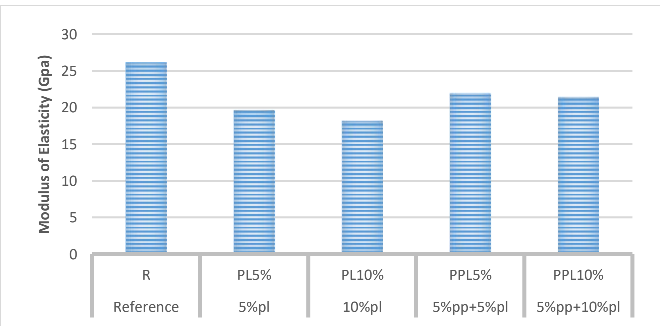

Fig. 14 modulus of elasticity.

5.1 Ultimate Load & First Crack Load

In general, the ultimate load and first crack load were higher in mixtures containing shredded paper in all specimens and lower in mixtures containing waste plastic, as shown in Tables (12-15).

5.2 Mid-Span Deflection

All of the specimens were measured for deflection at mid-span, and the results are shown in Tables (16and17). Deflection values showing that utilizing waste plastic was raised deflections values. Figures (16) to (19) show Load – Deflection curve for all concrete mixtures.

Table 11. Modulus of Elasticity and Poisson's Ratio.

Mixing Ratio	Identification	Modulus of Elasticity (GPa)	Reduction Comparing to Reference %	Poisson's Ratio	Increasing Comparing to Reference %
Reference	R	26.13	- 0.00	0.192	+ 0.00
5%pl	PL5%	19.65	- 24.8	0.215	+ 10.70
10%pl	PL10%	18.14	- 30.58	0.221	+ 13.12
5%pp+5%pl	PPL5%	21.92	- 16.11	0.196	+ 2.04
5%pp+10%pl	PPL10%	21.37	- 18.22	0.201	+ 4.48

Table 12. Ultimate Load.

Mixing Ratio	Identification	Slab Specimen Under Point Load (Kn)	Slab Specimen Under Distributed Load (Kn)	Beam Specimen (Kn)	Column Specimen (Kn)
Reference	R	163.30	595.12	261.11	1482.70
5%pl	PL5%	153.50	537.40	249.12	1423.60
10%pl	PL10%	145.63	482.06	242.40	1302.31
5%pp+5%pl	PPL5%	160.76	564.80	256.89	1479.00
5%pp+10%pl	PPL10%	152.41	538.20	246.52	1370.10

Table 13. Decreasing in Ultimate Load Comparing with Reference.

Mixing Ratio	Identification	Slab Specimen Under Point Load (%)	Slab Specimen Under Distributed Load (%)	Beam Specimen (%)	Column Specimen (%)
Reference	R	0.00	0.00	0.00	0.00
5%pl	PL5%	6.00	9.70	4.59	3.99
10%pl	PL10%	10.82	19.00	7.17	12.17
5%pp+5%pl	PPL5%	1.56	5.09	1.62	0.25
5%pp+10%pl	PPL10%	6.67	9.56	5.59	7.59

Table 14. First Crack Load.

Mixing Ratio	Identification	Slab Specimen Under Point Load (Kn)	Slab Specimen Under Distributed Load (Kn)	Beam Specimen (Kn)	Column Specimen (Kn)
Reference	R	70.11	312.00	119.12	1482.70
5%pl	PL5%	60.31	260.00	107.68	1423.60
10%pl	PL10%	57.36	255.30	101.85	1302.31
5%pp+5%pl	PPL5%	68.95	267.00	113.87	1479.00
5%pp+10%pl	PPL10%	66.98	268.00	105.67	1370.10

Table 15. Decreasing in First Crack Load Comparing with Reference.

Mixing Ratio	Identification	Slab Specimen Under Point Load (%)	Slab Specimen Under Distributed Load (%)	Beam Specimen (%)	Column Specimen (%)
Reference	R	0.00	0.00	0.00	0.00
5%pl	PL5%	13.98	16.67	9.60	3.99
10%pl	PL10%	18.19	18.17	14.50	12.17
5%pp+5%pl	PPL5%	1.65	14.42	4.41	0.25
5%pp+10%pl	PPL10%	4.46	14.10	11.29	7.59

Table 16. Deflection values for all specimens.

Mixing Ratio	Identification	Slab Specimen Under Point Load (mm)	Slab Specimen Under Distributed Load (mm)	Beam Specimen (mm)	Column Specimen (mm)
Reference	R	1.48	0.53	2.67	2.33
5%pl	PL5%	1.73	0.66	2.96	2.40
10%pl	PL10%	2.00	0.71	3.10	2.66
5%pp+5%pl	PPL5%	1.63	0.64	2.74	2.36
5%pp+10%pl	PPL10%	1.66	0.67	2.83	2.46

Table 17. Increasing in Deflection Comparing with Reference.

Mixing Ratio	Identification	Slab Specimen Under Point Load (%)	Slab Specimen Under Distributed Load (%)	Beam Specimen (%)	Column Specimen (%)
Reference	R	0.00	0.00	0.00	0.00
5%pl	PL5%	14.45	19.70	9.80	2.92
10%pl	PL10%	26.00	25.35	13.87	12.41
5%pp+5%pl	PPL5%	9.20	17.19	2.55	1.27
5%pp+10%pl	PPL10%	10.84	20.90	5.65	5.28

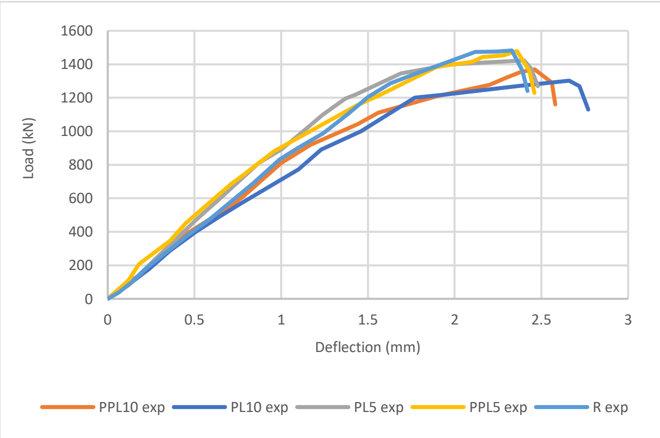

Fig. 16 Load –Deflection Curves for Columns Specimens.

