Compressive Strength of Light-Weight Concrete Material Made from Treated Wood Waste as a Coarse Aggregate

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The effect of replacing the conventional coarse aggregate with wood shavings was evaluated relative to the 28-day compressive strength of the concrete. Six groups were studied: group-1 represented the normal concrete (NC-CTRL1), group-2 (TW-CTRL2) comprised the specimens that had the replacement of the coarse aggregate with raw wood shavings, group-3, group-4, group-5, and group 6 represented the specimens that had the coarse aggregate as coated (treated) wood shavings with cement paste (group-3 and -4) and with tile adhesive paste (group-5 and -6), with and without the effect of the emulsifier, respectively. The density of the TW-CTRL2 concrete was 31.4% lighter than NC-CTRL1. However, the compressive strength of TW-CTRL2 was 75% of the NC-CTRL1, but within the acceptable limits stated in ASTM standards. The findings of this study showed a potential to use the produced concrete as concrete masonry unit when compared with the values reported in previous studies. Compared with TW-CTRL2, the compressive strength increased 45% and 20% for the coated wood shavings with cement and tile adhesive pastes, respectively. The effect of using the emulsifier in the coating process of the wood shavings increased the compressive strength by 20%, and reduced the voids of the concrete by 3%.

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INTRODUCTION

There are essential aspects in construction materials that researchers have been motivated to achieve in recent years. Some of these aspects are: a building material that is economically affordable, producing a lightweight construction unit, preserving the natural resource of materials, and sustainability *via* utilizing the available waste materials and reducing the negative impact of building construction on the environment (Goumans *et al.* 1991; Senden *et al.* 1997; Grosse 2007; Calkins 2008; Domone and Illston 2010; Zainuri *et al.* 2020). Conventional building materials consume a high amount of the natural resources (Jannat *et al.* 2020). Additionally, there is an evident increasing amount of the annual cumulative construction waste that requires recycling (Bakchan and Faust 2019). The above-mentioned aspects were achieved in the building units used as non-load bearing units (non-structural purposes) that were used as interior partition walls (dividers) and they can carry only their self-weight to the structural members of the buildings (columns and beams) and without being exposed to the severe environmental conditions. Clayey bricks, natural stones, and concrete masonry unit (CMU) are examples of these units (building materials) that have been used for non-structural purposes in building construction. In Middle Eastern, Greek, Roman, and Egyptian ancient cultures, masonry and natural stones were the oldest building materials used in construction (Domone and Illston 2010). Concrete units were made and used in the 1930s (Domone and Illston 2010). The main materials used in manufacturing the masonry and concrete units were natural, for instance natural clay, sand, and gravel. Regardless of the process of manufacturing, all the mentioned units require bonding and filler materials. From the cost perspective, the bonding materials is normally expensive compared with filler material. Moreover, the amount of the filler is higher than the bonding material, *i.e.*, more than 70% of the total volume (Gambhir 2004; Ashour *et al.* 2010; Domone and Illston 2010; Aginam *et al.* 2013). In recent years, researchers have devoted their studies to minimize the utilization of the natural resources as filler material and replace them with waste materials, representing the massive amounts of waste that propagate globally with the increasing demand in urbanization and construction (Tamanna *et al.* 2020; Akpokodje *et al.* 2021; Pitoyo *et al*. 2021; Miraldo *et al.* 2021). Furthermore, the high cost of construction materials has created an obstacle in obtaining decent and convenient housing. Thus, based on their review study, Lembi *et al.* (2021) recommended the use of green architectural construction materials such as wood waste to create affordable and sustainable housing solutions (Abed and Khaleel 2019; Lembi *et al.* 2021). Therefore, the use of wood waste in construction material will reduce the negative impact of the waste on the environment and will conserve natural resources. Construction and demolition waste is one of the materials that has been used to replace the conventional aggregate (Tang *et al.* 2021a,b). According to the study conducted to collect data on construction waste from nonresidential institutional building projects by Bakchan and Faust, wood waste was the primary contributor at 54% of the total construction waste (Bakchan and Faust 2019). Biobased waste material in general and wood waste in particular is one type of the materials that has been used as a replacement of the filler of the construction materials attributable to its lightweight and to its cost effectiveness (Abed and Khaleel 2019; Mangi *et al.* 2019; Liu *et al.* 2005; Antoun *et al.* 2021), for instance, CMU. Because the filling material provides approximately 75% of the volume of concrete (Gambhir 2004), there are always economic and technical reasons for using a high amount of aggregate compared with cement in concrete (Newman and Choo 2003; Kett 2009; Subandi *et al.* 2019; Tamanna *et al.* 2020).

