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Physico-Mechanical Study of an Ordinary Concrete Based On Wood Chips

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Abstract
An experimental method has been carried out for analyzing the thermo-mechanical characteristics of concrete based on treated and untreated red-wood chips and concrete based on treated and untreated chips of steamed beech wood. The obtained results of experimental study for concrete characteristics confirm the superior performances of studied concrete. The treatment improves relatively wood-matrix adherence. Wood chips can upgrade the thermal-conductivity of ordinary concrete. This innovative building material, based on renewable resources, can provide a good thermal insulation.

Keywords: Concrete, Wood chips, Treated untreated chips, Mechanical Strength, Thermal Conductivity.

1. Introduction
The construction sector is a leading worldwide employer. In Europe, for instance, this industrial sector accounts for 7.5% of total employment, contributing to about 10.4% of the Gross Domestic Product. The long-term asset value of this industry depends on its ability to cope with the changing environmental concerns such as the disposal of waste materials [1]. Thus, exploring new eco-friendly materials for construction and selecting their desired distinctive properties and functionalities would lead not only to innovation in material by design but also to expand new sustainable material, intended for construction possibilities. Moreover, this new bio-based composite materials can provide a better thermal resistance and compete with the traditional construction materials. These concerns have motivated the investigation of innovative building materials such as the use of waste wood chips as reinforcement for cement-based composites.
Plusieurs études ont porté sur l'utilisation de bois sous forme de cendres dans les bétons, jouant ainsi le rôle de filler. Une utilisation sous forme de copeaux dans une matrice de ciment ou bien dans une matrice de ciment et d'argile est également envisageable ce qui permet d'obtenir ainsi un béton léger, bon isolant thermique et acoustique [2] et de contribue à valoriser certains sous-produits de l'industrie du bois. The formulation of a new concrete based on the abundant resources, having equal or better characteristics than ordinary concrete, has become an economic requirement in terms of using and valorizing local materials. This technological solution solves twofold problems by providing a solution to the waste management problem of wood chips and by minimizing the usage of hydraulic cement and mineral aggregates. It is in these two contexts that this research work investigates the physico-mechanical characteristics of wood chips waste based concrete.

In the open literature, several research works exist on the use of waste wood in composites materials for construction. The majority of the research contributions were mainly concerned about improving the composites properties based on cementitious and clay matrices with additions of wood chips as aggregates, fillers and reinforcements such as in the work of Ledhem et al. [3]. The properties of these new concretes are closely related to the intrinsic characteristics of additions. Bouguerra et al. [4] have analyzed the influence of the microstructure of concrete, obtained from clay, cement and wood aggregates, on both mechanical and thermal properties. They showed that the compressive strength variation and the thermal conductivity are influenced by size and porosity distribution. Moreover, these characteristics are improved when more wood chips undergo treatment as mentioned in the study of Bederina et al. [5] about wood and concrete. Coatanlem et al. [6] also tend towards the same direction of a prior treatment of wood chips. It has been shown that the adherence is improved between the cement paste and the wood chips when they undergo an immersion before being used in a solution of sodium silicate. They proposed ettringite needles on the surface of wood chips, which reinforce the cement paste and woodchips link. Al Rim et al. [7] have analyzed the influence of the proportion of wood on the thermal and mechanical performances of clay-cement-wood composites. Li et al. [8] analyzed the mechanical and physical properties of hemp fiber reinforced concrete. This research revealed that the hemp fiber content (by weight) is the critical factor affecting the compressive and flexural properties of the composite. Recently, Belhadj et al. [9] analyzed the effect of the incorporation of barley straws and wood shavings on the physico-mechanical properties of sand concrete for the construction in arid zones. This research revealed the existence of strong relations between the thermophysical and mechanical properties of sand concretes.
This work consists of studying the influence of wood chips treatment issued from two types of wood namely redwood and hardwood as aggregates for hydraulic concrete. Properties in fresh and hardened state are studied as well as the mechanical performances in compression, bending and splitting tensile.
Thermal conductivity and scanning electron microscope (SEM) observations help explaining the treatment effect on upgrading the performance of the studied concretes.

