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# PROPERTIES OF LIGHTWEIGHT CONCRETE MADE OF RECYCLED WOOD WASTES

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**Abstract:**
Sustainable structural lightweight concrete has been produced using the waste of wood particles found in disposal areas of wood factories and carpenters. These wastes form a bunder on the environment and recycling them will provide a gain to the environment and the economy. Wood particles of aggregate size have been used in variation with percentages (0%,5%,7%,10%, 12% 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 of SP doses. The compressive strength ranged between 60 MPa for control samples to 30 MPa for 15% wood particle concrete, a max reduction of 54% is resulted, however the overall reduction was 42%. Applying superplasticizer SP has improved the results and reduction becomes 22% overall. The corresponding flexural strength ranged between (12 MPa to 22 MPa), with overall increase of 7% over the control specimens increased to 34% when using SP.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; Mechanical Propertie*

## 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.

B.S. Al-Numan and J.K. Ahmed (2019) [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/m$^3$ [7].

M. Li et al (2017) [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 [9-15].

## 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.

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)<br>Initial setting, hrs: min<br>Final setting, hrs: min | 1:30 (hr:min)<br>5:00 (hr:min) | 45 (min)<br>10 (max) |
| 3 | Compressive strength of mortar, (MPa)<br>3-day<br>7-day | 24<br>32 | 15 (min)<br>23 (min) |

**2.2 Sand**

The sieve analysis of used sand 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) | % | This Sample% | Specified |
| 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 Course Aggregate**

The aggregate that was used is for the control samples and it is replaced completely by wood aggregate. 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 | | Passing (%) |
|---|---|---|---|
| | Wt (g) | % | This Sample% |
| 2” | 0.00 | 0 | 100 |
| 1.5” | 0.00 | 0 | 100 |
| 1” | 0.00 | 0 | 100 |
| 19mm | 0.00 | 0 | 100 |
| 12.5mm | 303 | 3.700 | 96.3 |
| 9.5mm | 1182 | 14.437 | 81.863 |
| 4.75mm | 6674 | 81.519 | 0.344 |
| 2.36mm | 27 | 0.329 | 0.015 |
| 1.16mm | 1 | 0.012 | 0.003 |
| 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, Fig.1.

Tables 5 and 6 show the properties of the wood aggregate, and Fig. 2 shows the distribution of wood particle aggregate size.

Table 5: Physical properties of wood aggregate

| Physical Properties | Test Result | Limits of Iraqi Specification No.45,1984 |
|---|---|---|
| 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 | | Passing (%) |
|---|---|---|---|
| | Wt (g) | % | This Sample% |
| 2” | 0.00 | 0 | 100 |
| 1.5” | 0.00 | 0 | 100 |
| 1” | 0.00 | 0 | 100 |
| 19mm | 963 | 6.97 | 93.03 |
| 12.5mm | 3002 | 21.74 | 71.29 |
| 9.5mm | 8350 | 60.5 | 10.79 |
| 4.75mm | 1241 | 9 | 1.79 |
| 2.36mm | 248 | 1.79 | - |
| 1.16mm | 0.00 | 0 | - |
| pan | 0.00 | 0 | - |

