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STRUCTURAL BEHAVIOR OF REINFORCED LIGHTWEIGHT CONCRETE BEAMS MADE OF RECYCLED WOOD AGGREGATES

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Abstract:
This research includes the study of structural behavior of sustainable lightweight reinforced concrete beams with waste wood particles as aggregates. Wood particles of aggregate size have been used in variation with percentages (0%, 5%, 10%, and 15%) of the cement weight. The concrete produced becomes light weight reaching 1600 kg/m3 (33% reduction) The workability kept constant by controlling mix properties by a superplasticizer SP doses. Reference beams were made also for comparative purposes. Compressive strength ranged between 60 MPa for control samples to 30 MPa for 15% wood particle concrete and respective flexural strengths were 22 to 12 MPa. Twelve beams are molded of (100×150×900mm) dimension with different steel reinforcement ratio (ρ). Load-deflection relationships of beams were established. The effects of steel reinforcement ratio (ρ) on the displacement ductility of reinforced concrete beams were concluded. The lightweight beams have a softer response in terms of structural behavior, with more ductility than those made by reference concretes. These findings provide encouragement to use the wood particles lightweight concrete in structures. However, durability remains the main concern. The concrete should be protected from severe exposure and humidity. Therefore, it is recommended to be used in indoor exposure.

Keywords: *Lightweight Concrete; Recycled Waste Wood; Structural Behavior; Sustainability*

1. Introduction

One of the main sustainability measures in construction is to finding ways to recycle waste materials [1; 2]. Recycling is the reprocessing of old materials into the new products [3]. Recycling or re-using of wood wastes is an environmentally friendly way of eliminating it from the waste stream. Recycled wood particles recovered from carpenters can be utilized in the manufacture of new concrete mixtures [4]. At this way, it is possible to reduce the problem of demolition waste storage, and to reduce the consumption of natural materials. The utilization of wood particles waste and as an aggregate in mortar and concrete would have a positive effect on the economy also.

Al-Numan, BS, and Ahmed, JK [5] investigated light-weight aggregate concrete with wood particles and its issues according to physical and thermal properties and presented experimental work for the estimation of density, absorption, and thermal conductivity of light-weight wood-particles aggregate concrete. Wide range of wood-particles percentages were used in the experimental work. The authors in a following paper correlated thermal conductivity to the air-dry density of wood-particles aggregate concrete. The relation they established lied closely within the predictions presented in ACI 213 committee report [6] for a range of airdry density between 1400 to 1900 kg/m3 [7].

M. Li et al [8] through an experimental work, obtained elastic properties to develop a finite element model for simulating wood-concrete timber panels, tested in three-point bending. The difficulties in determining the mechanical properties of composite panels using cement as binder are discussed. The test results allow the computation of the moduli of rupture and elasticity. It is also shown that the ratio between flexural and compressive strength is around 47%.

Cement / concrete -wood products have been under many research work with many industrial applications [9; 10; 11]. The wood concrete is considered as a sustainable material in construction [12, 13]. Wood cement composite may required some treatment to improve the physio mechanical properties [14; 15].

Al-Numan and Ahmed [16] studied the properties of lightweight aggregate concrete made of waste wood particles and this work is a continuation to study the strength and load deflection behavior of reinforced beams made of this concrete.

2. Materials

2.1 Cement

A Portland cement CEM I 52.5 manufactured by Tasluja Company (Slemania, Iraq) was used. The chemical analysis of this cement is given in Table 1 and its mechanical properties, provided by the laboratory tests, are summarized in Table 2. [16].

Table 1: Chemical properties of Taslujas Cement

Compound Composition	Chemical Composition	OPC (%)	GP (%)	Astm-C618
Lime	CaO	61.66	9.868	
Silica	SiO_2	19.83	74.03	
Alumina	Al_2O_3	4.48	1.023	
Magnesia	MgO	3.14	0.108	
Ferrite	Fe_2O_3	2.32	4.739	
Sulfur Trioxide	SO_3	2.57	0.130	
Potassium Oxide	K_2O	0.68	0.198	
Sodium Oxide	Na_2O	0.19	8.024	
Loss on Ignition	LOI	1.5	1.830	
Tricalcium Silicate	Ca_3SiO_5	59.50		
Dicalcium Silicate	Ca_2SiO_4	11.98		
Aluminate Tricalcium	$Ca_3Al_2O_6$	7.95		
Tetra Calcium Aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	7.05		
$SiO_2 + Al_2O_3 + Fe_2O_3$, min. %			75.16	70
SO_3, max %			0.130	4
Moisture content, max %			-	3
Loss on ignition, max			1.830	10