Thandavamoorthy attempted to investigate the compressive strength of a concrete obtained by replacing conventional aggregate with recycled wood waste. A 25 MPa characteristic compressive strength was obtained from a concrete with four different percentages of replacement of the wood waste with aggregate (Thandavamoorthy 2016). Stahl *et al.* (2002) investigated the possibility of the use of waste wood as an aggregate for the light-weight CMU for non-structural purposes. The 28-day compressive strength attained in Stahl *et al.* (2002)'s study did not meet the recommended limit stated in ASTM C129 (2017). Quiroga *et al.* (2016) studied the use of wood waste after treating it in the wood-cement composites. They concluded that alkaline hydrolysis was the most effective method of treatment of the wood waste based on the improvement observed in the mechanical properties of the wood-cement composite material. Li *et al.* (2017) characterized the mechanical properties of wood-concrete panels. The use of the wood shavings waste from industry was considered as a softwood because the waste wood came from spruce specie wood. The resulting mechanical properties, particularly, the compressive strength of the wood-concrete materials of the panels did not meet the recommended value stated in ASTM C129 (2017), which was 5.29 MPa. Ikoko *et al.* (2021) evaluated the compressive strength of concrete that had the wood shavings as a partial replacement of the fine aggregate. Seven different percentages from 0% to 7.5% dosages of the wood shavings partial replacement were investigated with other additives (cassava starch and sodium chloride) in the study. The cited authors found that the compressive strength of the resulting concrete decreased when the wood shavings percentage exceeded 7.5%. The 28-day compressive strength of the concrete with the highest percentage (7.5%) of the partial replacement of the wood shavings of the concrete was approximately below 15 MPa (Ikoko *et al.* 2021). Morales-Conde *et al.* (2018) studied using the wood waste from domestic demolition as a partial replacement of sand in the production of lightweight mortar. The percentages of replacing the sand of the mortar with the wood waste from domestic demolition were 2.5, 5, 10, and 20%. The density of the mortar was decreased when wood shavings wood waste was used. Islam *et al.* (2021) studied the compressive strength of concrete that has the fly ash as partial replacement of the binder (cement) and the wood powder as a partial replacement of the fine aggregate. The percentages of the partial replacement of the wood powder with the fine aggregate were 5%, 10%, and 15% and 10%, 15%, and 20% were the percentages of the partial substitution of the cement. It was concluded that the 28-day compressive strength decreases when the wood powder percentage of the partial replacement of the fine aggregate exceeded the 5%. Fadiel *et al.* (2022) studied five different mixes of woodcrete by partially replacing the fine aggregate with wood shavings at percentages varying from 5% to 50% and evaluated the effect of this replacement *via* compressive strength and non-destructive tests. The achieved 90-day compressive strength of the woodcrete with 50% substitution of the wood shavings from the fine aggregate was below 10 MPa. Aigbomian and Fan (2013) used sawdust wood powder and waste paper to develop a new building material and the result was to have building material with a compressive strength ranging from 0.06 to 0.8 MPa (Aigbomian and Fan 2013). Dias *et al.* (2022) used wood chips and sawdust wood powder as wood aggregate in investigating the mechanical properties of lightweight concrete. Twelve mixes and 78 specimens (cubes) were studies at different amount of replacement with the wood chip and sawdust wood powder with superplasticizer. The concrete density decreased with the increase of the wood amount and the compressive strength increased with increased curing time (Dias *et al.* 2022). Baltazar (2021) studied two partial percentages of replacement of the wood waste from the natural sand in mortars. The results of Baltazar's study are encouraging to use wood waste as fine aggregate (Baltazar 2021). The mechanical and physical properties of 96 specimens of concrete block units made from partial replacement of the conventional aggregate with different percentages using sawdust wood powder were studied by Abed and Khaleel (2019). A 20% partial replacement was concluded to be the optimum replacement ratio that was achieved in their study (Abed and Khaleel 2019).

The previous literature reviewed in this study showed that the use of wood waste in the production of masonry units can have the following advantages and disadvantages:

(1) Advantages: Masonry units made from wood waste showed acceptable mechanical properties to be characterized as units for nonstructural purposes with a lighter weight compared with the masonry units made from the conventional materials. The low values of slump of the fresh concrete made from wood waste are acceptable in the reduction of this type of masonry unit. The masonry units produced from wood waste can be

produced with bigger size. Hence, less bonding mortar is required between the units. The use of these units will reduce the dead load of the interior partitions and hence, reduce the overall dead load of the structure. Thus, these lightweight masonry units will contribute in reducing the cross-section of the structural members required to carry the dead load of these units. Consequently, the use of lightweight masonry units from wood waste will reduce the load of the whole structure on the foundation. Additionally, masonry units made from wood waste showed better thermal properties (reduced thermal conductivity) and better sound insulation properties compared with the conventional masonry units.

(2) Disadvantages: There is a lack in the reviewed literature of having an acceptable compressive strength from full replacement to the conventional coarse aggregate using the wood waste. Attributable to the low mechanical properties of the masonry units made from wood waste, their use is limited to be for non-structural purposes (Mangi *et al.* 2019). Further efforts are required in treating the wood waste, to maintain acceptable properties of the masonry units and widen their application. Thus, a higher amount of the conventional aggregate can be substituted. The previous studies showed that an acceptable compressive strength can be obtained when the replacement ratio was below 40%. This makes an extensive demand to have a treatment process to the wood waste so that it can be used at a higher replacement ratio with acceptable properties to the resulting concrete.

The two objectives of the research presented are: (1) investigate the effect of the treatment process to wood shavings on the 28-day compressive strength of concrete that has 100% volumetric replacement ratio of the coarse aggregate (absolute elimination of the coarse aggregate of the concrete); (2) Investigate the acceptance criteria of the resulting 28-day compressive strength of the lightweight concrete to be used in the production of non-structural concrete units with 100% substitution of the coarse aggregate with wood shavings and compare its results with the results from previous studies.

In this study, 28-day concrete compressive strength was tested for control specimens that were made from the conventional components of concrete: cement, fine aggregate, coarse aggregate, and water. Then, these specimens were compared with the compressive strength of concrete specimens made from a full replacement of the coarse aggregate using wood shavings. The wood shavings used in this study were (1) untreated wood shavings, (2) treated wood shavings using cement mortar with and without the dispersion additive (emulsifier), and (3) treated wood shavings using tile adhesive mortar with and without emulsifier.

EXPERIMENTAL

Materials

Cement

Ordinary Portland cement (OPC) was used in this study and supplied from the local market. The commercial name is Al-Amara Cement (Maysan, Iraq). The physical and chemical properties of the used cement in this study were obtained based on the Iraqi-specifications standard (IQs No.5 (1984)(Central Organization for Standardization and Quality Control (COSQC) 1984) and in accordance with ASTM C150/C150M (2017) in Tables 1 and 2, respectively.