Figure 1: Oak tree, and its wood aggregate

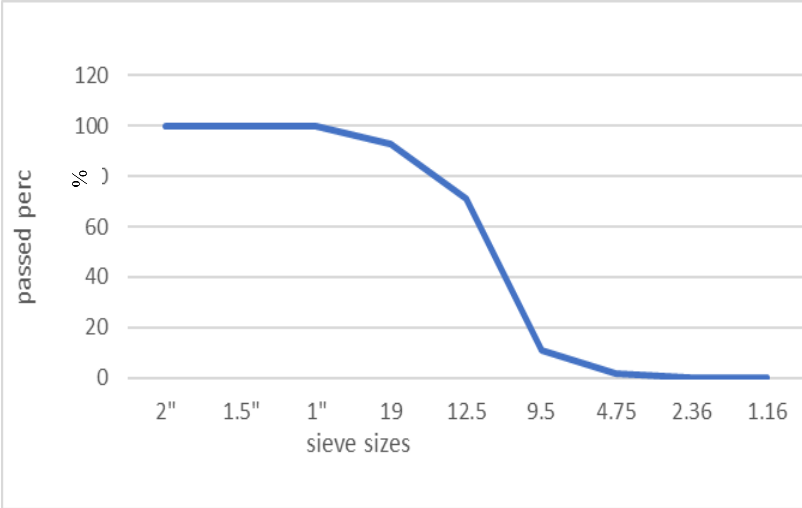


Figure 2: Passing percentage of wood aggerate

### 2.5 Admixture

Admixtures are added to the concrete, in addition to cement, water and aggregate, typically immediately before or during the mixing process. Both Superplasticizer and Hyperplast were used in the concrete mixtures (SP 33, PC 175). 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. Hyperplast, however, was used in control specimens only for workability and strength comparisons.

### 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.

## 3. Methodology

The purpose of this study is to produce a structural lightweight concrete that is sustainable, achieved that by incorporating wood waste particles as a replacement of coarse aggregate. In this research trials were made for finding the optimum wood percentage for the ideal lightweight concrete mixture that can be considered as a structural lightweight concrete.

### 3.1 Sample Preparation

All the experiments were performed in the Tishk International University laboratory. The mixture proportions of the concrete material containing wood aggregate used in the laboratory and are 3%, 5%, 7%, 10%, 12%, and 15%.

The density is ranged between 1600 and 1900 kg/m3 which lies within the range of light weight aggregate concrete based on ACI 213 report [6], and minimum water-to-cement weight ratio is w/c = 0.21.

### 3.2 Specimens Details

Various wood ratios were tried during the work with each mix may have different admixtures dose to reach similar workability (Fig. 3). Mix proportions used are shown in Table 7 for control specimens and Table 8 for wood particle lightweight concrete specimens without admixtures, and Table 9 for wood particle lightweight concrete specimens with admixture SP33.

Cubes used for compressive strength are of 100 mm size, and prisms (Table 10) used for flexural strength are of the size 100*100*500 mm. (Fig. 4)

Table 7: Mix proportion of control specimens

| No. | Code | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Gravel ($kg/m^3$) | w/c ratio | Admixture ($L/m^3$) |
|---|---|---|---|---|---|---|
| 1 | A1 | 400 | 600 | 1200 | 0.40 | -- |
| 2 | A2 | 400 | 600 | 1200 | 0.40 | -- |
| 3 | A3 | 400 | 600 | 1200 | 0.30 | SP33 (6) |
| 4 | A4 | 400 | 600 | 1200 | 0.30 | SP33 (6) |
| 5 | A5 | 400 | 600 | 1200 | 0.25 | PC175(4) |
| 6 | A6 | 400 | 600 | 1200 | 0.25 | PC175(4) |
| 7 | A7 | 400 | 600 | 1200 | 0.25 | SP33(11.5) |
| 8 | A8 | 400 | 600 | 1200 | 0.25 | SP33(11.5) |

Table 8: Mix proportion of lightweight concrete specimens

| No. | code | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Wood% To cement | Wood Aggregate ($kg/m^3$) | W/c ratio | Flow table diameter (cm) |
|---|---|---|---|---|---|---|---|
| 1 | B1 | 400 | 600 | 3 | 12 | 0.32 | 17 |
| 2 | B2 | 400 | 600 | 3 | 12 | 0.32 | 17 |
| 3 | B3 | 400 | 600 | 5 | 20 | 0.32 | 17 |
| 4 | B4 | 400 | 600 | 5 | 20 | 0.32 | 17 |
| 5 | B5 | 400 | 600 | 7 | 28 | 0.32 | 16.5 |
| 6 | B6 | 400 | 600 | 7 | 28 | 0.32 | 16.5 |
| 7 | B7 | 400 | 600 | 10 | 40 | 0.32 | 17 |
| 8 | B8 | 400 | 600 | 10 | 40 | 0.32 | 17 |
| 9 | B9 | 400 | 600 | 12 | 48 | 0.32 | 15.5 |
| 10 | B10 | 400 | 600 | 12 | 48 | 0.32 | 15.5 |
| 11 | B11 | 400 | 600 | 15 | 60 | 0.32 | 16 |
| 12 | B12 | 400 | 600 | 15 | 60 | 0.32 | 16 |