Table 2: Physical properties of the Taslujas Cement

No	Physical Properties	Test results	Limit of Iraqi specifications No.5,1984
1	Specific surface area (Blaine method) m2/kg	442.6	2300 (min)
2	Setting time (vicats method) Initial setting, hrs: min Final setting, hrs: min	 1:30 (hr:min) 5:00 (hr:min)	 45 (min) 10 (max)
3	Compressive strength of mortar, (MPa) 3-day 7-day	 24 32	 15 (min) 23(min)

2.2 Sand

The sieve analysis of used sand, which is brought from a local source in Erbil city is shown in Table 3. The specific gravity of sand is 2.66 and the water absorption is 3.5%.

Table 3: sieve analysis for the used sand.

Sieve size	Retained		Passing (%)	
	Wt (g)	%	Research Sample	Iraqi Specification 1984
9.5mm	0.00	0	100	100
4.75mm	652	17.74	82.26	90-100
2.36mm	659	17.93	64.33	75-100
1.18mm	490	13.33	51	55-90
600	325	8.845	42.15	35-59
300	499	13.582	28.573	8-30
150	1015	27.62	0.92	0-10
pan	34	0.92	-	-

2.3 Aggregate

The aggregate that was used is for the control samples. The sieve analysis of used aggregates is shown in Table 4. The specific gravity of sand is 2.6 and the water absorption is 1.4%.

Table 4: size of the aggregate

Sieve size	Retained	
	Wt (g)	%
2”	0.00	0
1.5”	0.00	0
1”	0.00	0
19mm	0.00	0
12.5mm	303	3.700
9.5mm	1182	14.437
4.75mm	6674	81.519
2.36mm	27	0.329
1.16mm	1	0.012
Pan	0.003	0.000

2.4 Wood Aggregate

The wood waste particles are used as a coarse aggregate in the concrete mixture to provide a sustainable lightweight concrete mix. The used wood aggregate is an oak tree origin.

Tables 5 and 6 show the properties of the wood aggregate, and Fig. 1 shows the distribution of wood particle aggregate size.

Table 5. Physical properties of wood aggregate

Physical Properties	Test Result
Wood particle density	632 kg/m^3
Specific gravity	0.87
Water absorption	40.78%

Table 6: Size of the wood waste Particles

Sieve size	Retained	
	Wt (g)	%
2”	0.00	0
1.5”	0.00	0
1”	0.00	0
19mm	963	6.97
12.5mm	3002	21.74
9.5mm	8350	60.5
4.75mm	1241	9
2.36mm	248	1.79
1.16mm	0.00	0
pan	0.00	0

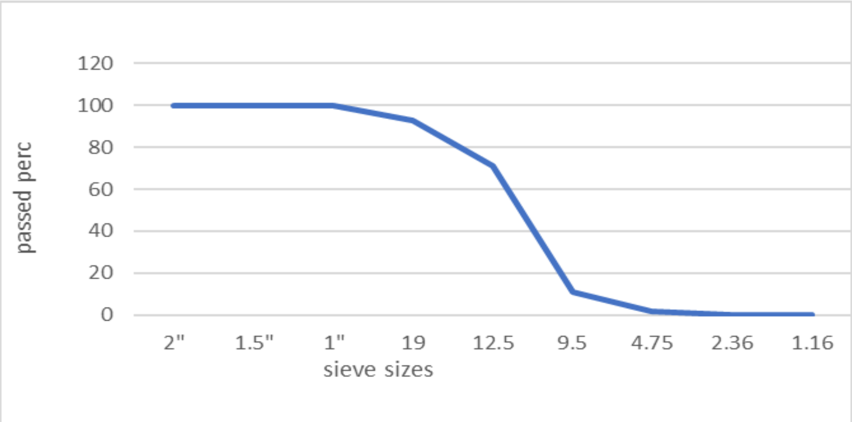

Figure 1: Passing percentage of wood aggerate

2.5 Admixture

Admixtures are added to the concrete, in addition to cement, water and aggregate, typically immediately before or during the mixing process. Superplasticizer SP33, which is Naphthalene-based (the second generation) high range water reducing superplasticizer admixture was utilized in specimens for compressive and flexural strengths to fulfill the desired flowability.

