

Original Research Paper

Mechanical Properties of Concrete Including Wood Shavings as Fine Aggregates

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Abstract: Residual and end-life products are a major hazard on the environment. Many researchers have considered waste as partial replacement of some construction materials to reduce their environmental and ecological problems. This kind of practices can be an important option for the protection of the environment. Wood shavings and saw dust are byproduct of the lumber industry. They are made from timber that's been sawn into planks in saw mills in almost every major city worldwide. This is a daily activity that generates piles of wood residuals at the end of each day. This research investigates the effect of using wood shavings on the mechanical properties of concrete. Fine aggregate was replaced by volume at different levels of replacement by wood shavings. Five different levels of replacement were used, namely 5, 10, 15, 30 and 50% and the results were compared to conventional concrete. Tests were carried out on concrete in fresh and hardened phase to determine slump, wet unit weight, compressive strength, splitting tensile strength, flexural strength, dry unit weight and absorption. The results showed that up to 10% level of substitution, the concrete maintained acceptable mechanical properties in comparison to conventional concrete.

Keywords: Saw Dust, Wood Shavings, Wood Crete, Fine Aggregate, Compressive Strength, Lightweight Materials

Introduction

The cost of building materials such as cement, granite, sand and coarse aggregates is constantly growing. Other low-cost materials, such as wastes and byproducts, are being investigated by researchers. Recycling waste into new construction materials could be a practical solution not only to the pollution problems, but also to the problem of high-cost construction materials.

In the last few years, end use and by-products have become focus for researchers and environmentalists due their negative impact on the environment and they usually generate complicated problems. Utilizing end use and by-products in engineering applications have become highly appreciated practice. Many researchers have investigated end used and by-products materials and have arrived to encouraging conclusions. Recycling of waste materials is been considered as feasible solution to save natural resources, save energy, reduce solid waste, decrease air and water pollutants and reduce greenhouse gases (Bolden *et al.*, 2013; Abu-Lebdeh *et al.*, 2014; Fadiel *et al.*, 2014; Ashraf, 2015; Fadiel, 2013; Adesanya and Raheem, 2009).

Several studies have considered using waste materials and end-life products as partial replacement of conventional construction materials as an effort to find a sustainable, sensible and environmentally sound solution. Several authors considered using crumb rubber generated from scrap and used tires in concrete (Abu-Lebdeh *et al.*, 2014; Fadiel *et al.*, 2014; Ashraf, 2015). (Fadiel, 2013; Fadiel *et al.*, 2014) studied the effect of crumb rubber on the thermal conductivity of cement-based materials and gypsum. They found that, by adding crumb rubber into mortar and gypsum, thermal conductivity of rubberized mortar was reduced by about 28% compared to conventional mortar and by 38% compared to ordinary gypsum.

Saw dust and wood shavings are waste products produced by the wood-based industries. They develop as little irregular chips or small debris of wood during the cutting of timber logs into various shapes and sizes. The proportions of saw dust and wood shavings are determined by the kind of wood and the size of the saw teeth. Every year, a significant quantity of saw dust is produced throughout the world. The dumping of timber industry byproducts on landfills negatively impacts the ecosystem.

According to United States Environmental Protection Agency (EPA), In 2018, wood waste equaled about 6.2% of total Municipal Solid Waste (MSW) with total of 18,090 thousand of U.S. tons. landfills received about 67% of total generated waste wood, only 17% of that amount was recycled (USEPA, 2021). Study done by (Daian and Ozarska, 2009) reported that in Australia, around 7 to 40-50% of the yearly supply of wooden raw material becomes leftovers throughout the operation of wood-related businesses. Saw dusts and shavings account for approximately 65-85 percent of the entire quantity of waste wood by weight. The expenditures incurred in purchasing the raw material, which is eventually disposed of or given away, are estimated to account for 85-95 percent of the real cost of wood waste.