Table 1. Physical Properties of the OPC Used in this Study According to Iraqi-Specifications Standards

Conducted Test	Result (%)	Recommended Value (%) Based on IQs No.5 (1984)
Fineness Test (cm^2/gm)	2590	2500
Initial Setting Time (min)	53	45
Final Setting Time (min)	530	600
Soundness Autoclave Expansion (%)	0.62	0.8
3-day Compressive Strength (MPa)	16.70	15
7-day compressive Strength (MPa)	26.29	23
Tensile Strength in Accordance with EN 1348 (1999) (MPa)	0.41	

Table 2. Chemical Properties of the OPC Used in this Study Based on IQs No.5 (1984)

Conducted Test	Result (%)	Recommended Value (%)
Lime	63.96	--
Silica	21.32	--
Alumina	4.58	--
Iron Oxide	3.25	--
Sulphate	2.52	< 2.8%
Loss on ignition	2.76	≤ 5%
Insoluble residue	3.47	≤ 4%
Lime saturation factor	1.09	≤1.5%

Adhesive material

Tile adhesive material (adhesive) known as Sika (Sika GCC, Dubai, UAE) and commercially available at the local market in Iraq was used in the coating (treatment process) of the wood shavings. This adhesive material consisted of white cement, sand, and additives. According to the material data sheet retrieved from the manufacturer website (ELE International, Bedfordshire, UK) the material has a density of 1600 kg/m^3. The material requires 8 h to be cured for temperature values above 40 °C and the pull out stress value is 0.8 MPa at 10 min after hardening.

Fine aggregate (natural sand)

The fine aggregate used in this study was a natural sand with a specific gravity of 1.641. The fine aggregate was provided from the southern region in Iraq from a city called Basra. Grading (passing percentages based on series of sieves) of the sand was computed based on IQs No.45/1984 Zone II as shown in Table 3.

Table 3. Grading of the Fine Aggregate Based on IQs No. 45 (1984)

Sieve Size (mm)	Passing Percentage (%)	Cumulative Passing (%)
10	100	100
4.75	95.80	90 to 100
2.36	85.83	75 to 100
1.18	73.05	55 to 90
0.6	49.25	35 to 59
0.3	16.75	8 to 30
0.15	3.90	0 to 10

Coarse aggregate (natural crushed gravel)

The coarse aggregate used in this study was naturally available in the eastern region of Iraq, from a place known as Chlaat (Maysan, Iraq) and used in the concrete material. The maximum size of the coarse aggregate used this study was 10 mm. Grading of the coarse aggregate was computed based on the IQs No.45 Zone II (1984) as shown in Table 4. Additionally, the specific gravity of the coarse aggregate was 2.67 in accordance with ASTM C29/C29M (2017).

Table 4. Grading of the Coarse Aggregate Based on IQs No. 45 (1984)

Sieve Size (mm)	Passing Percentage (%)	Cumulative Passing (%)
20	100	100
14	100	95 to 100
10	100	30 to 60
4.75	5	0 to 10

Water

Reverse osmosis (RO) water was used in the wood shavings treatment process and the regular tap water was used in the concrete mixing and curing processes.

Emulsifier

A locally available emulsifier known as Katsan (Katsan Gida, Beylikdüzü İstanbul, TÜRKİYE) was used as a dispersion material used during the wood shavings treatment (coating). The emulsifier has a gel consistency and contains mono diglycerides of fatty acids, polyglycerol esters of fatty acids, and fatty acid sodium. The percentage ratios of these components were not reported in the product by the manufacturer.

Fig. 1. Raw (untreated or coated) wood shavings

Wood Shavings

The wood shavings used in this study were supplied from a local carpentry shop in Maysan city (Maysan, Iraq). The wood shavings were wood waste from a rendering machine. Figure 1 shows a sample of the used wood shavings. To avoid using controlled climate conditions, to ensure the wood shavings used in this study can be stored at ambient climate conditions, and therefore to be used for commercial purposes without prior controlled climate conditions storage requirement, the wood shavings were stored in the laboratory for 14 days prior to use in the concrete mix under the same ambient climate conditions in which its temperature and relative humidity are reported in Fig. 4. Thus, the moisture content of the wood shavings was not measured (ASTM D4442-16 2016).

Methods

The coating process of wood shavings (wood shavings treatment)

A ratio of 1:1 water to cement wt% and 1:1 water to tile adhesive wt% ratio was used to prepare a paste of cement and paste of tile adhesive to be used in the coating process of the wood shavings. The paste was prepared in accordance with ASTM C305 (2014). Next, a 1:4 paste to wood shavings v% ratio was used to coat the wood shavings. A paste with and without 1.5 wt% of the emulsifier with respect to the cement amount was used to coat the wood shavings, to have treated (coated) wood shavings with and without the effect of emulsifier. A mechanical concrete mixer type JQ (JQ, Shandong, China) with 0.13 m^3 volume capacity was used in the process of treating the wood shavings. A 10-min mixing time (coating) with a rotating speed of 36 RPM (rounds per minute) was used during the coating process. In the same essence mentioned earlier, the paste from the tile adhesive material was used to coat the wood shavings with and without the effect of the emulsifier. Figure 2 shows the difference between the treated wood using the cement paste with and without the emulsifier as regards the agglomeration of the fine wood particles attributable to the emulsifier effect (Fig. 2 A) . After the coating process (the treatment), the wet-coated wood shavings layer was distributed in less than 50 mm thin layer over a surface greenhouse plastic sheet inside the laboratory at the ambient climate conditions, as shown in Fig. 3. Table 5 shows the specific gravity of the raw wood shavings (R-WS), the cement paste-treated wood without the use of emulsifier (CBTW-WOE), cement paste-treated wood shavings with the use of emulsifier (CBTW-WE), tile adhesive material-treated wood shavings without the use of emulsifier (ABTW-WOE), and the tile adhesive-treated wood shavings with the use of emulsifier (ABTW-WE).

