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RESEARCH

Time-dependent behavior of eco-friendly sand concrete using treated wood shavings

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Abstract
Given a circular economy, wood waste has become an important secondary raw material. For this purpose, an experimental study was conducted to characterize concrete mixes containing wood shavings for structural and nonstructural construction applications. In this study, treated wood shavings (TWS) from woodworking waste were used by replacing natural sand for making sand concrete (SC) with different mixing ratio (0%, 10%, 20%, 30%, 40%, and 50%) by volume of sand. The behavior of sand concrete samples containing wood was then explored. Wood shavings treatment, X-ray diffraction (XRD), resistance, porosity, thermal conductivity, fire resistance, and scanning electron microscopy (SEM) were used to investigate the behavior of SC using TWS (SCWS). The results showed that most of the SCWS samples had acceptable mechanical strength and density. Increasing the amount of (TWS) decreased the density, compressive strengths, and thermal conductivity of the mixtures by up to 38%, 35%, and 35% respectively. However, all the mixtures could be considered structural LWC mixtures as they developed acceptable strength in terms of structural design and use. Additionally, the novel composite reportedly possesses adequate thermal conductivity and fire resistance.

Finally, sand concrete based on wood shavings could be used as a fire insulator when combined with other relevant fire-resistant materials.

Keywords Sand concrete · Wood shavings · Wood treatment · Thermal conductivity · Fire resistance · Microstructure · Recycling · Environment

1 Introduction

The fast expansion of the building sector around the world has resulted in a rise in raw material usage. As a result, certain nonrenewable resources have been depleted (Khan et al.

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2020). One of the prospective solutions to this economic problem is the use of local sands for construction materials (Bederina et al. 2009; Ladjel et al. 2022; Nshimiyimana 2021). The literature on sand concrete showed in particular structures that sand concrete could represent an alternative to ordinary concrete (Bederina et al. 2009). In addition, they represented various required properties such as workability, lightness, and thermal conductivity (Corinaldesi et al. 2016).

On the other hand, significant attention has been paid to industrial waste, which is causing environmental issues in some countries. Recent studies have begun to consider the value of this waste in the construction industry (Miraldo et al. 2021; Oi et al. 2021; Pitoyo and Vebrian 2021; Tamanna et al. 2020). The use of this waste in the construction industry has the potential to solve three major issues by lowering construction material costs, conserving natural raw materials, and preserving the environment (Tamanna et al. 2020). Previous studies on bio-based cement composites, such as wood concrete, have been conducted. Given the abundance of wood waste and the potential to replace significant amounts of cement and aggregates (Guo et al. 2019; Morales-Conde et al. 2018; Siddique et al. 2019). Moreover, the high cost of building materials has created a barrier to getting convenient housing. Therefore, certain authors recommended the use of green architectural construction materials such as wood waste to create affordable housing solutions (Abed and Khaleel 2019; Jacob Lembi et al. 2021). Thus, the use of wood waste in construction materials will reduce the negative impact of the waste on the environment and will save natural resources.

Furthermore, because of their porous and fibrous structure, they exhibit interesting properties such as acoustic and thermal properties (Wu et al. 2021).

However, these lignocellulosic materials are frequently treated before being included in composites (Vo and Navard 2016; Wang et al. 2016). Previous studies showed that acceptable compressive strength can be obtained when the replacement ratio is less than 40%. As a result, there is a great demand for a treatment process for wood waste so that it can be used at a higher replacement rate with acceptable properties in the resulting concrete (Alrubaie et al. 2023).

Various known treatments can be classified into three categories. First of all, physical treatment, which consists of coating or impregnating wood to limit the release of sugar and the absorption of water intended for cement hydration (Quiroga et al. 2016). Bederina et al. (2012) investigated the effects of this treatment by coating wood shavings with three distinct pastes: cement, lime, and a mixture of the two. In addition, the treatment of wood shavings by impregnating them in oil was examined. The results showed that oil treatment produced the best results in terms of drying shrinkage, lightness, and thermal conductivity. In terms of mechanical strength, cement coating was the most effective because it increased the rigidity of wood aggregates.

Thermal treatment is the second type of treatment. This treatment's goal is to extract or degrade hemicellulose by modifying the chemical structure of the wood. Previous studies suggested that hot water at 80 °C could be used to extract cellulose, lignin, and other substances that could inhibit cement setting (Amiandamhen and Izekor 2013). Da Gloria and Toledo Filho (2016) investigated the proportion of extractives eliminated after washing the shavings in hot water. They claimed that three or five washings were sufficient to extract a significant amount of sugar.