Materials made of wood fibers, have good sound absorption and thermal conductivity close to that of expanded polystyrene and glass wood (Bederina *et al.* 2007; Koohestani *et al.*, 2016; Li *et al.*, 2017). Wood shavings are now employed in the production of cement-based goods such as cement bound particle board. The compatibility of wood and cement has stimulated the interest of academics, who are looking into its usage as a partial substitute for sand in concrete mixes (Boltryk and Pawluczuk, 2014). Another significant advantage of employing wood byproducts is their low cost, availability in big quantities and ease of processing. Researchers agree that saw dust may be used as a source of energy or as a raw material in the production of particle board, fine board and other products (Siddique *et al.*, 2020).

The work present herein is aimed to provide more understanding to the mechanical behavior of woodcrete (concrete contain wood shavings) and find an optimum replacement ratio of wood shavings to be used in concrete without compromising its mechanical properties hence promote their use as possible construction material.

Experimental Program

An extensive experimental program was established to examine the effect amount of wood shavings on the properties of concrete. Control mixture was designed based on American Concrete Institute ACI 211.

At the hardened phase different sizes of specimens were prepared according to ASTM C192, to test compressive strength, splitting tensile strength and flexural strength. also, dry unit weight and absorption were tested at this phase. In addition, during the fresh phase of concrete the slump, wet unit weight were evaluated according to relative ASTM standards.

Materials

Cement

Portland cement type I (42.5 N) with specific gravity of 3.11 was used in this research, the physical and mechanical properties of the cement are listed in Table 1. The cement met the standard requirements of ASTM C150-12.

Table 1: Physical and Mechanical properties of cement

Property	Value	Standard
Initial setting time, (min)	115	>45
Final setting time, (min)	220	<600
Soundness, (mm)	2	<10
Specific Surface Area, (m ² /Kg)	312	minimum 260
Compressive strength, (MPa)	3 days = 17	12 MPa
	7 days = 30.5	19 MPa

Table 2: Sieve analysis of coarse aggregate

Sieve size (mm)	38.1	19	12.5	9.5	4.75	2.36
Passing (%)	100	93.64	47.05	21.78	0.99	0.23
Standards	100	90 -100	----	20 - 55	0 -10	0 - 5

Wood Shavings (WS)

Sand

Gradation of sand used in this study conformed to the ASTM C33 standards. specific gravity and absorption for sand was tested according to ASTM C128 and found to be 2.67 and 0.3% respectively. Sand has bulk density of 1767 kg/m³.

Coarse Aggregate

Gradation of Coarse aggregate used in this research conformed to the ASTM C33 standards (Table 2). specific gravity and absorption for coarse aggregate was tested according to ASTM C127 and it found to be 2.59 and 1.4% respectively. Coarse aggregate has Fineness Modulus (FM) of 7.36 and bulk density of 1534 kg/m³. coarse aggregate has impact and crushing values of 16.4 and 24% respectively.

Wood shavings with particle size ranged from 0.15 to 4.75 mm used in this study (Fig. 1). Gradation of WS and sand are presented in Fig. 2. WS has a specific gravity and absorption of 1.18 and 19% respectively. WS has fineness modulus of 2.79. WS has a loose density of 244 kg/m³ and bulk density of 465 kg/m³. The wood shavings was used in saturated surface dry condition throughout the course of the study, also, it showed be mentioned that wood shavings did not exposed to any type of chemical treatment. It was noted that with saturated wood shavings would disperse better in the dry mixture and will not absorb the free water which is intended to hydrate of cement and maintain acceptable workability of concrete (Bederina *et al.*, 2007).

Mix Proportioning and Casting

Concrete mix was designed based on (The American institute of concrete) Table 3 shows the research plan and mix proportions of each concrete mix. In addition to the control mix (concrete without WS), five levels of replacement of wood shavings by volume of fine aggregate were used. Namely, 5, 10, 15, 30 and 50%. Mix contain 5% of WS was labeled as 5% WS and so on. ASTM standards were followed to determine fresh and hardened properties of mixtures. workability, unite weight, compressive strength, split tensile strength, flexural strength and absorption. The

sizes of testing specimens used in this research were: (100 × 100 × 100 mm) cubes, (100 × 200 mm) cylinders and (100 × 100 × 500 mm) beams. A total of 36 cubes, 36 cylinders and 36 beams were prepared and tested for ages of 7 and 28 days. All mixtures were mixed in a laboratory pan mixer with a volume capacity of 0.056 m³. Cement, Fine aggregate, coarse aggregate and wood shavings were first mixed for 1-2 min in dry condition. After homogenous distribution was achieved,

water was added gradually and mixed for extra 2 min. After confirming that the mix was workable, the mix was poured into the molds and vibrated on a vibrating table. Then excess mix was removed and the specimen's surface was finished with a steel trowel. The specimens were covered with plastic bags for 24 h to maintain humidity. After that, the specimens were de-molded and placed in the cure tank up to the age of test (Fig. 3).