2. Materials Identification and Characterization

Concrete is a multi-phase material, which makes its properties impossible to be determined without an analysis of the effect of its individual components on the service properties. Of the factors that influence the properties of wood chips based concrete, particular importance is attributed to the wood chips morphology, wood chips treatment and volume fraction.

2.1. *Woodchips*

Two types of wood chips resulting from two kinds of woods have been used in this study. We refer to them as WI-and WII.
Wood I (WI): Red wood sawing, originally from Sweden (Figure 1a),
Wood II (WII): Steamed beech sawing, originally from Romania (Figure 1b).

-a- WI -b- WII

Figure 1: Image of wood shaves (WI and WII)

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The wood chips used are carpentry wastes with irregular shape appearance and a higher granulometric limit of about 12.5 mm and a lower granulometric limit of about 0.5 mm. The chips have a fibrous appearance (figure 2) very marked. Canals that lead the sap confer to material a large porosity communicating through orifices. Thus leads to a strongly hygroscopic character .The surface texture and surface topography of two selected wood chips surfaces are given in Figure 3.

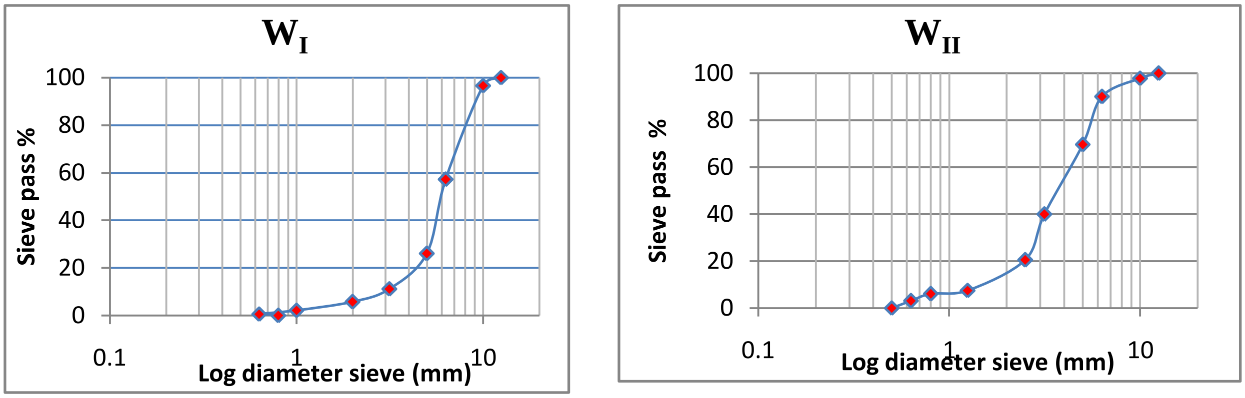

Figure 2: Granulometric curves of wood chips (WI and WII)