Table 5. Specific Gravity of Different Types of Substituted Coarse Aggregate

Type of Coarse Aggregate Substitute	Specific Gravity (SG)
R-WS	0.06
CBTW-WOE	0.49
CBTW-WE	0.60
ABTW-WOE	0.44
ABTW-WE	0.46

The temperature and relative humidity of the storage place of the treated wood shavings were monitored with 15-min sampling interval during the drying duration, as shown in Fig. 4. Elitech temperature and relative humidity data logger (Elitech Technology, Milpitas, CA, USA) was used to record the temperature and the relative humidity. The average temperature and relative humidity recorded were 15.9 °C and

47.4%, respectively. No water curing occurred during the drying process of wood shavings treatment (coating).

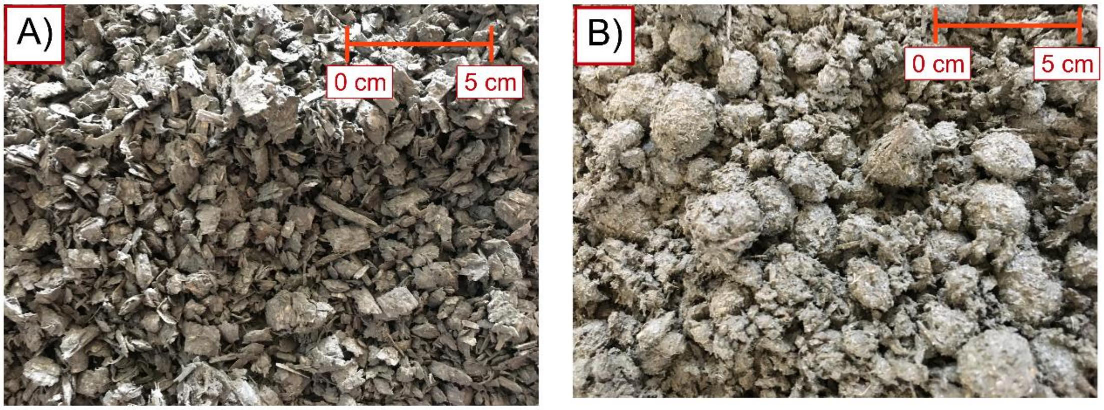

Fig. 2. Coating process of the wood shavings: A) cement paste coated wood shavings without emulsifier, B) Cement paste coated wood shavings with emulsifier

Fig. 3. Drying process of the wet-coated wood shavings: A) Cement paste coating, B) Tile adhesive paste coating

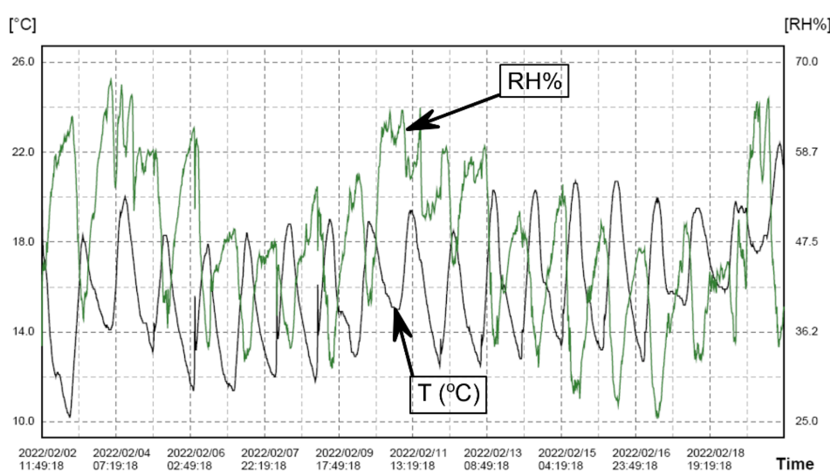

Fig. 4. Monitoring the temperature T (°C) and relative humidity RH (%) during the drying process of the coated (treated) wood shavings

Mixture proportioning

Preliminary trial mixes were conducted to obtain the target design mix proportions to investigate the complete substitution of the coarse aggregate with wood shavings, and these trial mixes were evaluated based on the properties of fresh concrete mix in accordance with ASTM C143 (2015), ASTM C403/C403M (2016), ASTM C511 (2013). For cost-effectiveness purposes, the trial mixes in the preliminary study were made in small volume with a target to obtain 40 MPa (C40) compressive strength at 28 days. A volumetric mixing proportions method was used to design the mix of the cement: fine aggregate: coarse aggregate to be 1:1:2 with 0.5 water to cement ratio (w/c) wt% ratio in accordance with ASTM C173/C173M (2016) and ASTM C1064/C1064M (2012) standards.

Concrete compression test

Two types of concrete cube-shape specimens with [length (L), width (W), and height (h)] 100 mm × 100 mm × 100 mm, and 150 mm × 150 mm × 150 mm, and concrete cylinder-shaped specimen with 150 mm diameter (D) and height (H) of 300 mm were prepared out of the fresh concrete. These specimens were placed in the prepared molds, and cured for 28 days after 24 h of concrete pouring and de-molding, in accordance with ASTM C31/C31M (2017). These types of specimens were prepared for each group of the six groups (Table 6) of this study. The compressive strength of each group and for each type of specimen was conducted using an ELE ADR touch solo 3000 BS EN compression machine (ELE International, Bedfordshire, UK) with a loading capacity of 3000 kN. The loading rate for the concrete specimens (cubes and the cylinders) was 0.27 MPa/s in accordance with ASTM C39/C39M (2017) and EN 12390-3 (2001).