Chemical treatment is the third option. This is the most commonly used method. Its goal is to keep water molecules from being bound by wood's hydroxyl groups (Rowell 2006). Coatanlem et al. (2006) experimental investigation revealed that pretreatment of wood shavings by soaking in sodium silicate solution improved the interfacial cement past zone.

The previous literature reviewed in this study showed many advantages of using wood waste in construction materials. For instance, the use of lightweight elements from wood

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waste reduces the load on the entire structure on the foundation. In addition, bricks made from wood waste showed better thermal properties (reduced thermal conductivity) and soundproofing properties compared to traditional bricks (Elshahawi et al. 2021). However, according to Mangi et al. (2019), the low mechanical properties of the masonry units made from wood waste limit their use for nonstructural purposes. Further efforts are required in treating the wood waste to maintain acceptable properties of the masonry units and widen their application.

Although research has been carried out to study the application of TWS in buildings, several characteristics of the designed materials still need to be improved. The research on the effectiveness of the treatment on the thermo-mechanical properties and fire resistance needs to be studied further.

Few studies in the literature report the effect of thermal treatment on lightweight wood sand concrete particularly under elevated temperatures. The goal of this research was to reduce the negative impact of lignocellulosic material on the physicomechanical properties of sand concrete, particularly in terms of fire resistance. In this study, the TWS are used as a replacement of natural sand. The resulting SCWS could be used under beds for the construction of floors and ceiling panels where significant savings can be achieved by reducing the dead load. It is also used in some insulated sections of floors and walls (Agrawal et al. 2021).

2 Materials and experiments

All mixtures were made with blended cement (CEM II), which contains 10% limestone powder. It has a 28-day compressive strength of 42.5 MPa and a specific surface area of 320 m^2/kg. Figure 1(a) depicts its mineralogical composition. The sand used is from Oued Souf, a southern province of Algeria, with a modulus of fineness of 2.73 g/cm^2 and equivalent sand content of 85%, indicating that it is clean sand. According to the XRD analysis (Fig. 1(b)), it is silico-calcareous sand.

The filers used are made from limestone obtained from a quarry in the northern region of Blida (Algeria) by screening crushed waste (80 mm mesh screen). They have a specific density of 2.59 g/cm^3 and Blaine's specific surface area of 2800 kg/m^3. It should be noted that fines are required for the production of sand concrete to improve its strength and workability (Bederina et al. 2012).

Wood shavings from woodworking waste with a fibrous appearance, an irregular shape, a density of about 160 kg/m^3, and a water absorption coefficient of about 254% were used to lighten the concrete (Fig. 2). The X-ray diffraction curves of raw and treated wood shaving are shown in Fig. 3. X-ray diffraction analysis revealed that cellulose was a key component in the wood shavings samples. Wood shaving samples represent lignocellulosic materials in shape (Marcovich et al. 1996; Segal et al. 1959). The intensity of diffraction increased after the wood shaving was modified. These findings show that heat treatment of wood shaving results in an increase in the crystallinity index and an improvement in the order of crystallites. According to (Alemdar and Sain 2008; Benyoucef and Harrache 2015), due to the reduction of hemicelluloses during processing, the degree of cellulose crystallinity is higher in treated samples than in raw sawdust.

The water used in this study is potable water with a PH value of 7.2. To maintain similar workability when using limestone sand, a superplasticizer must be used (Bederina et al. 2013). As an admixture, a Superplasticizer / High water reducer of the new polyvalent generation with a density of 1.060 kg/m^3 was used.

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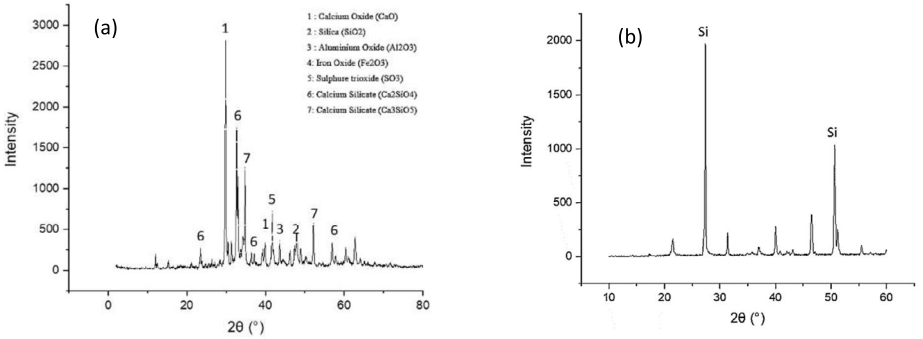
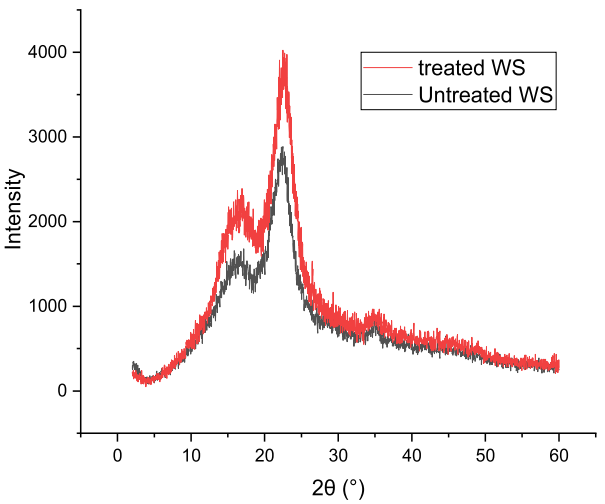