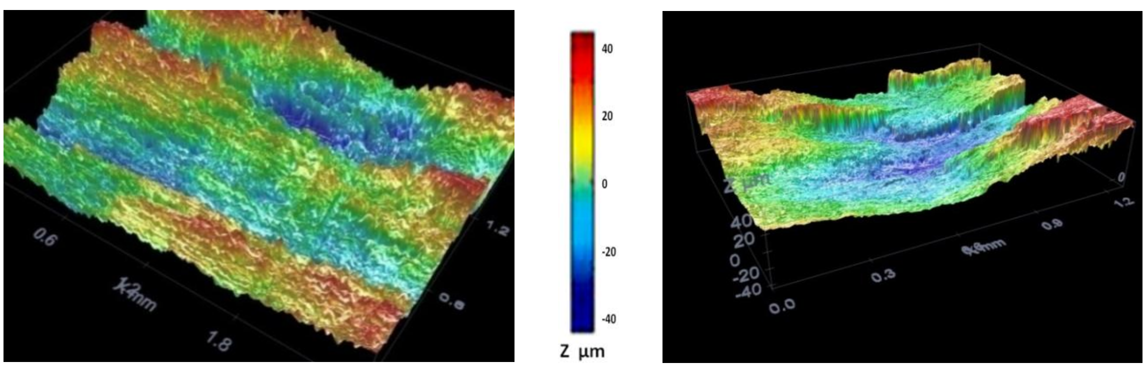

Figure 3: Structure the surface topography of (WI) and WII wood chips

These pictures have been obtained using a white light interferometry technique. However, one has to be aware of the limitations of this approach since the surface 3D reconstruction depends on surface images having texture and features that can be used for cross-correlation analysis. Despite the mentioned limitations, the approach appears suitable for complementing Scanning Electron Microscopy (SEM) of surface structures. SEM observations were also performed in order to analyze the microscopic structure of wood chips used. It is clearly noticeable that the two types of wood are relatively compacted material and they have the same fibers direction (Figure 4).
From the SEM photographs (Figure 5), one can notice the cement particles are at chapped and randomly distributed. The wood chips geometrical dimensions can be also be observed. In accordance with SEM analysis, it is observed that the wood chips without treatment exhibit a poor recovering property of the wood chips, showing consequently a weak interfacial adhesion between the wood and the cement matrix figure 5.

2.2. *Cement*
Although aggregates account for most of the volume in concrete, cement significantly influences the behavior of fresh and hardened normal concrete. The cement used in this study is a Portland cement composed of class CPJ-CEM II/A 42.5 corresponding to the Algerian standard NA 442 from HDJAR ESSOUD, county of SKIKDA ALGERIA. Its mineralogical composition and properties are illustrated in Table 1. These results were provided by the manufacturer. [10]

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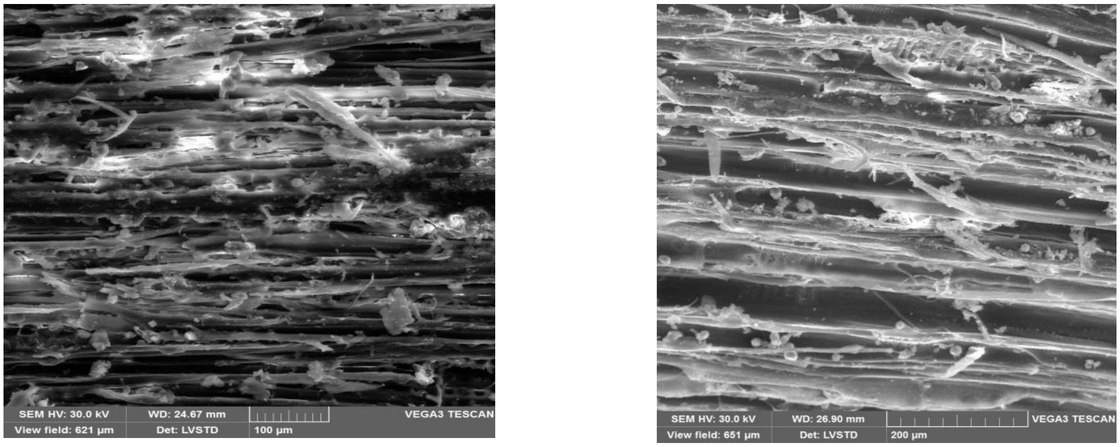