Table 3: Mix ID and mix proportions for cubic meter

	Cement	Sand	Weight (kg) per m ³ Coarse Aggregate	WS	water	W/C Ratio
CM	418	671.2	1012.5	0	205	0.49
5% WS	418	637.6	1012.5	14.8	205	0.49
10% WS	418	604.1	1012.5	29.7	205	0.49
15% WS	418	570.6	1012.5	44.5	205	0.49
30% WS	418	469.9	1012.5	89.0	205	0.49
50% WS	418	335.6	1012.5	148.3	205	0.49



Fig. 1: Wood shavings

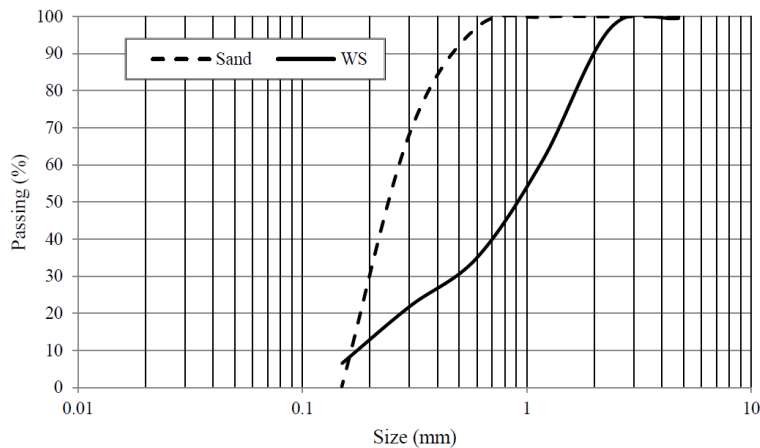


Fig. 2: Gradation of fine aggregate and wood shavings



Fig. 3: Specimens

Results and Discussion

Workability

The workability of concrete mixtures were evaluated using slump test apparatus, the slump test was performed according to ASTM C143/C143M. The results of the slump, indicating the workability of the woodcrete are presented in Fig. 4. The slump values decrease as the WS content increases. The slump for concrete mixtures 5, 10, 15, 30 and 50% WS were decreased by 30, 37.5, 70, 71.5 and 77.5% respectively compared to control mix which has slump of 200 mm.

Reduction of the slump values indicates the reduction of the workability of concrete mixtures containing wood shavings. As the amount of wood shavings increased, the internal friction between individual partials in the concrete increased which cause to produce less workable mixtures.

Wet Unit Weight

Wet unit weight represent the density of fresh concrete. ASTM C138 was followed to determine the wet unit weight of all mixtures. Simply, wet unit weight is determined by weighing the compacted fresh concrete in standard container of known volume and mass. Figure 5 represents the wet unit weight values. The wet unit weight for concrete mixtures 5, 10, 15, 30 and 50% WS were reduced by 8.8, 16.7, 19.5, 26.3 and 37% respectively compared to control mix. The wet unit weight for wood Crete varied from 2211 to 1528 kg/m³. It's obvious that the inclusion of wood shavings decreases the weight of concrete mixtures since the wood shavings has lower specific gravity than fine aggregate.

Absorption

ASTM C642-13, Fig. 6 demonstrate the effect of wood shavings particles on water absorption of concrete. It was

observed that, the water absorption increased as the amount of wood shavings increased. The water absorption ratio of 5, 10, 15, 30 and 50% WS were 9.0, 7.9, 9.8, 17.6 and 26.8% respectively. While the control mixture has absorption of 5.9%. Logically, the increase of water absorption is due the ability of wood to absorb water, so with the increase of wood shavings content the absorption will increase. However, the absorption of all concrete mixtures containing wood shavings were less than 30%. Consequently, the wood crete can be utilized in inner and outer walls in buildings (Li *et al.*, 2017).