Fig. 1 XRD analysis of (a) cement (b) sand

Fig. 2 General aspect of used shavings



Fig. 3 XRD analysis of wood shavings



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Table 1 Concrete mixtures proportion ratios

Mix code	S. (kg/m^3)	C. (kg/m^3)	L. (kg/m^3)	TWS (kg/m^3)	W. (kg/m^3)	S.P (kg/m^3)
SC	1470			0.00	220	2.1
SCWS10	1323			09.33	213.30	2.06
SCWS20	1171	350	110	18.67	206.60	1.95
SCWS30	1029			28.00	200.00	1.9
SCWS40	882			37.33	193.20	1.8
SCWS50	735			46.67	186.50	1.72

C _ Cement, S _ Sand, L _ Limestone, TWS _ Treaded wood shavings, Water, S.P _ Superplasticizer.

3 Sample preparation and wood shaving treatment

The preparation of the wood sand concrete was done in two steps. The first step was to determine the best sand concrete composition using the experimental method of SABLOCRETE (Jean-Danie 1994). Second, aside from the control concrete, five percentages of shavings were considered: WS = 10, 20, 30, 40, and 50%, as shown in Table 1. The WS ratio was calculated by volume replacing the natural sand according to the following equations (1), (2), (2′), (3) and (4):

$$\rho\, sand = \frac{Ms}{Vs}\ (1),\ \rho\, ws = \frac{Mws}{Vws}\ (2)\ \rightarrow Vws = \frac{Mws}{\rho\, ws}\ (2')$$

$$Vws = ratio\% * Vs\ (3) \rightarrow Mws = Vws * \rho\, ws\ (4)$$

ρ: density; M: mass; V: volume.

It is well known that bio-materials are typically made up of cellulose, hemicellulose, and lignin (Uysal et al. 2014). The sugar in them may lower the pH of the cement matrix and inhibit cement hydration, thereby affecting the mechanical properties of lightweight concrete. To avoid this phenomenon, the treatment used consisted of boiling the shavings in water for four hours. According to Da Gloria and Toledo Filho (2016), this is enough to change the chemical composition of the wood and thus eliminate the organic matter. After treatment, the content of cellulose, lignin, and hemicelluloses of WS used are respectively 48%, 22.3%, and 25%. To keep the W/C ratio constant across all mixtures, it was calculated after taking into account the amount of water absorbed by the treated WS after they were dried for 24 h at 80 °C, then subtracting it from the initial amount of water. The wood shaving's moisture content before and after treatment was respectively 6.90% and 8.70%.

4 Test procedure

For all mixtures, ASTM C642-13 (Astm 2013) and NF P18-406 (AFNOR) standard methods were used to conduct density and compression tests on 40 × 40 × 160 mm^3 prisms. The compression test was performed on three different ages: 7 days, 14 days, and 28 days. The results were obtained by taking the average of three specimens.

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The porosity accessible to water was measured using glass desiccators with a perforated disc linked to a vacuum pump and a negative pressure manometer in accordance with the NF EN18-459 standard (NF 2010).

Thermal conductivity was measured using an instrument called the "CT METER" in accordance with the EN 993-15 standard (EN 2005). The thermal conductivity of the studied samples was determined using an annular probe of type 15. R (diameter 15 mm) intended to be inserted between two pieces of the sample.