2.6 Water to cement Ratio

The water to cement ratios are varied based on wood waste percentage and admixture starting from 0.4 for control samples and decrease with the usage of superplasticizer in the concrete mix to 0.2.

2.7 Reinforcement

Steel bars were 10-mm and 6-mm diameter bars. Tests shows yield strength fy = 460 MPa, ultimate strength fu = 565 MPa, and elongation 10.5%.

3. Methodology

Structural lightweight concrete beams that are sustainable, are obtained by incorporating wood waste particles as a replacement of coarse aggregate. In this research wood percentage for the lightweight concrete mixture that can be considered in structural lightweight concrete beams, were used as 5%, 10%, and 15% by weight of cement. The density of concrete was ranged 1600 to 1900 kg/m3.

3.1 Compressive Strength

The concrete cubes were (100x100x100) mm tested for compressive strength by a compression machine.

3.2 Flexural Strength

Flexural strength, also known as modulus of rupture, three-point bending tests on 12 reinforced concrete beams had been constructed at the construction lab of Department of Civil Engineering of the Tishk international University.

3.3 Flexural strength of Reinforced Concrete Beams

All the cast reinforced beams were tested at age 90 days. Three wood particle cement replacement percentages (5%, 10% and 15%) were investigated in addition to the control beams. The beams cross-section is 100×150 mm [16], while the effective depth to total depth ratio d/h was equal to 0.86. The beams were reinforced only in tension with three different percentages: (minimum reinforcement: 2 6-mm bars), (maximum reinforcement: 3 10-mm bars) and (60% of the maximum reinforcement: 2 10-mm bars) based on ACI Code (ACI 318-19) [17]. All the beams were cast from the four different batches and shear reinforcement all along of the beam's length was provided as closed stirrups of 6-mm bars at 30 mm spacing.

4. Results

4.1 Compressive Strength

Table 7 shows the 28-day compressive strength of control and lightweight wood particle concrete.

Table 7: Compressive Strength Control and Lightweight Wood Particle Concrete

Code	Cement	Sand	Gravel	Wood% To cement	Wood Aggregate (g)	w/c ratio	Admixture SP33	Compressive Strength MPa (days)
A1	400	600	1200			0.40	--	60.3
A2	400	600	1200			0.30	6g	70.2
B1	400	600	-	5	20	0.32	-	36.75
B2	400	600	-	10	40	0.32	-	35.5
B3	400	600	-	15	60	0.32	-	30.2
C1	400	600	-	5	20	0.215	7	54.1
C2	400	600	-	10	40	0.23	6	48.2
C3	400	600	-	15	60	0.232	6	29.5

The control specimens without SP at w/c = 0.4 yield an average 7-day strength of 40.6 MPa, increased to 60.3 MPa when using (6L/m3) SP33 (49% increase) compared to 41% increase when doubling the dose. However, the corresponding increase at 28-day strength were found (17%) and (5%), respectively, indicating higher early strength is gained when using the admixture. The decision was to continue with SP33 at dose of (6L/m3) based on workability and control compressive strength results.

The control specimen 28-day strength was 60.5 MPa. For the lightweight wood waste concrete with 5%, 10%, and 15% wood waste aggregate percentages having similar workability level, the 28-day compressive strength results (rounded to 0.5 MPa) were 37, 35.5, and 30 MPa, respectively. Compared to control results without SP, the reduction is 38%, 41%, and 50%, respectively. In overall, average reduction is 43%. With SP33, the corresponding results were 54, 48, and 30 MPa, respectively. Compared to control results without SP, the reduction is 10%, 20%, and 50%, respectively. In overall, average reduction using SP is 26%.

The lightweight concrete specimens showed in general a decreased compressive strength compared to control specimens. This decrease in compression strength is resulted as the wood waste particles percentage is increased. However, with the use of SP, the results were significantly improved.

4.2 Flexural Strength

Flexural strength results based on three-point flexural load on 100×100×500 mm prisms of sustainable structural lightweight concrete with a compressive strength and density ranging from 30 to 60 MPa and 1600–1900 kg/m3, respectively, are listed in Table 8.