Dry Unit Weight

Dry unit weight is calculated according to ASTM C 642-13 and demonstrated in Fig. 7. The test results revealed that the dry unit weight was decreased as the amount of wood shavings increased and ranged from 1507 to 2234 kg/m³, while the dry unit weight of control mix was about 2420 kg/m³. The decrease in the dry unit weight is attributed to the lighter weight of WS compared to sand and also due the increase of air content in the mixtures contain WS. According to ACI 213 R-87 concrete with densities ranged between 300 to 1800 kg/m³ and compressive strength ranged from 7 to 17 MPa is considered as lightweight concrete. Concrete mixture with 30% of WS has a density of 1798 kg/m³ and compressive strength of about 7.5 MPa, so it could be considered as lightweight concrete.

Compressive Strength

Compressive strength of concrete mixtures was determined according to BS 1881: Part 116: 1983. The average compressive strength of three specimens of each concrete mixture was allocated as the compressive strength of that concrete mix. Figure 8 demonstrates the compressive strength of concrete mixes containing different amounts of

WS at ages of 7 and 28 days. At 7 days, concrete mixes 5, 10, 15, 30 and 50% WS showed 39.2, 54.4, 67.2, 85.0 and 96.0% respectively lower compressive strength compared to control concrete. However, 5 and 10% WS mixtures have compressive strength of 23 and 17.5 MPa respectively. Likewise, at 28 days, reduction in compressive strength was recorded. Concrete mixtures 5, 10, 15, 30 and 50% WS, showed 32.3, 46.1, 67.3, 84.6 and 95% lower compressive strength in comparison to control concrete. However, mixtures containing 5 and 10% of wood shavings showed acceptable compressive strength which are 32 and 25.5 MPa. The linear regression analysis of data demonstrate the compressive strength decreased almost linearly as the amount of wood shavings increased. The coefficient of determination (R^2) found to be 0.9 for the age of 7 days and 0.86 for the age of 28 days. The decrease of compressive strength can be attributed to poor bond between wood shavings particles and the surrounding cement paste, wood shavings particles are less stiff than sand and the water released from WS particles during mixing procedure increases the free water hence increases the actual w/c ratio.

The inclusion of wood shavings caused a degradation in the compressive strength (Usman *et al.*, 2018), Siddique *et al.* (2020) and Bederina *et al.* (2009) reported similar observation. However, up to 10% level of replacement, the concrete mixtures exhibited acceptable compressive strength which can be considered for nonstructural elements. The effect of wood shavings on the compressive strength at higher percentage is more pronounced, however, at up to 10% level of replacement the existence of wood shavings does not have much effect on the interface between coarse aggregate and hydrated cement paste. In addition, the good quality of coarse aggregate use herein may have a great impact on the compressive strength and limited the degradation of the compressive strength of concrete mixtures containing wood shavings.

Splitting Tensile Strength

The split tensile strength was carried out according to ASTM C496. The average of three cylindrical specimens of each concrete mixture was assigned as the splitting tensile strength of that mix Fig. 9. The splitting strength was calculated based on the following equation:

$$f_t = \frac{2P}{\pi DL}$$

Where:

- f_t : Splitting tensile strength (MPa)
- P : The failure load (KN).
- D : The diameter of the concrete cylinder (mm).
- L : The height of the concrete cylinder (mm).

The split tensile strength decreased as the amount of wood shavings increased. Figure 10 illustrates the average splitting tensile strength for different mixtures at ages of 7

and 28 days. At 7 days, concrete mixtures 5, 10, 15, 30 and 50% WS, showed 29.1, 32.8, 59.3, 79.8 and 92.1% reduction in splitting tensile strength compared to control concrete. Likewise, at 28 days, the splitting tensile strength was decreased as the amount of wood shavings increased. The 5, 10, 15, 30 and 50% WS mixes, showed 38.8, 35.3, 52.9, 76.8 and 91.2% lower splitting tensile strength than that of control concrete. The linear regression analysis of data demonstrate the splitting tensile strength decreased almost linearly with increase of wood shavings content. The coefficient of determination (R^2) found to be 0.91 at 7 days and 0.96 at 28 days. For concrete mixtures containing 5 and 10% of wood shavings the development of splitting strength was higher at early testing age than later testing age. Other concrete mixtures showed lower rate of reduction at 28 days compared to control mix.