To test the fire resistance of concrete, 28-day-old specimens were transported to an electric furnace and heated at a constant rate of 10 °C/min to four different temperature cycles ranging from 80 °C to 100, 200, and 400 °C. Once the electrical furnace reached the target temperature, it was held constant for two hours to ensure uniform distribution throughout the concrete specimens in accordance with ISO 834 (ISO 1999). At the end of each heating temperature cycle, the samples cooled to room temperature in the sealed furnace for 24 hours before being visually examined with a digital camera to assess the presence of porosity and cracks (Fig. 12), then physical and mechanical tests were conducted.

The microstructure of the investigated composites was examined using a Thermofisher tungsten Scanning Electron Microscope (SEM), which can analyze nonconductive samples like wood. Initially, the sample to be analyzed is glued to a circular metal sample holder adaptable to the object holder of the microscope. To perform the scan, the device containing the sample is placed in the inner chamber of the microscope and moved using verniers. Because the microscope has a controlled pressure characteristic, the sample is not metalized before a backscattered electron detector produces primary electrons from a tungsten filament heated to 2700 k (Benyoucef and Harrache 2015). The micrographs obtained make it possible to observe the microstructure of the surface of untreated and treated wood shaving, then to determine the effect of the heat treatment used on the microstructure of wood shaving.

5 Results and discussion

5.1 Density

Density values for all mixes are shown in Fig. 5. The presence of WS reduces the density of the new concrete. The findings reveal that when the WS content is low, the density loss of concrete is less visible. It varied from 6% for SCWS10% to 19% for SCWS50%. Morales-Conde et al. (2018) also discovered the same thing. Furthermore, the density of the examined concretes was 1942.41 kg/m^3 after 28 days of curing, which is a lightweight concrete according to the NF EN 206-1 (AFNOR) standard, which classifies composites with a density of 800 kg/m^3 to 2000 kg/m^3 as lightweight concretes. All of the samples examined can be classified as lightweight concrete. As shown in Fig. 4, SCWS10, 20 and 30% are in class (D2.0), while samples with 40 and 50% of WS enter the class (D1.8).

Sand concrete has a lower granularity and is therefore lighter than conventional concrete. As a result, replacing sand with WS, which is even lighter, reduced the density even more (Bederina et al. 2007; Bederina and Quéneudec 2010). This lightness could be attributed to the low density of WS. Furthermore, the evolution of this parameter based on the WS ratio at 7, 14, and 28 days, as shown in Fig. 4, shows a significant decrease in density as a function of curing age. The findings are consistent with other studies that have found that two major factors are to blame for these findings. The evaporation of the water absorbed by the wood shavings during drying resulted in additional porosity in the matrix and the porous structure of the wood (Taoukil et al. 2013).

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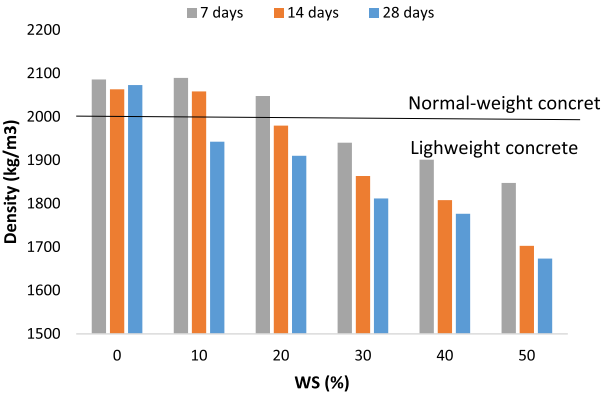