Figure 3: Preparation of mixtures components

Table 9: Mix proportions of wood waste particle concrete with admixture

| No. | Code | Cement (kg/m³) | Sand (kg/m³) | Wood% To cement | Wood Aggregate (kg/m³) | W/c ratio | SP33 (L/m³) | Flow table diameter (cm) |
|---|---|---|---|---|---|---|---|---|
| 1 | C1 | 400 | 600 | 3 | 12 | 0.25 | 8 | 25 |
| 2 | C2 | 400 | 600 | 3 | 12 | 0.25 | 8 | 25 |
| 3 | C3 | 400 | 600 | 5 | 20 | 0.215 | 7 | 17 |
| 4 | C4 | 400 | 600 | 5 | 20 | 0.215 | 7 | 17 |
| 5 | C5 | 400 | 600 | 7 | 28 | 0.23 | 6 | 17.5 |
| 6 | C6 | 400 | 600 | 7 | 28 | 0.23 | 6 | 17.5 |
| 7 | C7 | 400 | 600 | 10 | 40 | 0.23 | 6 | 17.5 |
| 8 | C8 | 400 | 600 | 10 | 40 | 0.23 | 6 | 17.5 |
| 9 | C9 | 400 | 600 | 12 | 48 | 0.232 | 6 | 17.5 |
| 10 | C10 | 400 | 600 | 12 | 48 | 0.232 | 6 | 17.5 |
| 11 | C11 | 400 | 600 | 15 | 60 | 0.232 | 6 | 16.5 |
| 12 | C12 | 400 | 600 | 15 | 60 | 0.232 | 6 | 16.5 |

Table 10: Mix proportion for concrete prisms

| No | Code | Cement (kg/m³) | Sand (kg/m³) | Aggregate (kg/m³) | Wood % | Sp33 |
|---|---|---|---|---|---|---|
| 1 | A | 400 | 600 | 1200 | - | - |
| 2 | A | 400 | 600 | 1200 | - | - |
| 3 | B | 400 | 600 | 1200 | - | ✓ |
| 4 | B | 400 | 600 | 1200 | - | ✓ |
| 5 | C | 400 | 600 | 1200 | - | |
| 6 | C | 400 | 600 | 1200 | - | |
| 7 | D | 400 | 600 | - | 3 | - |
| 8 | D | 400 | 600 | - | 3 | - |
| 9 | E | 400 | 600 | - | 5 | - |
| 10 | E | 400 | 600 | - | 5 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | F | 400 | 600 | - | 10 | - |
| 12 | F | 400 | 600 | - | 10 | - |
| 13 | G | 400 | 600 | - | 15 | - |
| 14 | G | 400 | 600 | - | 15 | - |
| 15 | H | 400 | 600 | - | 3 | ✓ |
| 16 | H | 400 | 600 | - | 3 | ✓ |
| 17 | I | 400 | 600 | - | 5 | ✓ |
| 18 | I | 400 | 600 | - | 5 | ✓ |
| 19 | J | 400 | 600 | - | 10 | ✓ |
| 20 | J | 400 | 600 | - | 10 | ✓ |
| 21 | K | 400 | 600 | - | 15 | ✓ |
| 22 | K | 400 | 600 | - | 15 | ✓ |

Figure 4: Concrete prisms

### 3.3 Compressive Strength

All the concrete cubes were tested for compressive strength by a compression machine in TIU Lab. See Fig. 5


Figure 5: Testing cubes for compression

### 3.4 Flexural Strength

Flexural strength, also known as modulus of rupture, was measured using a three point flexural test technique. Fig.6

Figure 6: Flexural test

## 4. Results and Discussions

### 4.1 Unit Weight

Generally, unit weight of normal-weight concrete is around 2400 kg/m3. Concrete unit weight generally depends on the entrapped air and water cement ratio.