The typical failure modes of concrete cylinders were observed. Control mix experienced one failure along the line of the loading strip, control mix failed in brittle manner. On the other hand, wood crete showed a ductile failure mode. Figure 12, shows the failure modes of control mix and mixtures specimen contain 50% of wood shavings under split tensile load.

Flexural Strength

The flexural strength or (the modulus of rupture) was performed according to ASTM C78 (third point loading Fig. 11).

The average of three beam specimens of each concrete mixture was assigned as the flexural strength of that mixture. Table 4 and Fig. 12. show the flexural strength of mixtures containing WS particles at 7 and 28 days. Like the case of the compressive strength, the flexural strength of concrete was found to decrease proportionally with the increase of wood shavings content. At 7 days, concrete mixtures of 5, 10, 15, 30 and 50% WS showed 23.9, 33.7, 39.1, 70.7 and 31.5% respectively lower flexural strength compared to control mix. Up to 30% level of replacement the flexural strength decreases with the increase of wood shavings content, however, the reduction in the flexural strength of 50% WS concrete mixture was less than other concrete mixtures where the mix recorded 3.15 MPa. Similarly, at 28 days, reduction in flexural strength was recorded. The flexural strength of concrete mixtures of 5, 10, 15, 30 and 50% WS, showed 42, 45.6, 51.2, 71.2 and 44% were less than control mixture. The 50% WS concrete mixture showed same trend, the mixture recorded a 3.5 MPa which is higher than the values obtained by mixes contain (10 - 30%) of wood shavings. The reduction of flexural strength at age of 28 days was higher than that of 7 days age.

The lack of a conventional fine aggregate was directly resulted in the loss of flexural strength. The increase of flexural strength at 50% level of replacement can be attributed to the increase of wood shavings content which act like fibers in concrete mixture which leads to improve the

capacity of energy absorption due the distributed stresses along the failure surface caused by wood shavings.

All woodcrete mixtures, have same failure pattern, where the line of fracture occur at the middle third of

the specimens. Table 4 presents the average compressive strength, splitting tensile and flexural strength at ages of 7 and 28 days.

Table 4: Summary of mechanical properties of different concrete mixtures

Mixture ID	Compressive strength (MPa)		Splitting tensile strength (MPa)		Flexural strength (MPa)	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
CM	38.1	47.1	3.4	4.1	4.6	6.3
5% WS	23.1	31.9	2.1	2.9	3.5	3.6
10% WS	17.4	25.4	2.2	2.7	3.1	3.4
15% WS	12.5	15.4	1.6	1.7	2.8	3.1
30% WS	5.7	7.3	0.8	0.8	1.4	1.8
50% WS	1.5	2.4	0.3	0.3	3.2	3.5

Table 5: Compressive strength and split tensile strength ratio

Age (day)	(Compressive strength/Split tensile strength)					
	CM	5% WS	10% WS	15% WS	30% WS	50% WS
7	11.19	11.12	7.89	7.81	7.20	5.00
28	11.63	11.11	9.34	9.33	8.84	7.34