Fig. 4 Density of concrete

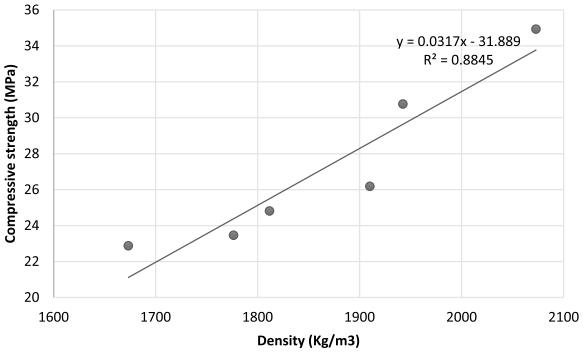


Fig. 5 Correlation of compressive strength and density of concrete

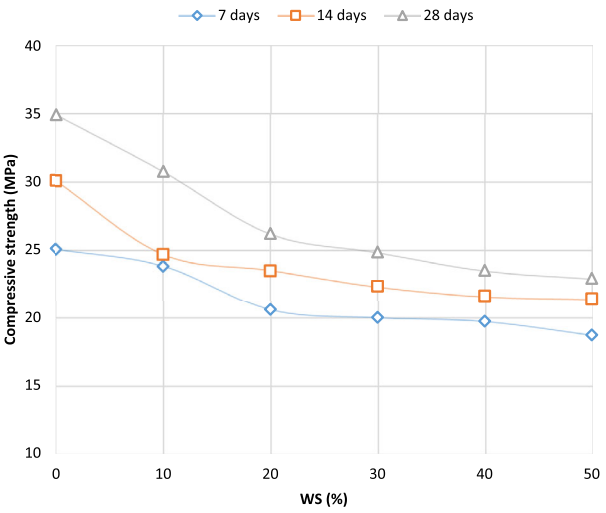


Fig. 6 Compressive strength of concrete versus WS content

5.2 Compressive strength

Figure 5 describes the relation between concrete compressive strength and density. Concrete's compressive strength is proportional to its density. As shown in Fig. 6, there is

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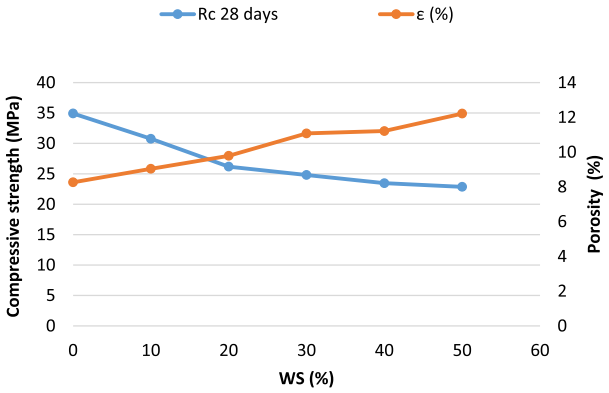


Fig. 7 Variation of compressive strength (Rc 28 days) and porosity (ε) of concrete according to WS content

a significant reduction in resistance when moving from the control concrete to the most lightweight concrete. The loss of strength ranged from 12% for SCWS10 to 35% for SCWS50. The more wood there is in the concrete, the less resistant it is. Morales-Conde et al. (2018) reached the same conclusion. The decrease in strength can be attributed to the high porosity introduced by WS, as illustrated in Fig. 7. Indeed, the addition of WS as sand aggregate substitute increased the porosity of the samples significantly (Guo et al. 2019). Moreover, the substitution of WS for sand increased the specific surface area while causing a lack of cement content to coat the high specific area (Siddique et al. 2019). Furthermore, Guo et al. (2019) reported that the decrease in strength could be attributed to the low bonding between the WS and the SC matrix. The compressive strength values of the mixtures in the literature vary greatly, depending on many factors such as the type of cement used, the type of wood, the treatment of wood particles, the water/cement ratio, and the mixing process. Tamba et al. (2007) measured 6.7 MPa with different wood species but the same ratio, while Sotannde et al. (2012) measured 8.5 MPa. Despite differences in compressive strength results, the authors agree that the strength of WSCC decreases as the volume of the wood particles increases.

5.3 Flexural strength

Flexural strength was also evaluated at 7, 28, and 90 days, and the measurements are shown in Fig. 8. When comparing the results of the addition of wood waste to sand concrete in terms of flexural and compressive strength, the same effect is observed in flexural strength as for compressive strength. The resistance values of compounds decrease by 19 and 45% compared to the reference concrete. Similarly, Siddique et al. (2019) observed the same rate for both strengths.

5.4 Thermal conductivity

Figures 9, 10, and 11 show the thermal conductivity results and their relationship to the concrete parameters. There is a strong link between those variables, and the loss in conductivity is clear as the amount of wood increases. The new concrete has a conductivity that is about 35% lower than the reference concrete. This decrease in thermal conductivity is caused by the interplay of the lower thermal conductivity of wood with the higher thermal conductivity of concrete. Furthermore, the wood shavings generate a matrix cell structure within the concrete, resulting in a decrease in conductivity and, as a result, an increase in

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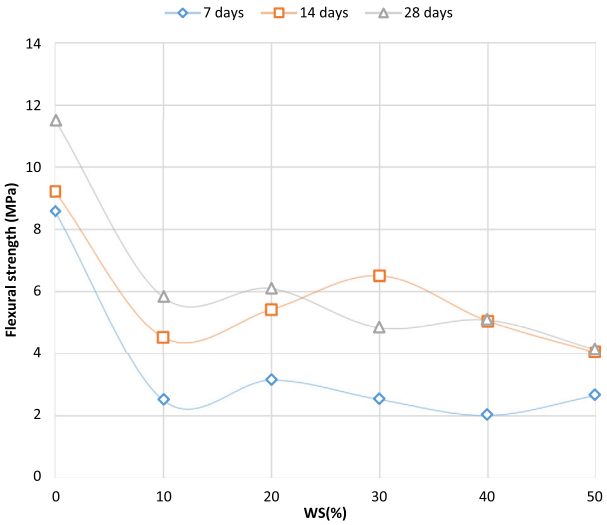