Based on the casted samples and comparison between the control sample and the wood aggregate samples the results were as following: Control specimens density ranged between 2375 to 2425 kg/m3. The density of lightweight wood particle concrete is ranged between 1600 to 1900 kg/m3. Details are listed in Table 13.

After casting all the control specimens as well as the sustainable structural lightweight concrete specimens that contains wood waste particles, the unit weight values showed a decrease starting from approximately 2400 kg/m3 for control specimens to 1600 kg/m3 for concrete with 15% wood particles using SP33, i.e., it is decreased about 33%.

### 4.2 Workability of Concrete

Concrete workability basically refers to how easily freshly mixed concrete can be placed, consolidated, and finished with minimal loss of homogeneity. The primary factors that affect the workability of concrete are water to cement w/c ratio, aggregate, and admixtures. Table 11 shows the workability of the specimens.

For control specimens, the slump was measured 115 mm when using SP dose 6 L/ m3 of concrete, reduced to 30 mm when the dose is approximately doubled with lower w/c ratio.

This dose (SP33 dose 6 L/m3) is found the best after many trials of testing regarding the workability performance of the lightweight waste wood concrete. No difference was found when using other SP type (PC175) compared to SP33 at approximately same dosages. The result of the workability test was constant with range between (155mm to 175mm) using flow table testing.

Table 11: Workability and Density of Control and Lightweight Wood Particle Concrete

| Code | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Gravel ($kg/m^3$) | Wood% To cement | Wood Aggregate | w/c ratio | Admixture (SP33) ($L/m^3$) | Slump Test (cm) | Density ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 400 | 600 | 1200 | - | - | 0.40 | -- | | 2415 |
| A2 | 400 | 600 | 1200 | - | - | 0.40 | -- | | 2440 |
| A3 | 400 | 600 | 1200 | - | - | 0.30 | 6 | 11.5 | 2375 |
| A4 | 400 | 600 | 1200 | - | - | 0.30 | 6 | 11.5 | 2375 |
| A5 | 400 | 600 | 1200 | - | - | 0.25 | PC175(4) | 19.0 | -- |
| A6 | 400 | 600 | 1200 | - | - | 0.25 | PC175(4) | 19.0 | -- |
| A7 | 400 | 600 | 1200 | - | - | 0.25 | 11.5 | 3.00 | 2400 |
| A8 | 400 | 600 | 1200 | - | - | 0.25 | 11.5 | 3.00 | 2440 |
| B1 | 400 | 600 | - | 3 | 12 | 0.32 | | 17 | 2220 |
| B2 | 400 | 600 | - | 3 | 12 | 0.32 | | 17 | 2220 |
| B3 | 400 | 600 | - | 5 | 20 | 0.32 | | 17 | 2210 |
| B4 | 400 | 600 | - | 5 | 20 | 0.32 | | 17 | 2210 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B5 | 400 | 600 | - | 7 | 28 | 0.32 | | 16.5 | 2109 |
| B6 | 400 | 600 | - | 7 | 28 | 0.32 | | 16.5 | 2109 |
| B7 | 400 | 600 | - | 10 | 40 | 0.32 | | 17 | 2106 |
| B8 | 400 | 600 | - | 10 | 40 | 0.32 | | 17 | 2106 |
| B9 | 400 | 600 | - | 12 | 48 | 0.32 | | 15.5 | 2102 |
| B10 | 400 | 600 | - | 12 | 48 | 0.32 | | 15.5 | 2102 |
| B11 | 400 | 600 | - | 15 | 60 | 0.32 | | 16 | 2030 |
| B12 | 400 | 600 | - | 15 | 60 | 0.32 | | 16 | 2030 |
| C1 | 400 | 600 | | 3 | 12 | 0.25 | 8 | 17.5 | 1900 |
| C2 | 400 | 600 | | 3 | 12 | 0.25 | 8 | 17.5 | 1860 |
| C3 | 400 | 600 | | 5 | 20 | 0.215 | 7 | 17 | 1770 |
| C4 | 400 | 600 | | 5 | 20 | 0.215 | 7 | 17 | 1777 |
| C5 | 400 | 600 | | 7 | 28 | 0.23 | 6 | 17.5 | 1699 |
| C6 | 400 | 600 | | 7 | 28 | 0.23 | 6 | 17.5 | 1766 |
| C7 | 400 | 600 | | 10 | 40 | 0.23 | 6 | 17.5 | 1803 |
| C8 | 400 | 600 | | 10 | 40 | 0.23 | 6 | 17.5 | 1769 |
| C9 | 400 | 600 | | 12 | 48 | 0.232 | 6 | 17.5 | 1650 |
| C10 | 400 | 600 | | 12 | 48 | 0.232 | 6 | 17.5 | 1690 |
| C11 | 400 | 600 | | 15 | 60 | 0.232 | 6 | 16.5 | 1648 |