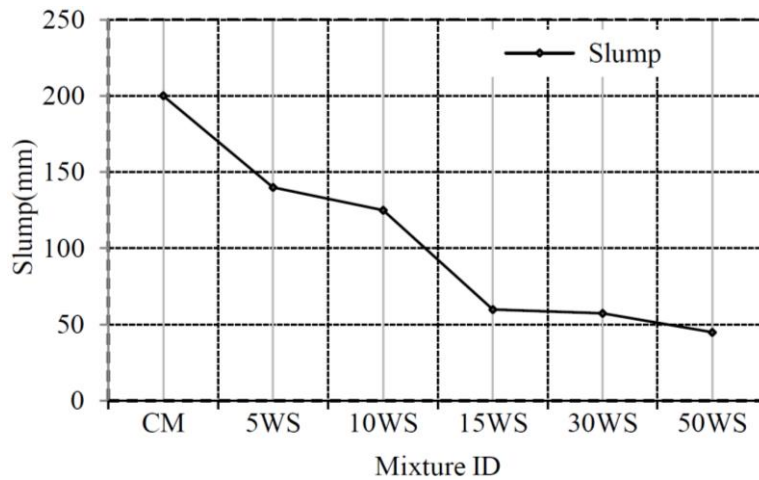


Fig. 4: Slump test values

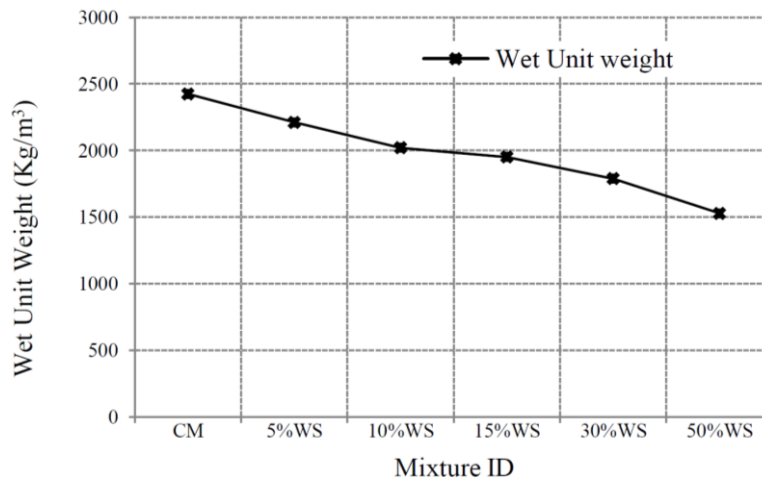


Fig. 5: Wet unit weight results

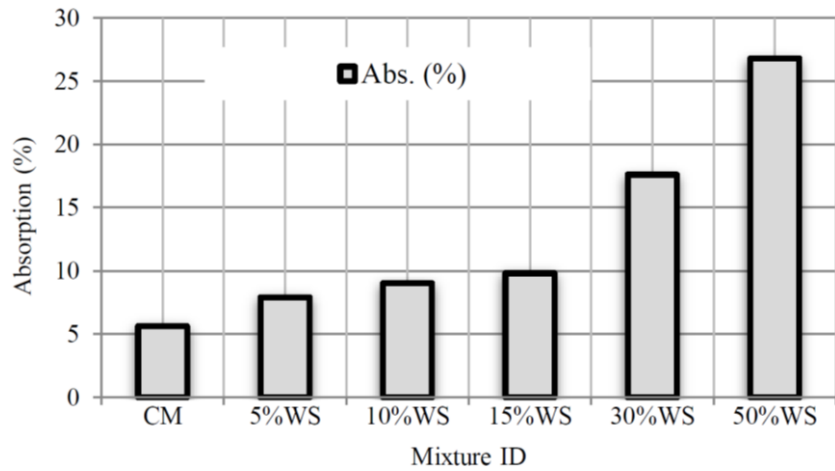


Fig. 6: Water absorption for varies concrete mixtures

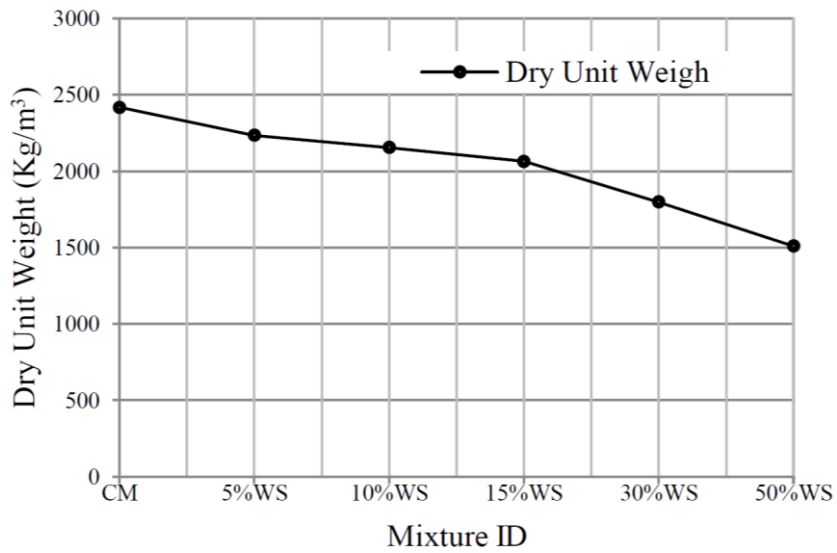


Fig. 7: Dry unit weight results

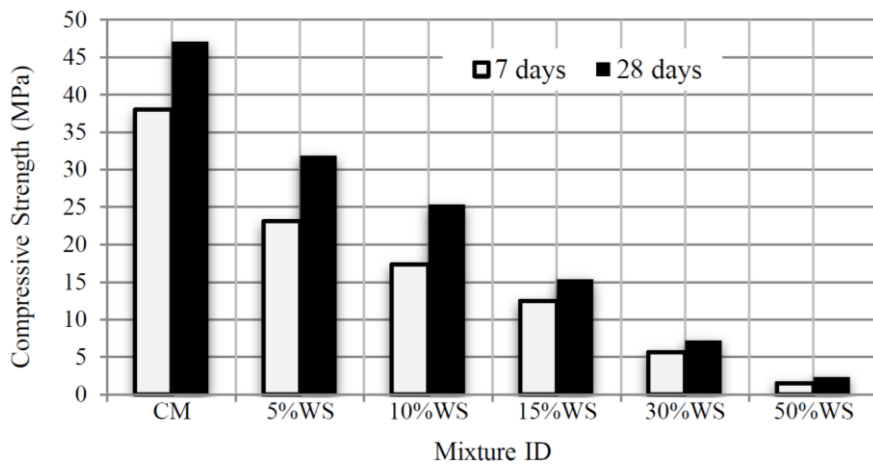