Fig. 8 Flexural strength of concrete versus WS content

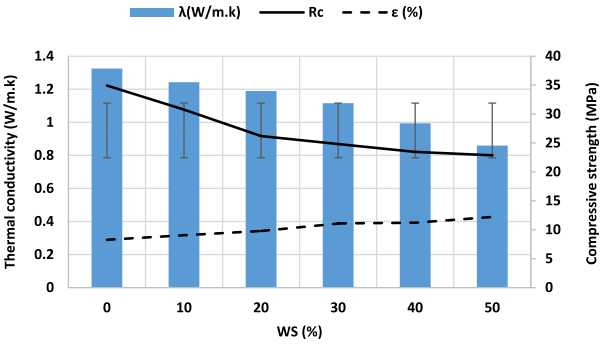


Fig. 9 Variation of thermal conductivity, compressive strength (28 days), and porosity of concrete according to WS content

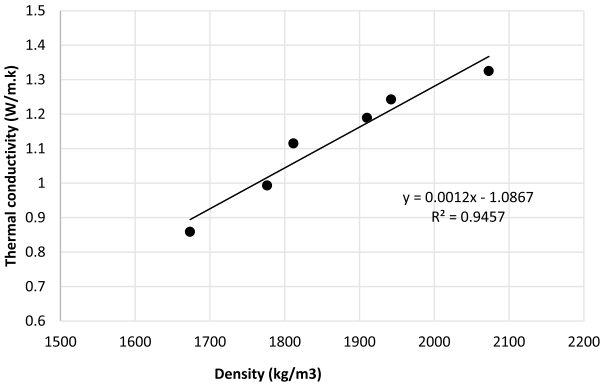


Fig. 10 Thermal conductivity of concrete versus density of the concrete

thermal insulation. These findings are in accordance with research (Bederina et al. 2007; Corinaldesi et al. 2016; Morales-Conde et al. 2018) that found a decrease in thermal conductivity in the new mixture when wood waste was added. Furthermore, the porosity of

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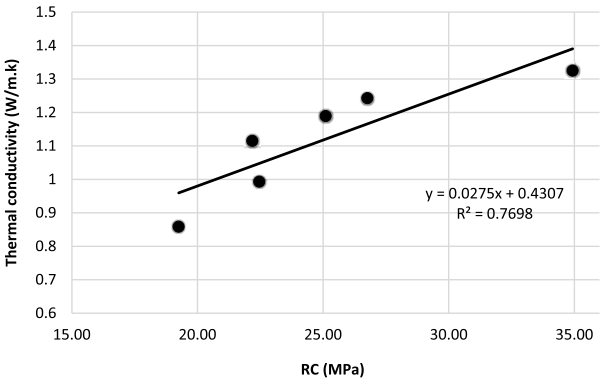


Fig. 11 Thermal conductivity of concrete versus compressive strength of the concrete

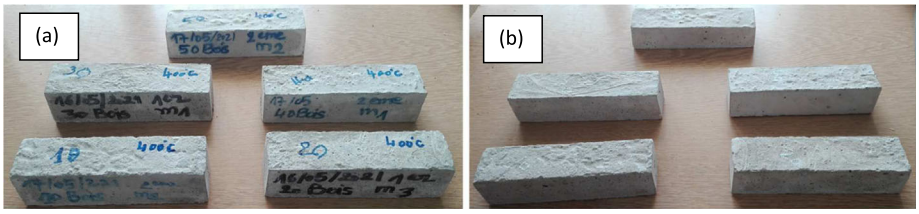


Fig. 12 Aspect of the specimen before (a) and after (b) fire exposition

concrete determines its thermal conductivity, which also determines its mechanical strength (Wu et al. 2021). Nonetheless, the obtained values are slightly higher than the values recommended by the standards for considering these SCWS as insulating concrete. This is due to the SCWS absorbing a large amount of water. According to Taoukil et al. (2013), the thermal conductivity of the concrete increased significantly as the amount of water in the concrete increased.