Table 6. Summary of the Six Groups with the Label Description of Each Specimen of Each Group

Group Numbering	Acronym/Specimens-Label/Group Name	Description
Group-1	NC-CTRL1	Control mix of normal concrete that contains natural coarse aggregate
Group-2	TW-CTRL2	Control mix of normal concrete that contains 100% replacement of natural coarse aggregate with untreated-raw wood shavings
Group-3	CBTW-NE	Cement-based treated-coated wood shavings without emulsifier
Group-4	CBTW-WE	Cement-based treated-coated wood shavings with emulsifier
Group-5	ABTW-NE	Adhesive-based treated-coated wood shavings without emulsifier
Group-6	ABTW-WE	Adhesive-based treated-coated wood shavings with emulsifier

RESULTS

Slump Test

The slump test was conducted for the fresh concrete of each group of this study in accordance with ASTM C143/C143M “standard test method for slump hydraulic-cement concrete”(ASTM International 2015) and reported in Table 7.

Table 7. Slump Test of the 6 Groups of the Concrete of this Study to the Nearest 5 mm

Group Name	Slump (mm)
NC-CTRL1	45.0
TW-CTRL2	10.0
CBTW-NE	15.0
CBTW-WE	20.0
ABTW-NE	15.0
ABTW-WE	10.0

Water uptake of the concrete specimens containing 100% wood shavings coarse aggregate

A total number of 18 specimens were used to measure the water uptake of the concrete made from 100% replacement of the coarse aggregate using the wood shavings (coated or uncoated). Three cubes of concrete specimens of each group with 100 mm^3 dimensions were immersed in the curing water for 60 days and the water uptake was computed based on Eq. 1. The water uptake (%) is reported in Table 8 with the coefficient of variation of the three specimens of each group (CV). Equation 1 is as follows,

$$\text{Water uptake (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \tag{1}$$

where W_2 is the mass (gm) of the specimen after 60 days of immersion in water and W_1 is the mass (gm) of the specimen before immersion and after demolding the specimen.

Table 8. Water Uptake (%) and Density of the Concrete Specimens of Each Group After 60 Days Immersion

Group Name	Water Uptake (%)	CV (%)	Density (kg/m^3)	CV (%)
NC-CTRL1	-	-	2363.08	3.25
TW-CTRL2	11.64	8.33	1620.88	6.77
CBTW-NE	6.60	7.04	1835.00	8.98
CBTW-WE	2.48	4.52	1860.00	8.76
ABTW-NE	3.8	3.21	1739.63	2.67
ABTW-WE	3.00	2.13	1833.38	5.12

Density of the concrete

The density reported in Table 8 was reported for the concrete specimens after 60 days of immersion.

28-day Concrete compressive strength

A total number of 72 specimens for 28-day compressive strength were tested. Table 9 summarizes the average compressive strength test result of the concrete specimens of each group of this study. Each group had three specimens of the cubes with dimensions of L = W = H = 150 mm, and the cylinders that had D = 150 mm and H = 300 mm. Whereas six specimens were tested for cubes that had dimensions of L = W = H = 100 mm.

Table 9. 28-day Compressive Strength of the Six Different Groups of Concrete Specimens for Three Different Shapes of Specimens

Group Name	Compressive Strength (MPa)					
	Cubes (Size 1)	CV (%)	Cubes (Size 2)	CV (%)	Cylinder (Size 3)	CV (%)
NC-CTRL1	39.63	3.31	39.54	2.52	39.5	3.18
TW-CTRL2	9.26	4.14	9.90	3.86	8.40	6.17
CBTW-NE	12.08	5.19	18.45	0.38	12.7	3.40
CBTW-WE	14.19	8.16	18.20	0.78	13.90	5.23
ABTW-NE	8.59	7.54	11.90	2.38	10.10	3.65
ABTW-WE	10.48	3.63	10.20	0.00	10.40	9.76

DISCUSSION

Slump test of the fresh concrete mix was measured to evaluate the workability of each group of this study. Even though the w/c ratio used in this study was 0.5, the slump results were below 45 mm, which is considered a low workable fresh concrete. However, because the objective of this study is to have a concrete with properties that comply with ASTM C129-17 (2017), *i.e.*, this low workable concrete is considered acceptable for the purposes of producing CMUs (Mangi *et al.* 2019). This low workability is attributable to: the high amount of the binder (cement) used in the mix 1:1:2 (*i.e*., high water absorption at the hydration process); and to the rough surface of the wood shavings aggregate compared with the smooth surface of the conventional un crushed coarse aggregate.