Fig. 8: Compressive strength of concrete incorporating WS

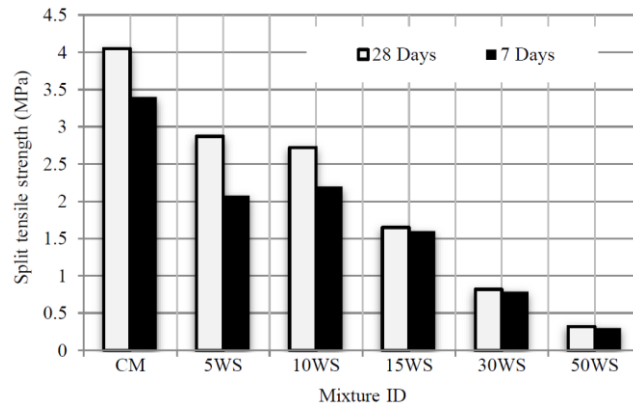


Fig. 9: Average splitting tensile strength of concrete mixtures incorporating wood shavings

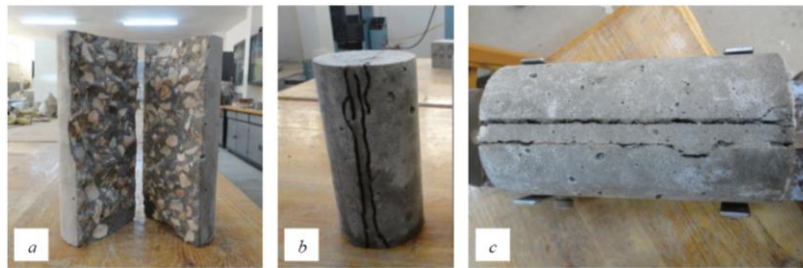


Fig. 10: Failure modes of splitting tensile strength for different mixes: (a) control mix, (b) 30% WS concrete mix and (c) 50% WS concrete mix