5.5 Fire resistance

Temperatures ranging from 80 °C to 100 °C, 200 °C, and 400 °C are used to explore the behavior of new concrete when exposed to fire. The mechanical properties are shown in Figs. 13 and 14, and the loss of mass is shown in Fig. 15. This type of analysis could be utilized to ensure the quality of concrete made using WS waste. The weight loss is related to the WS content at different temperatures. As shown in Fig. 15, the higher the WS percentage, the more weight the samples lost. In addition, this loss was more pronounced at high temperatures. For example, it varied from 2% to 6% for the sample SCWS10 exposed to 100 °C and 400 °C, respectively, whereas it was 69 percent higher for the sample SCWS50. Similarly, Morales-Conde et al. (2018) discovered that the mass loss and degradation of mortars varied depending on the amount of wood waste.

Furthermore, the compressive and flexural strengths are all lower than the reference concrete SC at all temperatures (Figs. 13 and 14). The pyrolysis phenomena of lignocellulosic materials appear to be associated with the pattern of mechanical strength decreases at high temperatures (Morales-Conde et al. 2018). Khan et al. (2020) discovered a delay in compressive strength reduction between 100 °C and 200 °C, while Akçaözolu (Akçaözoğlu 2018) discovered that all specimens retained some mechanical strength at temperatures of 150 °C

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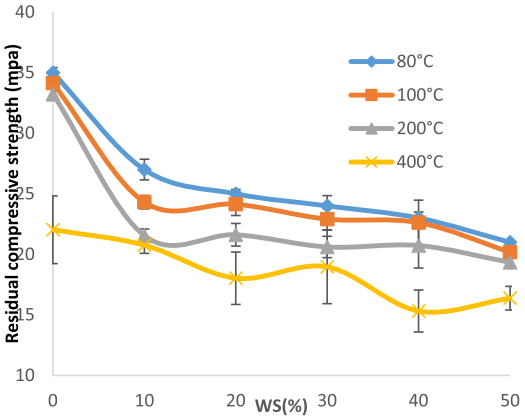


Fig. 13 Compressive fire strength of concrete

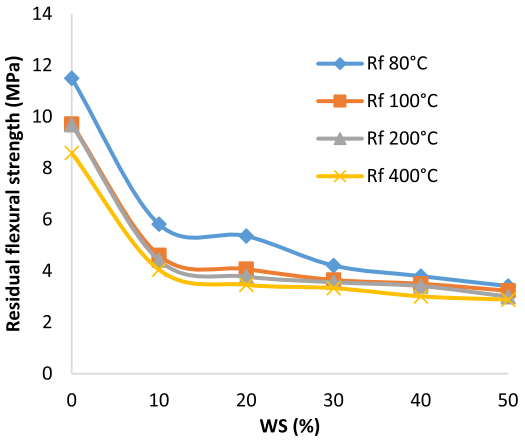


Fig. 14 Flexural fire strength of concrete

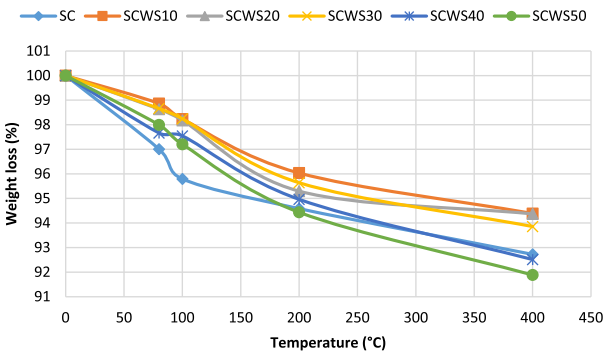


Fig. 15 Weight loss in different mixes subjected to elevated temperatures

and 300 °C. According to the literature, this stable behavior was attributed to a decrease in the initial vapor perturbation induced by the evaporation of physically bound water at 100 °C (Hager 2013).

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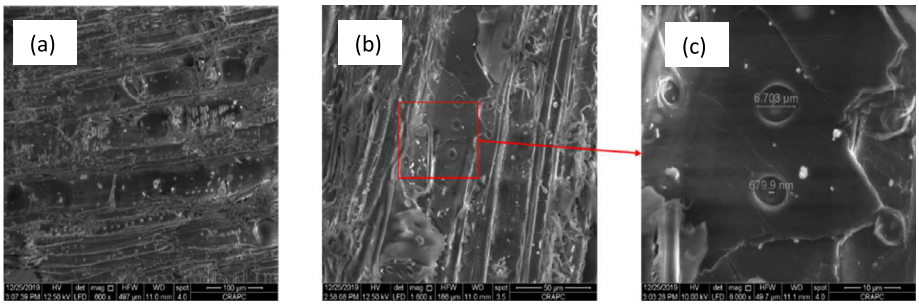


Fig. 16 Visualization of the surface roughness (a) and porous structure (b) of wood shavings