Table 8: Flexural strength of concrete prisms

No.	Mix	Wood aggregate %	Flexural load, kN	Flexural strength, MPa
1	NS+0W	0	20.17	13.8
2	S+0W	0	32.13	22.16
3	NS+5W	5	20.28	13.99
4	NS+10W	10	22.89	15.79
5	NS+15W	15	17.33	11.95
6	S+5W	5	28.39	19.5
7	S+10W	10	26.63	18.35
8	S+15W	15	25.75	17.7

The control specimens without SP yield an average 28-day flexural strength of 13.8 MPa, increased to 22.16 MPa when using (6L/m3) SP33 (60% increase).

For the lightweight wood waste concrete with 5%, 10%, and 15% wood waste aggregate percentages having similar workability level, the 28-day flexural strength compared to control results without SP, yield respective variations of +1%, +14%, and –13%. With SP33, the corresponding variations compared to control results without SP, were +41%, +33%, and +28%, respectively.

The lightweight concrete specimens showed in general an increased flexural strength compared to control specimens. This increase in flexural strength is resulted maybe because that the wood particles act as fibers that improves the flexural strength.

However, with the use of SP, the results were significantly improved. Their average increase was +34%, compared to an average of +1% for specimens without SP.

4.3 Flexural behavior of wood-aggregate reinforced concrete beams

Table 9 shows arrangement of the 12 beams and their test results.

Table 9: Flexural strength of control and lightweight reinforced beams

No	Code *	Wood %	Reinforcement ratio	Maximum deflection (mm)	Flexural load (kN)	% Decrease or increase from (control beam)
1	B-0W-min	0	Minimum	16.6	44	-
2	B-0W-0.6 max	0	0.6 max	18.2	61	-
3	B-0W-max	0	Maximum	19.7	78.9	-
4	B-5W-min	5	Minimum	18.5	23	– 47.7%
5	B-5W-0.6 max	5	0.6 max	10.7	66.5	+ 9.0%
6	B-5W-max	5	Maximum	17.1	55.6	– 29.5%
7	B-10W-min	10	Minimum	19.7	21.6	– 50.9%
8	B-10W-0.6max	10	0.6 max	25.4	56.7	– 7.0%
9	B-10W-max	10	Maximum	19.7	66.6	– 15.6%
10	B-15W-min	15	Minimum	19.8	23.8	– 45.9%
11	B-15W-0.6max	15	0.6 max	22.0	54.6	– 10.5%
12	B-15W-max	15	maximum	19.8	62.4	– 20.9%

***** beam B-0W-min means beam of 0% wood aggregate with min. reinforcement

beam B-10W-0.6max means beam of 10% wood aggregate with 0.6 of max. reinforcement.

beam B-15W-max means beam of 15% wood aggregate with max. reinforcement.

The results of beams flexural strengths are given in Table 9. The flexural strength is shown decreasing based on the percentage of wood particles and reinforcement ratio inside the sustainable structural lightweight concrete beam samples. The decrease in strength is more pronounced in lighter (ACI code [16] minimum) reinforced wood particles concrete beams (47.7%, 50.9%, 45.9%) decrease respectively for beams with (5%, 10%, and 15%) wood aggregates. The corresponding decreases of strength in beams with ACI code [17] maximum ratio of steel are (29.5%, 16.6%, and 20.9%).

The results show that as wood particle ratio increased from 5%, to 10%, to 15%, a small decrease in strength is obtained. For beams with 0.6 of maximum steel ratio, the maximum strength is respectively 66.5 kN, 56.7 kN, and 54.6 kN with maximum reduction percentage of 18% from the 5% wood particle concrete beam strength.

4.4 Load – Deflection Behavior

Figs (2 to 5) show load- midspan deflection behavior of 12 reinforced control and lightweight wood waste concrete beams, with different wood aggregate ratios and different reinforcement ratios. General view of the curves shows that in the pre-cracking stage, the deflection increases linearly with an increase in load. As the value of reinforcement ratio (ρ) is increased, stiffer responses to loading are obtained in general due to a higher moment of inertia.

Although the flexural strength is decreased in beams that contained wood as a replacement of aggregate, they showed more deflection during the flexural test of moderate reinforced lightweight concrete beams and the cracking propagations were more pronounced in the lightweight specimens. As the wood waste particles ratio is increased the load-deflection response becomes softer. For lightweight concrete beams with wood waste particles aggregates, initial cracking was observed at loads ranging from about 25% of ultimate load to 35%. There is change of slope in the load-deflection curve in the post cracking stage due to the reduction in the effective moment of inertia. The failure mode of lightweight concrete beams was more gradual than that of the control beams, however, at maximum ratio of reinforcement both types of beams express similar mode of failure that is less ductile. The extent of cracking was mor pronounced in the lightweight beams.