W I W II

Figure 4: SEM Observation of two wood types

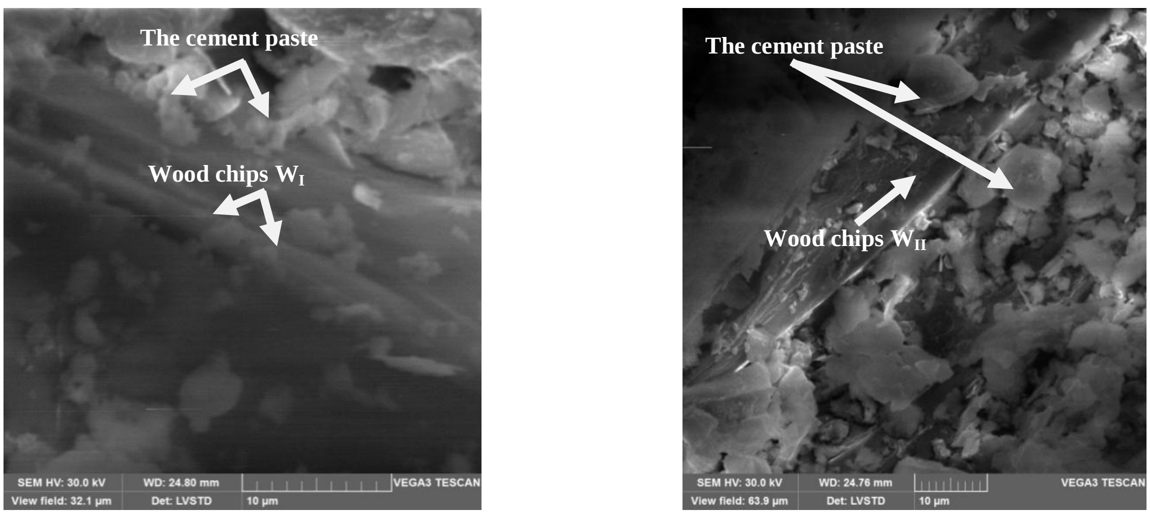


Figure 5: Microstructural observation (with SEM) of wood chips treated with cement Paste.

Table 1: Cement Characteristics

<table>
<tr><th rowspan="2">Absolute density</th><th rowspan="2">Apparent density</th><th rowspan="2">Blaine specific surface</th><th colspan="7">Mineralogical composition</th></tr>
<tr><th colspan="2">C_3S</th><th colspan="2">C_2S</th><th colspan="2">C_3A</th><th>C_4AF</th></tr>
<tr><td>3000 kg/m^3</td><td>1020 kg/m^3</td><td>3480 g/cm^2</td><td colspan="2">58,2 %</td><td colspan="2">18,5 %</td><td colspan="2">9,3 %</td><td>8,2 %</td></tr>
<tr><th rowspan="2">normal consistency</th><th rowspan="2">initial setting time</th><th rowspan="2">final setting time</th><th colspan="7">Chemical composition</th></tr>
<tr><th>CaO</th><th>SiO_2</th><th>Al_2O_3</th><th>Fe_2O_3</th><th>SO_3</th><th>MgO</th><th>CaO_{free}</th></tr>
<tr><td>27 %</td><td>1h : 40min</td><td>4h : 50min</td><td>60,41 %</td><td>21,91 %</td><td>5,19 %</td><td>2,94 %</td><td>1,6 %</td><td>2,19 %</td><td>1,01 %</td></tr>
</table>

2.3. *Aggregates*

Three kinds of aggregates are used in the concrete mixture: rolled sand, fine aggregate and coarse aggregate (Figure 4). The properties of the aggregates are gathered in Table 2 and Table 3.

Table 2: Main characteristics of the used Aggregates

haracteristics	Rolled sand.	crushed fine gravel	crushed gravel	Unit	The standard
Apparent density	1380	1390	1360	(Kg/m^3)	NF P 18 554 and 18 555.
Absolute density	2 600	2500	2450	(Kg/m^3)	NF EN 1097-3
Fineness modulus	2.21	-	-	-	NF 18-540
visual sand equivalent	84.72	-	-	(%)	NF EN 933-8
d/D	0/5	3/8	8/16	-	-
Resistance to fragmentation (los Angeles)	-	23	23	(%)	NF EN 1097-2
wear resistance(Micro-Deval)	-	16	16	(%)	NF EN 1097-1
Kurtosis	-	8	8	(%)	NF P 18-561
Water Absorption	-	0,2	0,2	(%)	NF P 18 554 and 18 555