### 4.3 Compression Strength

Table 12 shows the 28-day compressive strength of control and lightweight wood particle concrete. Fig. 7 shows a bar chart of the results.

Table 12: Compressive Strength Control and Lightweight Wood Particle Concrete

| Code | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Gravel ($kg/m^3$) | Wood% To cement | Wood Aggregate ($kg/m^3$) | w/c ratio | Admixture SP33 ($L/m^3$) | Compressive Strength MPa (days) |
|---|---|---|---|---|---|---|---|---|
| A1 | 400 | 600 | 1200 | | | 0.40 | -- | 40.6 (7) |
| A2 | 400 | 600 | 1200 | | | 0.40 | -- | 60.3 (28) |
| A3 | 400 | 600 | 1200 | | | 0.30 | 6g | 61.9 (7) |
| A4 | 400 | 600 | 1200 | | | 0.30 | 6g | 70.2 (28) |
| A5 | 400 | 600 | 1200 | | | 0.25 | PC175(4g) | -- |
| A6 | 400 | 600 | 1200 | | | 0.25 | PC175(4g) | -- |
| A7 | 400 | 600 | 1200 | | | 0.25 | 11.5 | 57.2 (7) |
| A8 | 400 | 600 | 1200 | | | 0.25 | 11.5 | 63.3 (28) |
| B1 | 400 | 600 | - | 3 | 12 | 0.32 | - | 42.8 |
| B2 | 400 | 600 | - | 3 | 12 | 0.32 | - | 44.7 |
| B3 | 400 | 600 | - | 5 | 20 | 0.32 | - | 37.6 |
| B4 | 400 | 600 | - | 5 | 20 | 0.32 | - | 35.9 |
| B5 | 400 | 600 | - | 7 | 28 | 0.32 | - | 31.6 |
| B6 | 400 | 600 | - | 7 | 28 | 0.32 | - | 30.1 |
| B7 | 400 | 600 | - | 10 | 40 | 0.32 | - | 33.1 |
| B8 | 400 | 600 | - | 10 | 40 | 0.32 | - | 37.9 |
| B9 | 400 | 600 | - | 12 | 48 | 0.32 | - | 31.7 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| B10 | 400 | 600 | - | 12 | 48 | 0.32 | - | 32.8 |
| B11 | 400 | 600 | - | 15 | 60 | 0.32 | - | 30.8 |
| B12 | 400 | 600 | - | 15 | 60 | 0.32 | - | 29.6 |
| C1 | 400 | 600 | - | 3 | 12 | 0.25 | 8 | 57.8 |
| C2 | 400 | 600 | - | 3 | 12 | 0.25 | 8 | 62.6 |
| C3 | 400 | 600 | - | 5 | 20 | 0.215 | 7 | 52.5 |
| C4 | 400 | 600 | - | 5 | 20 | 0.215 | 7 | 55.7 |
| C5 | 400 | 600 | - | 7 | 28 | 0.23 | 6 | 44.6 |
| C6 | 400 | 600 | - | 7 | 28 | 0.23 | 6 | 49.7 |
| C7 | 400 | 600 | - | 10 | 40 | 0.23 | 6 | 47.7 |
| C8 | 400 | 600 | - | 10 | 40 | 0.23 | 6 | 48.7 |
| C9 | 400 | 600 | - | 12 | 48 | 0.232 | 6 | 39.6 |
| C10 | 400 | 600 | - | 12 | 48 | 0.232 | 6 | 40.9 |
| C11 | 400 | 600 | - | 15 | 60 | 0.232 | 6 | 32.9 |
| C12 | 400 | 600 | - | 15 | 60 | 0.232 | 6 | 26.1 |