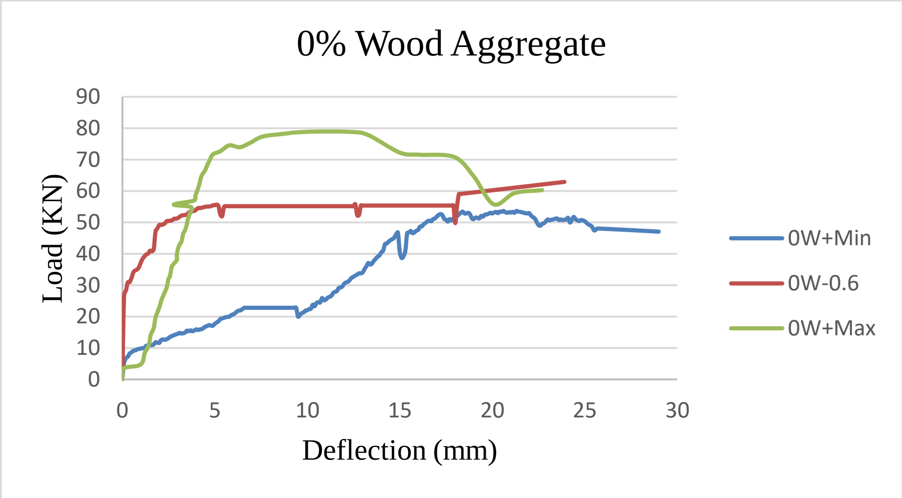

Figure 2: Load / deflection behavior for beam 0% Wood Aggregate

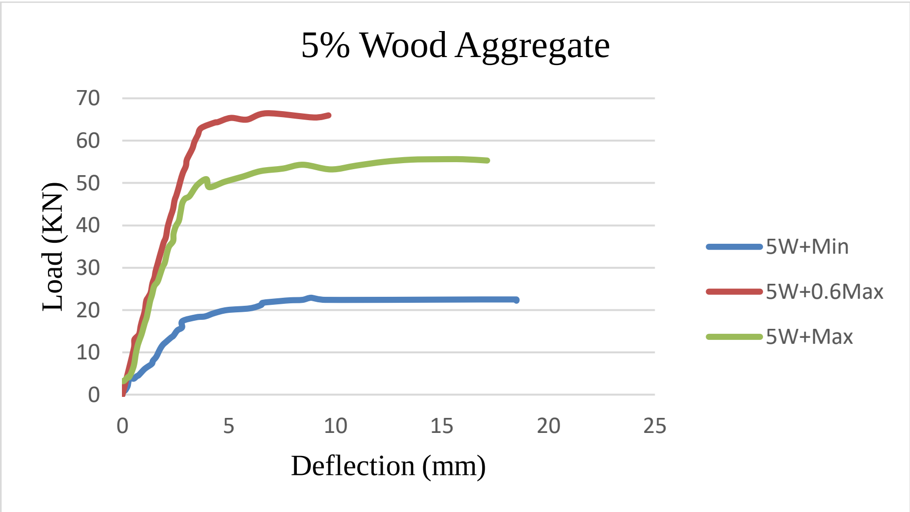

Figure 3: Load / deflection behavior for beam 5% Wood Aggregate

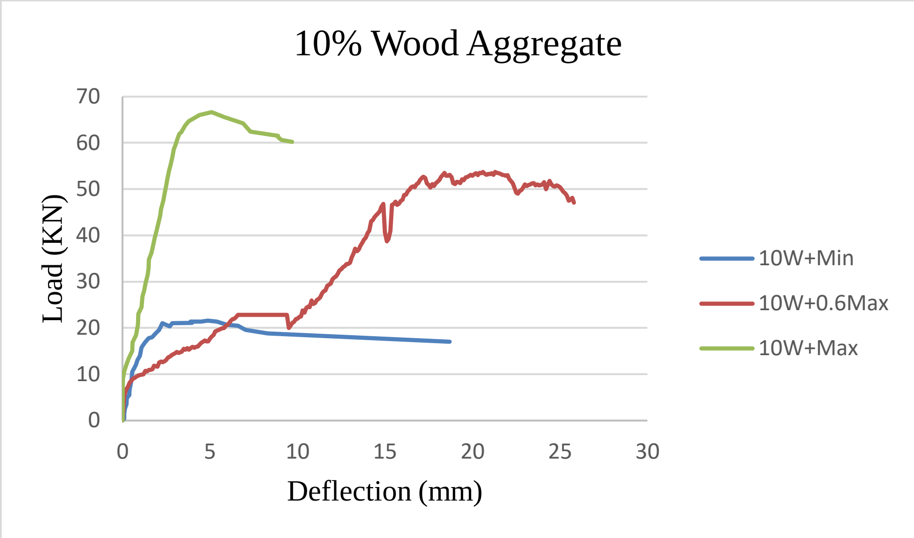

Figure 4: Load / deflection behavior for beam 10% Wood Aggregate

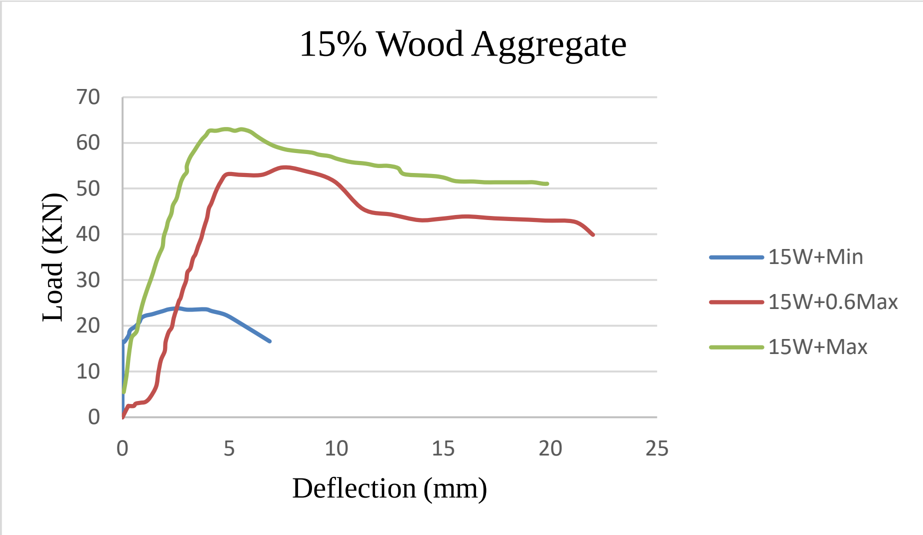

Figure 5: Load / deflection behavior for beam 15% Wood Aggregate

5. Conclusion

1. The density of sustainable structural lightweight concrete using wood waste particles is decreased from 2400 kilogram per cubic meter to 1600 kilogram per cubic meter. This decrement (33%) in weight is due to the increment of the wood waste particle of 15% of cement weight.
2. Keeping the workability constant (flow table test results were between 155 to 175 mm for all mixes), a wide range of compressive strength varying with wood particle percentage of the concrete mixture. The control specimen's strength average was 63 MPa decreased to 29 MPa as a minimum value obtained with 15% of wood particles (54% max decrease)
3. The flexural strength of sustainable structural lightweight concretes with 15% wood particles, has been reduced by approximately 20% from the control specimens' results. The reduction is less than that of compressive strength, maybe because that the wood particle act as fibers that improves the flexural strength.
4. Sustainable structural lightweight reinforced concrete beams were constructed and tested in flexure under third point loading arrangement as permitted by the ACI Code 318-19. The load-deflection curves were obtained and showed

- Reductions in ultimate strengths were obtained for lightweight concrete beams compared to control ones. The decrease in strength is more pronounced in lighter reinforced wood particles concrete beams (49% in average) for beams with wood aggregates. The corresponding decrease of strength in beams with maximum ratio of steel are (22%) in average.
- The results show that as wood particle ratio increased, a decrease in strength is resulted. For beams with 0.6 of maximum steel ratio, the maximum strength of 15% wood particle concrete beam is reduced by 18% from the 5% wood particle concrete beam strength.
- Similar although softer load deflection behavior is obtained for waste wood concrete beams compared with control ones.
- Cracking propagations were more pronounced in the lightweight specimens.
- Mode of failure is more ductile in the lightweight specimens.
- ACI reinforcement ratios can be recommended to the lightweight specimens.

5. In general, the sustainable structural lightweight Reinforced concrete using wood particle is recommended to be used in building construction. Durability remains a concern, therefore it is recommended to use them in interior exposure and carefully protected in exterior exposure.

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