Table 3: Chemical Composition of aggregate

	Fe %	CaO %	SiO2 %	MgO %	Al2O3 %	PF %
Gravel	0,12	54,70	0,11	nil	0,45	43,74

2.4. Concrete Formulation

Concrete is a mixture of glue binding together the fillers (fine aggregates, coarse aggregates and wood chips). The paste and the fillers constitute the heterogeneous material called concrete. The concrete composition of this study is calculated by Dreux-Gorisse method [11]. Figure 6 presents a particle size curve of each component (sand 0/5, gravel 3/8 and gravel 8/16). The following type of concrete are considered (Table 4).

. W0: Ordinary concrete. This concrete is used a reference

. WU1; WU2; WU3 and WU4: Untreated wood chips based concrete U. (1%, 2%, 3%, 4%).

. WT1; WT2; WT3 and WT4: Treated wood chips based concrete T. (1%, 2%, 3%, 4%).

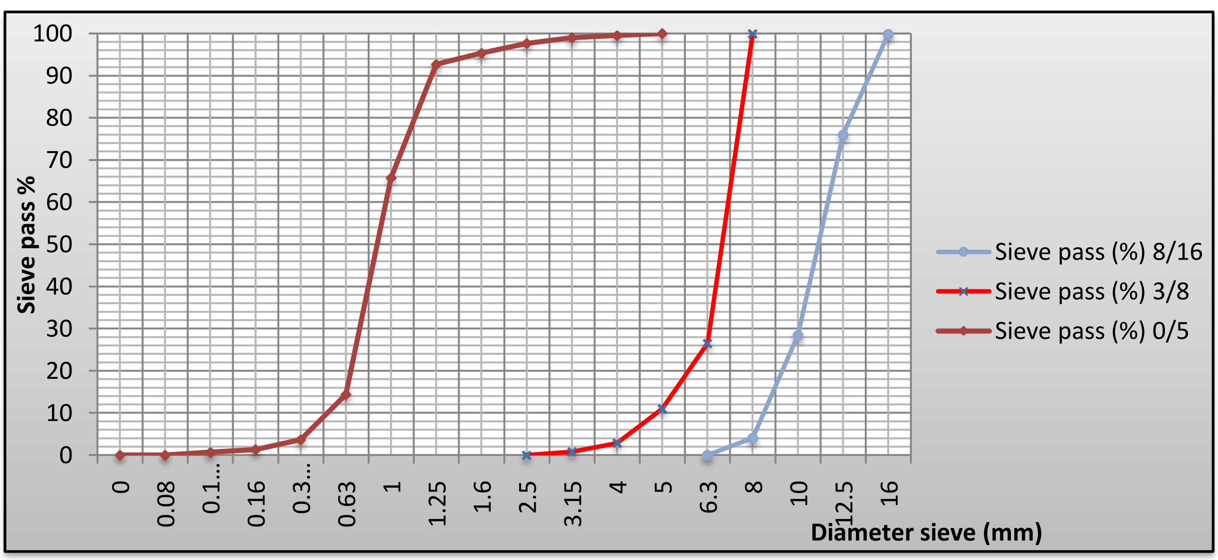


Figure 6: Granulometric Curves for Concrete Formulation

Table 4: Concrete Formulation

Concrete Types	Dosage of constituents (Kg/m^3)							
	Cement	**water**	**E/C**	**sand**	**Fine gravel**	**Gravel**	**Chips**	**% of chips**
W_0	400	208	0.55	626.53	168.68	927.75	-	0%
$WU_1 – WT_1$	400	208	0.55	620,27	167	918,47	17,22	1%
$WU_2 – WT_2$	400	208	0.55	614	165,30	909,2	34,45	2%
$WU_3 – WT_3$	400	208	0.55	607,73	163,61	899,91	51,66	3%
$WU_4 – WT_4$	400	208	0.55	601,46	161,93	890,64	68,91	4%

3. Experimental Characterizations and Analyzes

3.1. The characterization of different concrete mixes based treated and untreated wood chips have been carried out by an experimental work.