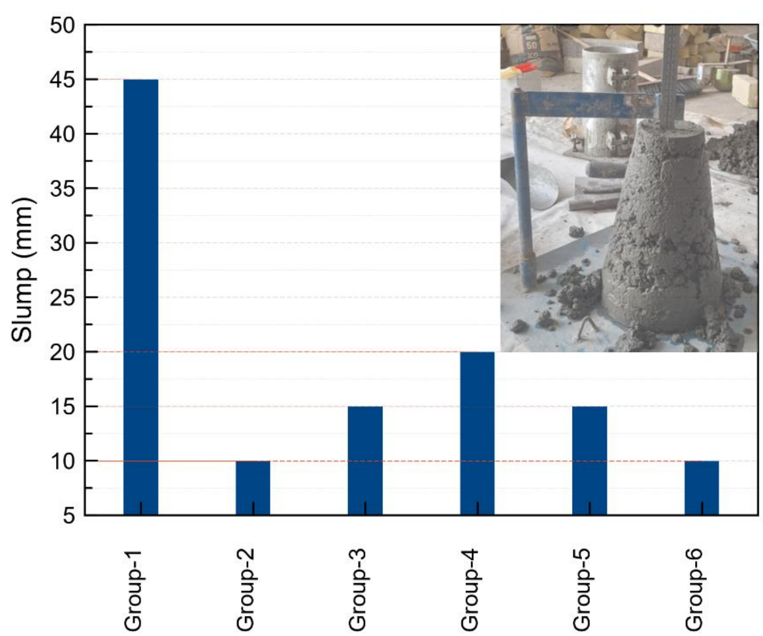

Fig. 5. Slump of fresh concrete of the six groups; Group-1 (NC-CTRL1), Group-2 (TW-CTRL2), Group-3 (CBTW-NE), Group-4 (CBTW-WE), Group-5 (ABTW-NE), and Group-6 (ABTW-WE)

The enhanced slump values were attributable to the emulsifier for the concrete that has the wood shavings coated with cement paste as shown in Fig. 5, but there was no effect of the emulsifier on the wood shavings coated with the tile adhesive paste. However, with a complete replacement of the coarse aggregate using the wood shavings, the slump value of this study was still lower than the values reported in previous studies in Table 10. After the use of emulsifier in the production of the cement paste-coated wood shavings, the slump value of this study (lowest value obtained) in group TW-CTRL2 was 85% lower than the slump value reported in the study conducted by Thandavamoorthy (2016) when 25% of the coarse aggregate was replaced with a shredded wood. Nevertheless, the workability of this study (TW-CTRL2) was 300% higher than the workability (slump) reported in the study conducted by Abed and Khaleel (2019) when 30% of the coarse aggregate was replaced by wood waste chunks. The wood waste (wood shavings) used in this study contains wood particles at different size. To ensure better dispersion and avoid agglomeration of wood particles, a locally available cooking emulsifier was proposed to be used in the production of treated coarse aggregate. The effect of emulsifier (dispersion agent) enhanced the properties of the fresh concrete and the hardened concrete (Ortiz-Álvarez *et al.* 2021).

The effect of coating of the wood shavings used in concrete contributed to reducing the water uptake of the concrete specimens as shown in Figs. 6 and 7. The water uptake decreased from 11.6% to 3.0% to each group. Consequently, the wood treatment contributed in increasing the density of the concrete made from wood shavings, as shown in Fig. 7. Additionally, the effect of the emulsifier reduced the water uptake and this is attributable to the better dispersion of the binder particle on the surface of the treated wood shavings. Moreover, the water uptake reduction for the wood shavings treated with cement paste with emulsifier was 166.1%, compared with the wood shavings treated with cement paste without emulsifier. The water uptake of the wood shavings treated with tile adhesive material with emulsifier was 26.7%, compared with the wood shavings treated with tile adhesive material without emulsifier. This difference in the reduction of water uptake is believed to be due to the difference in the particles weight of the cement particles compared with particles weight tile adhesive materials and the effect of the emulsifier, consequently (Ortiz-Álvarez *et al.* 2021). In other words, the lighter particles disperse better.

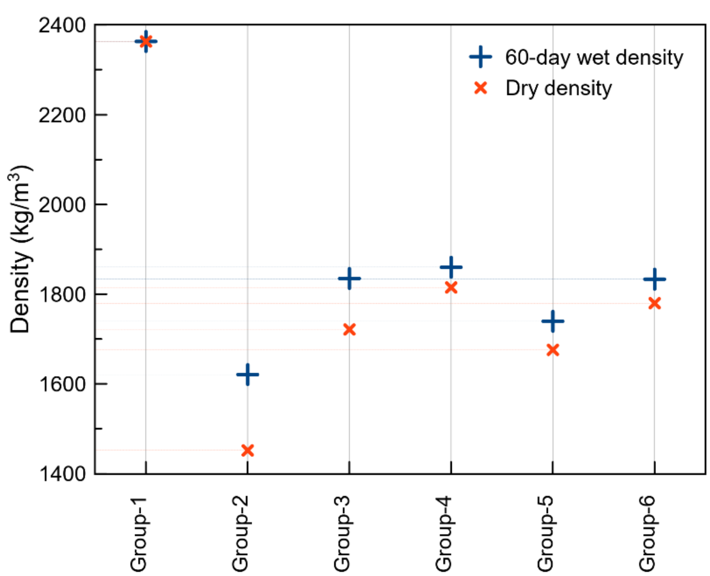

Fig. 6. Dry density *versus* wet density of concrete specimens

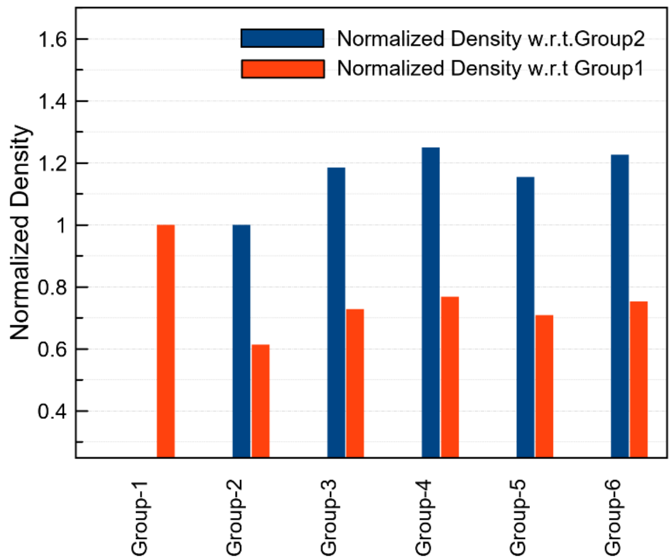

Fig. 7. Normalized dry density with respect to (w.r.t) Group-2 (TW-CTRL 2), and Group-1 (NC-CTRL 1)