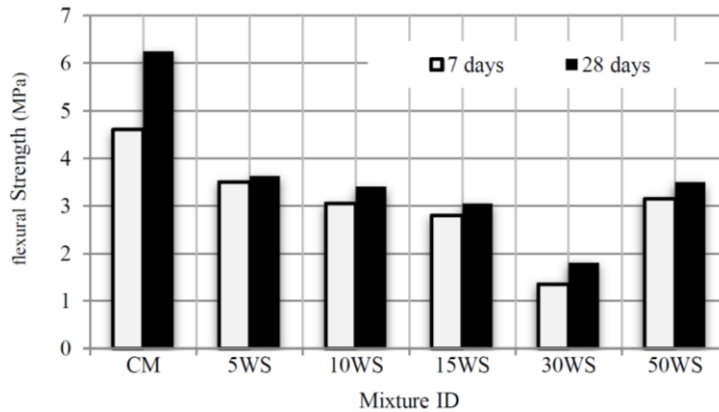


Fig. 11: Flexural strength of mixes incorporating wood shavings



Fig. 12: Flexural test setup

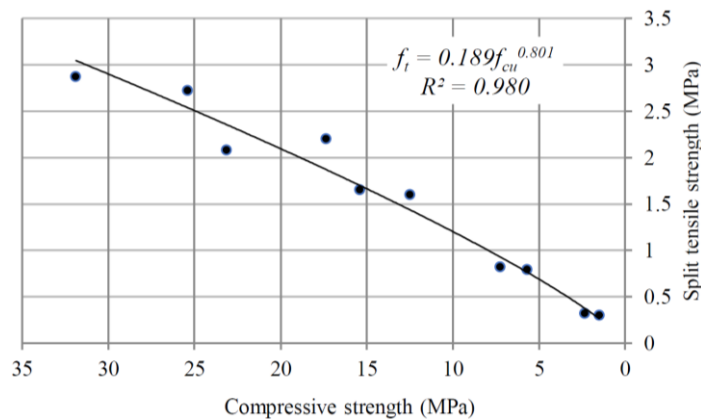


Fig. 13: Compressive strength and splitting tensile strength of concrete containing wood shavings

Relation between Compressive Strength and Splitting Tensile Strength

The ratio of compressive strength and splitting tensile strength of woodcrete and control mix are presented in Table 5. At all ages, the development of compressive strength and splitting tensile strength of wood crete is less than control mix, moreover, the compressive to splitting tensile strength ratio decreased as the amount of wood shavings increased. In addition, 50% WS mixture showed lower compressive strength and splitting tensile strength ratio and this may be due to the resistance provided by wood shavings which acts as fissber in this stage causing improvement in the energy absorption. Figure 13 illustrates relation between compressive strength and split tensile strength of control concrete and concrete mixtures contain wood shavings. The equation of relation between compressive strength and splitting tensile strength of woodcrete is given below, Similar equations were derived by (Siddique *et al.*, 2020; Mohammed *et al.*, 2014).

$$f_t = 0.189f_{cu}^{0.801}R^2 = 0.98$$

Where:

f_t : Split tensile strength (MPa)

f_{cu} : Compressive strength for cubic specimens (MPa).

Conclusion

Some conclusions can be drawn from this study as follows.

The study reveals there is a possibility to produce light weight concrete with up to 15% wood shavings inclusion with acceptable compressive strength.

The workability decreases as the amount of wood shavings increases which may be attributed to the increase in the internal friction between individual partials in the concrete increased which cause to produce less workable mixtures.

The increase in wood shavings content decreases the weight of concrete mixtures by noticeably decreasing the density of. This might be due the lighter weight of wood shavings compared to conventional fine aggregate and to the produced air voids which is notably obvious in concrete mixtures contain higher wood shavings content.

The absorption of concrete mixtures increases with increase of wood shavings content.

The degradation in the mechanicals properties of woodcrete is obviously increased as the amount of wood shavings increased, however, up 15% level of replacement concrete mixtures exhibited acceptable compressive strength. Hence, this type of concrete could be used for non structural elements.

Up to 30% wood shavings concrete mixtures the flexural strength diminishes as the amount of wood shavings increases. At 50% level of replacement, the flexural strength increases, but, still less than of that of control mix.

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Author's Contributions

Ashraf Fadiel: Conducting the experimental program and writing manuscript.

Taher Abu-Lebdeh: Participated in manuscript writing and the analysis of the finding.

Ethics

The authors would to disclose that Dr. Taher Abu-Lebdeh (Co-author) is a member of the editorial board for the American Journal of Engineering and Applied Sciences.

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