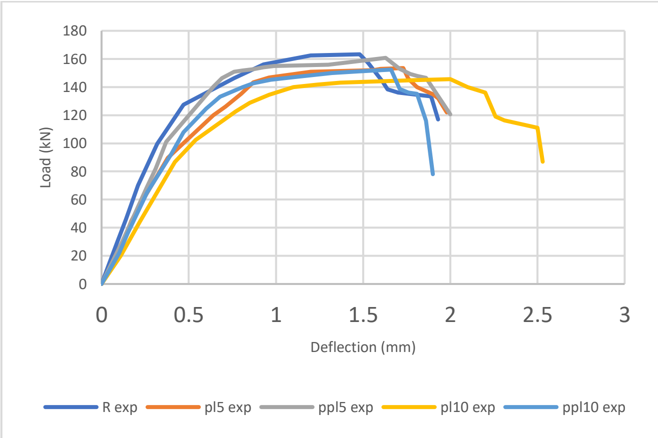

Fig. 18 Load–Deflection Curves for Slab Specimens under Point Load.

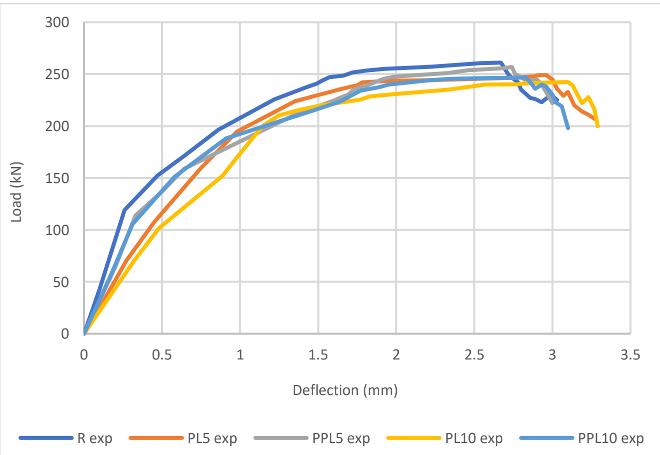

Fig. 17 Load –Deflection Curves for Beams Specimens.

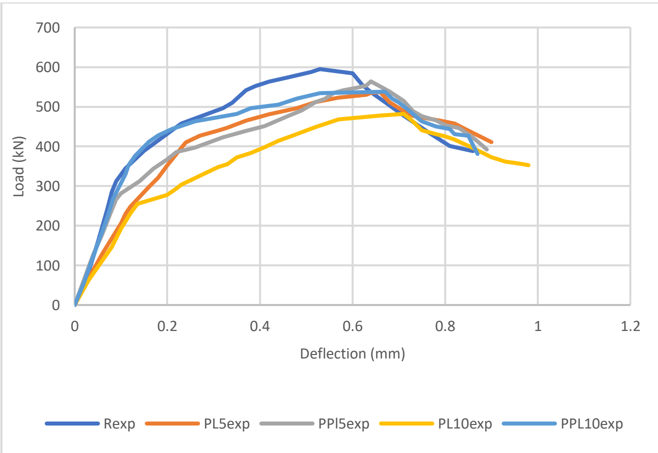

Fig. 19 Load–Deflection Curves for Slab Specimens under Distributed Load.

Fig. 20

Beam Specimens

Fig. 21

Slab Specimens
Under Distributed Load

Fig. 22

Column Specimens

Fig. 23

Slab Specimens
Under Point Load

6. Conclusions

Based on experimental results the following conclusions can be deduced:

1. Results reveal that increasing of waste plastic ratio decrease compressive strength for all mixtures types between (2.78 - 7.39) % comparing to reference mixture, opposite to that addition of paper sludge ratio to maximum (5%) improve compressive strength, the higher percentage will reduce the compressive strength.
2. Both splitting tensile and flexural Strength are inversely proportional with waste plastic quantity, while adding paper sludge increase strength values for all mixtures. Generally, the decreasing was ranging between (3.22 - 12.86) % for splitting strength and (8.39 - 22.85) % for flexural strength when compared to reference mixture.
3. Modulus of elasticity of the mixture that contains waste plastic was decreased by (16.11) % to (30.58) %, while it was increased when shredded paper added to concrete mixtures comparing to modulus of elasticity of reference mixture.
4. Unlike other properties Poisson's ratio was increased in range between (2.04 - 13.12) percent for all waste plastic ratios compared to reference mixture, while decreased for concrete mixtures containing shredded paper.
5. In general, the ultimate load and first crack load were higher in mixtures containing shredded paper in all specimens and lower in mixtures containing waste plastic. Ultimate load was decreased by (0.25 - 19) %, while first crack load was reduced by (0.25 - 18.19) % comparing to reference mixture.
6. Deflection values showing that utilizing waste plastic was raised deflections values between (1.27 - 26) %, reverse effect was noticed when adding paper sludge.

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