To ensure an acceptable compressive strength of the concrete made from wood shavings as coarse aggregate in this study was produced, a high amount of the binder material (mortar) was used compared with the volume of the coarse aggregate. Thus, the lowest density achieved in this study was 1621 kg/m^3. Whereas other researchers (Li *et al.* 2017; Fadiel *et al.* 2022), as shown in Table 10, were able to obtain lower values of the density 764 kg/m^3 and 1530 kg/m^3, respectively. This can be related to the high porosity achieved in their concrete and that can be concluded from the low values of the compressive strength, 5.3, and 2.8, respectively. However, the density of the concrete produced in group TW-CTRL2 is classified as a lightweight concrete, based on the density classification stated in the ASTM C129-17 (2017).

Compressive strength depends on the strength of the aggregate and the bond between the filler and the binder at the interfacial zone of the concrete. Thus, using a low strength aggregate results in a low strength concrete. Additionally, the reduction in the compressive strength is believed to be attributable to the voids of the material produced from the fresh phase of the production of the material due to the high water content (Newman and Choo 2003; Gambhir 2004). This resulted in the reduction noticed in the compressive strength of Group-1 (NC-CTRL1) compared with the remaining groups of this study. To better characterize the reduction in the strength of the concrete made from conventional coarse aggregate and the strength of the concrete made from wood shavings as a coarse aggregate, normalized values with respect to (w.r.t) NC-CTRL1 were compared to each other, as shown in Fig. 8. The concrete that contained wood shavings wood aggregate treated by cement paste showed less reduction in the compressive strength compared with concrete made from untreated wood shavings aggregate and the concrete made from wood shavings treated using the tile adhesive material. In contrast, the effect of treatment to the wood shavings showed a good improvement to the compressive strength of the concrete as shown in Fig. 9. The effect of the size of the aggregate of the concrete and the size of the specimen on the compressive strength of the concrete was previously investigated (Issa *et al.* 2000), as shown in Fig. 10. This change in the compressive strength values is attributable to the change in the nominal maximum aggregate size with respect to the size of the specimen which also affected the coefficient of variation (CV) of the compressive strength (*i.e.* the smaller the size of the specimen, the higher the CV value) (Issa *et al.* 2000). The 28-day compressive strength results of three different sizes of specimens are reported in Table 9. These results were normalized with respect to the specimens with dimensions (L = W = H = 150 mm) (*i.e.*, size 2), and the difference was less than 30% as shown in Fig. 10.

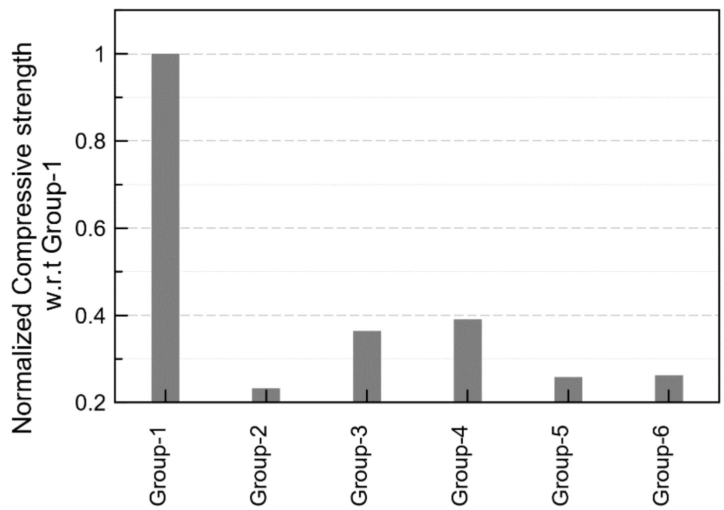

Fig. 8. Normalized compressive strength of the concrete of each group with respect to (w.r.t) Group-1 (NC-CTRL1)

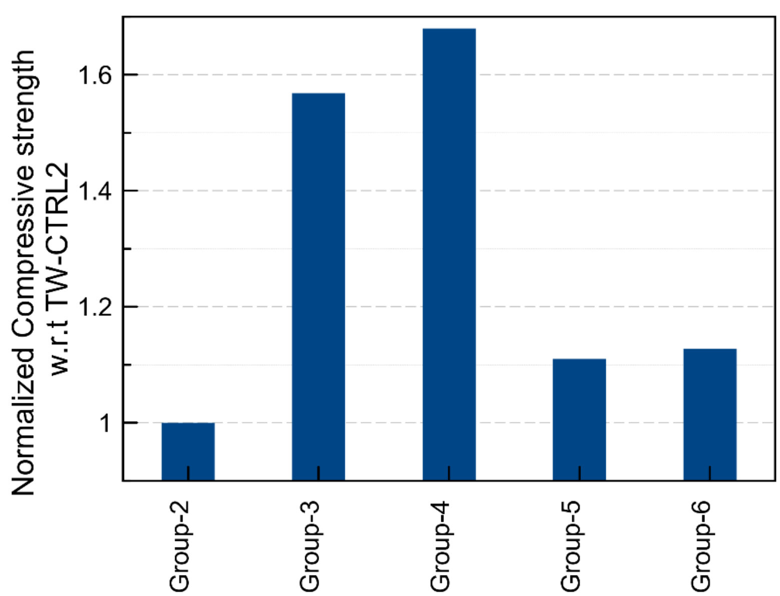

Fig. 9. Normalized compressive strength of the concrete made from wood shavings as coarse aggregate with respect to (w.r.t) Group-2 (TW-CTRL2)