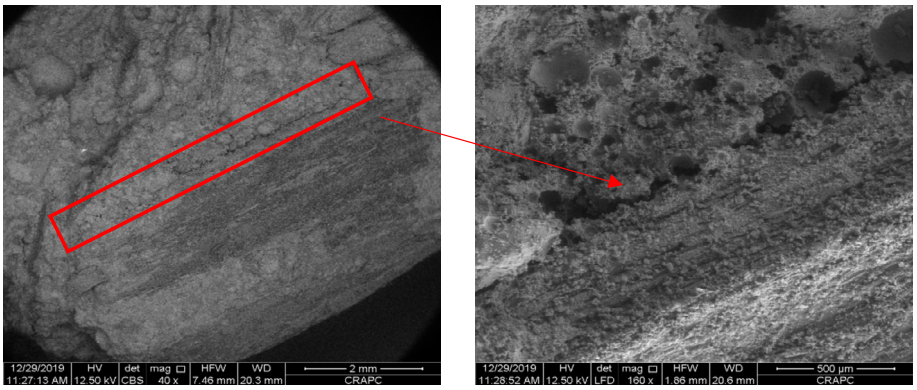


Fig. 17 Visualization of the interface transition zone between TWS and cement matrix

5.6 SEM analysis

A microstructural analysis was performed using SEM images to thoroughly explain some of the obtained results. The microstructure of WS is shown in Fig. 16(a) to have two dominant features: fiber (continuous layer) and particle (aggregates) (Garcia and Sousa-Coutinho 2013). Figures 16(b) and 16(c) depict the presence of intercellular voids in the form of partially exposed longitudinal cavities in wood shaving before thermal treatment. Figures 16(a) and 16(b) show a horizontal section of wood shaving with horizontal tubes known as tracheids. These are cells that are elongated in the longitudinal direction and support and conduct the sap. In the image enlarged to 1000×, the thickened walls of the tracheids are marked by lines of minor and major holes known as punctuations (see Fig. 16(a)). These punctuations allow substances to exchange with neighboring cells, allowing the adsorption mechanism to function (Benyoucef and Harrache 2015).

The morphology of the WS (Fig. 16) indicates that there ought to be good adhesion with the cement matrix (Bederina et al. 2016). However, we see that there is occasionally damage in this component based on the regions surrounding the WS in Fig. 17. Due to the evaporation of water absorbed by the WS and the stress produced by water loss/gain, this damage manifests as a more porous area, and the presence of cracks around the light-weight aggregate (Bederina et al. 2007; Dias et al. 2022). A similar effect was noticed by Fu et al. (2020), and it indicates that there is a weak adhesion between the WS and the cement paste.

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This might be the reason why mechanical resistance has decreased (Akkaoui 2014). We can also see a lot of pores on the cement matrix by looking at the SEM images. This is the porosity caused by the addition of WS according to Ammari et al. (2020). As a result, the presence of a transition interface between the aggregates and the matrix hurts a composite's mechanical properties because it represents a weak zone (Yu 2019).

6 Conclusions

This paper presents the results of the behavior of lightweight concrete incorporating treated wood shavings in different percentages. The following conclusions were drawn based on the presented findings:

- Most of the designed LWCs were successfully classified to the density category D1.8 and D2.0, whereas the strength values were found to be capable of satisfying the strength (LC30/33) for SCWS10, (LC25/28) for SCWS20, (LC22/25) for both samples containing 30 and 40% of WS, while SCWS50 was classified under (LC20/22) category. Accordingly, all mixtures could stand alone as structural LWC mixtures as they developed acceptable strength in terms of structural design and use.
- The density and mechanical strengths of sand concrete are considerably reduced when the content of treaded wood shavings is increased. The reason was a lack of bonding between the bio-based aggregates and the cement matrix. As a result, increasing the proportion of treaded wood shavings reduces thermal conductivity and, as a result, increases the thermal insulation of sand concrete. In conclusion, lightning sand concrete with treaded wood shavings increased the composite's fire resistance.
- Although this type of concrete has shown interesting thermal properties, it may suffer from a lack of fire protection. Thus, it is suggested to use it in combination with other appropriate materials capable of resisting fire.

The use of wood waste requires a specific approach to ensure sufficient properties for the sand concrete. Particularly when using it in combination with other suitable fireproofing material, specific precautions and measures are necessary to be taken into account, especially for the soundproofing and fire resistance. Further research is needed to investigate different methods and techniques for treating waste wood and adding additives to reduce the water/cement and binder content.

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Declarations

Competing interests The authors declare no competing interests.

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