The mixing and the mix are delicate operations because it is necessary to ensure the status of coating and the holding of the chips, therefore respect a order of introduction of the constituents and a speed of mixing low enough in the order of 50 turns.mn-1. The sand, the cement, gravels and woods chips, dried beforehand, were mixed for 1 min at slow speed. Once the mixture has become perfectly homogeneous. The mixing water was added gradually for 4 min at low speed. The use of the vibrating table ; a speed of 50 Hz and vibrating time of 1min, leads to a segregation of different elements. Filling the molds is performed manually.

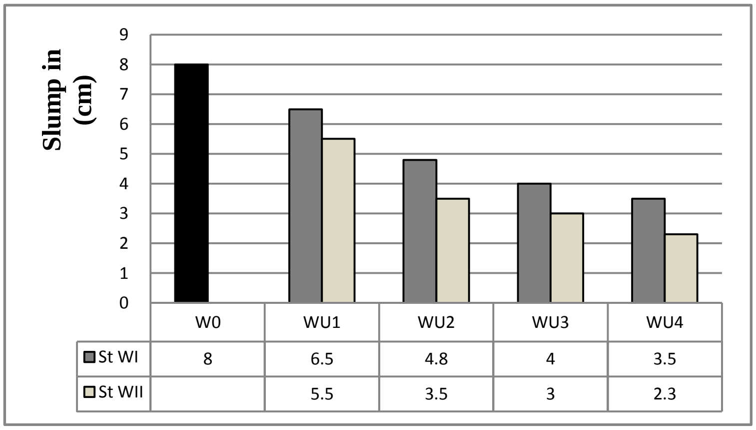
After mixing, the slump test of concrete is measured via Abrams cone (AFNOR P 18-451). The handling is measured using the Abrams cone slump. The introduction of the fresh concrete in the mold is carried out on a table vibrating for one minute. Three types of molds are used: cubic (10x10x10 cm^3), prismatic (7x7x28 cm^3) and cylindrical (11x22 cm^2). The specimens are kept in a suitable place for 24 hours and the rest of the time in water according to the NFP18404 norm. For the mechanical analyzes, a set of six samples were tested at ambient temperature.

3.2.1. *Workability*

The workability is one of the physical parameters of concrete, which affects the strength and durability of the wood chips based concrete. It is defined as the property of fresh concrete. The workability of the concrete is indicated by the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product. The workability of the concrete is measured using Abrams cone (AFNOR P 18-451) slump test. The amount of slump of the concrete cone is influenced by the amount of aggregate, the relative proportions of fine and coarse aggregate, and the different aggregate properties. From these experimental results (figure 7 and figure 8), we observe that concrete slump decreases when the rate of chips increase. This is mainly due to the fact that they absorb a quantity of mixing water, which affects the workability of the mixtures. In addition, the cement paste that coats the chip reduces its water absorption and thus decreases the concrete workability.