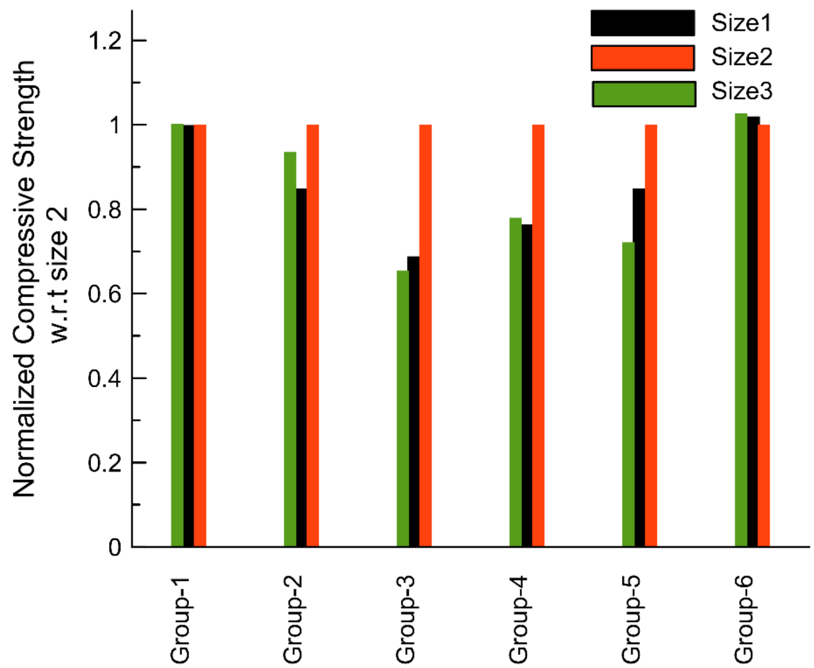

Fig. 10. Effect of the size of the specimen on the 28-day compressive strength of concrete

Table 10. Comparison of the Compressive Strength L = W = H = 150 mm of the Concrete, Density, and Slump with Previous Studies

Source	**28-day Compressive Strength (MPa)**	**Density (kg/m^3); Slump (mm)**	**Constituent Replacement or Mix Proportions (kg/m^3)**	**Type of Waste**	**Replacement %**
This Article					
TW-CTRL2	9.90	1620.88; 10	Coarse aggregate	Wood shavings	100
CBTW-NE	18.45	1835.00; 15			
CBTW-WE	18.2	1860; 20			
ABTW-NE	11.90	1739.63; 15			
ABTW-WE	10.20	1833.38; 10			
Thandavamoorthy (2016)			Coarse aggregate	Shredded wood waste	
	32.36	-; 110			15
	26.26	-; 125			20
	22.60	-; 135			25
Li *et al.* (2017)	5.3	764	Cement=267.2, Quartz sand=96.3, wood=330.4	Wood Shavings	-
Ikoko *et al.* (2021)	13.27	-; 0	Fine aggregate 1:2:4		7.5
Islam *et al.* (2021)	< 22.5	-; -	Fine aggregate and fly ash 10% additive	Wood powder	15
Fadiel *et al.* (2022)	2.8@ 90 days	1530; -	Fine aggregate	Wood shavings	50
Abed and Khaleel (2019)	6.78	1758; 25	Coarse aggregate	Wood waste chunks	30

In summary, the concrete produced in this study is not applicable to be used for structural purposes. Conversely, the concrete of this study can be used as CMU for non-structural purposes, as stated in strength requirement of ASTM C129-17 (2017). The lowest compressive strength in this study was 139% higher than the required strength stated in the ASTM C129-17 (2017). A lower amount of coarse aggregate replacement produced higher strength of concrete and this was reported in the study conducted by Thandavamoorthy (2016). When Thandavamoorthy (2016) replaced 25% of the conventional coarse aggregate with shredded wood waste, the produced strength of the concrete was 22% higher than the maximum strength produced in this study, as shown in Table 10.

Further studies are required to study different methods and techniques of treatment of the wood waste, and the addition of additives that reduce the w/c and the reduction in the use of binder content. Likewise, further studies are required to investigate producing CMUs and different configurations in accordance with ASTM C129-17 (2017) and the cost effectiveness in producing and building with these units, compared with the locally available CMU units. Moreover, the authors recommend to study the sound insulation, and thermal conductivity, the fire resistance, and the durability of these CMU units made from wood waste.

CONCLUSIONS

1. Conventional aggregate can be fully substituted in producing lightweight concrete material using waste materials, especially for non-structural purposes.
2. The compressive strength obtained from this study showed a potential interest of producing concrete masonry units (CMU) for non-structural purposes using wood shavings as a coarse aggregate. The effect of test replicates, and the size of the specimens showed a small difference among other size of specimens.
3. The emulsifier used in treating the wood shavings contributed to the decreased the roughness the surface of the wood shavings. Moreover, the use of the emulsifier used in treating the wood shavings decreased the voids in the resulted concrete because of the agglomeration of the small particles of wood shavings and form spherical-shape aggregate. Thus, an improvement in the workability of the compressive strength was noticed. Additionally, the use of the emulsifier decreased the water uptake due to the coating effect of the rough absorbent surface of the wood shavings.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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