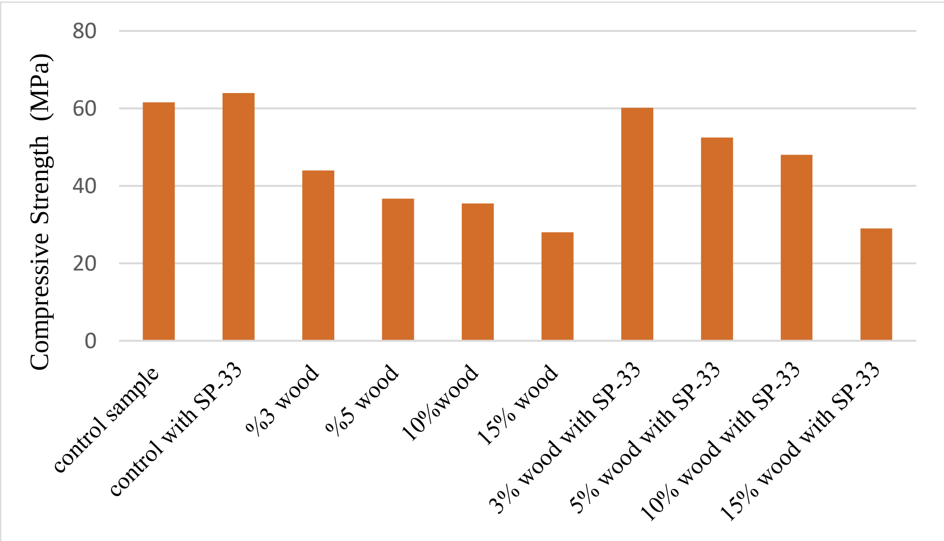


Figure 7: Compressive strength at 28 days

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.

For the lightweight wood waste concrete with 3%, 5%, 7%, 10%, 12% and 15% wood waste aggregate percentages having similar workability level, the 28-day compressive strength results (rounded to 0.5 MPa) were 44, 37, 31, 35.5, 32, and 30 MPa, respectively. Compared to control results without SP, the reduction is 27%, 38%, 48%, 41%, 47% and 50%, respectively. In overall, average reduction is 42%. With SP33, the corresponding results were 60, 54, 47, 48, 40, and 30 MPa, respectively. Compared to control results without SP, the reduction is 0%, 10%, 22%, 20%, 33% and 50%, respectively. In overall, average reduction using SP is 22%

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. For specimens with 3% to 10% of wood aggregates minimal reduction was recorded from 0 to 20%, respectively, with a structural level of strength (60 to 47 MPa), respectively.

### 4.4 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 13 and Fig. 8 shows a bar chart of the results.

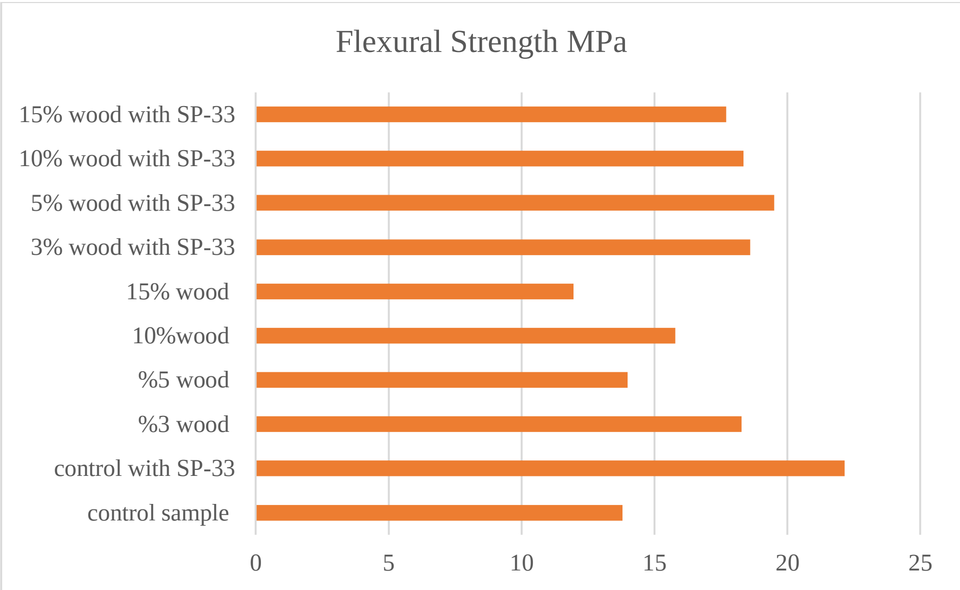


Figure 8: Flexural strength at 28 days

Table 13: Flexural strength of concrete prisms

| No. | With or without SP | Wood aggregate % | Flexural load, kN | Flexural strength, MPa |
|---|---|---|---|---|
| 1 | without SP | 0 | 20.17 | 13.8 |
| 2 | with SP | 0 | 32.13 | 22.16 |
| 3 | without SP | 3 | 26.53 | 18.28 |
| 4 | without SP | 5 | 20.28 | 13.99 |
| 5 | without SP | 10 | 22.89 | 15.79 |
| 6 | without SP | 15 | 17.33 | 11.95 |
| 7 | with SP | 3 | 26.97 | 18.6 |
| 8 | with SP | 5 | 28.39 | 19.5 |
| 9 | with SP | 10 | 26.63 | 18.35 |
| 10 | with SP | 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 3%, 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 +27%, +1%, +14%, and –13%. With SP33, the corresponding variations compared to control results without SP, were +35%, +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 particle 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 +7% for specimens without SP.

## 5. Conclusion

1. The density of sustainable structural lightweight concrete using wood waste as aggregates is decreased from 2400 kg/m3 to 1600 kg/m3. This decrement (33%) in weight is due to the increment of the wood waste particle.
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 is recorded. The control specimen's strength average was 60.3 MPa decreased to 30 MPa as a minimum value obtained with 15% of wood particles (50% max decrease). The overall average of reduction is 42%.
3. Using superplasticizer SP33 with an optimum dose found in this work of (6L/m3 of concrete) improved the compressive strength. The overall average of reduction is improved to 22%. For compressive strength of specimens with 3% to 10% of wood aggregates minimal reduction was recorded from 0 to 20%.
4. Keeping the workability constant (flow table test results were between 155 to 175 mm for all mixes), a range of flexural strength varying with wood particle percentage of the concrete mixture is recorded. The control specimen's strength average was 18.6 MPa is found to be increased with wood particles. The overall average of increase is 7% for wood aggregate concrete without SP. With the SP, the average improved to 34%. This increase in flexural strength is resulted maybe because that the wood particle act as fibers that improves the flexural strength.
5. In general, based on compressive and flexural strengths obtained in this work, 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.

## 6. Recommendation

More research work is recommended especially in structural behavior of light weight concrete made of recycled wood wastes.

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