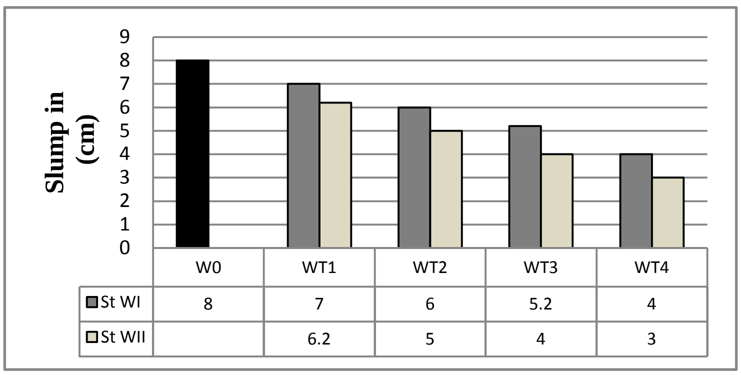
3.2.2 *Density*

The density is estimated after vibration of the fresh composite concrete. From figure 9 one could notice that for fresh concretes based on untreated chips, the density decreases from 2.56 g/cm^3 to 1.37 g/cm^3 and 1.41 g/cm^3 for untreated wood chips based concrete. In the meanwhile, the density decreases to 1.82 g/cm^3 and 1.99 g/cm^3 for treated wood chips based concrete as depicted on Figure 10. In addition, the density of the concrete decreases when the rate of the wood chips increase. For hardened concrete, the density drops from 2.47 g/cm^3 to 1.29 g/cm^3 (Figure 11), for untreated wood chips based concretes, and it decreases to 1.76 g/cm^3 for concrete treated with cement paste (Figure 12).



	W0	WU1	WU2	WU3	WU4
St WI	8	6.5	4.8	4	3.5
St WII		5.5	3.5	3	2.3

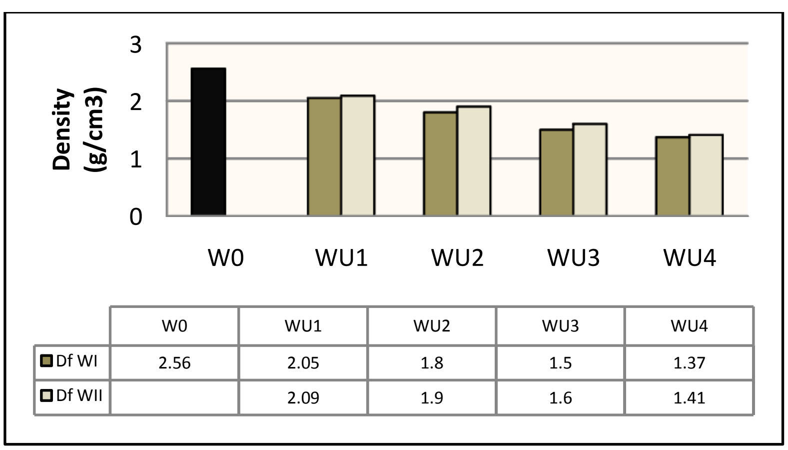
Figure 7: Evolution of the workability (fluidity) of the concrete with non-treated wood



	W0	WT1	WT2	WT3	WT4
St WI	8	7	6	5.2	4
St WII		6.2	5	4	3

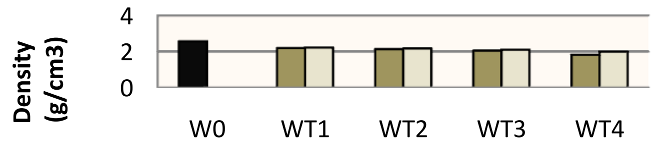
Figure 8: Evolution of the workability (fluidity) of the fresh concrete with treated wood chips.

Concrete density decreases with increase of wood chips percentage that due to unlike in hardened state, elsewhere concrete density decreases due to water evaporation phenomenon and the cement hardening. The properties of hardened cement control the properties of the concrete.



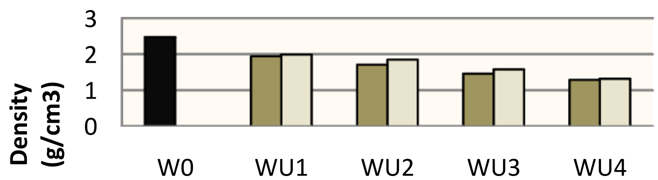
	W0	WU1	WU2	WU3	WU4
Df WI	2.56	2.05	1.8	1.5	1.37
Df WII		2.09	1.9	1.6	1.41

Figure 9: Density of fresh concrete with non treated wood chips



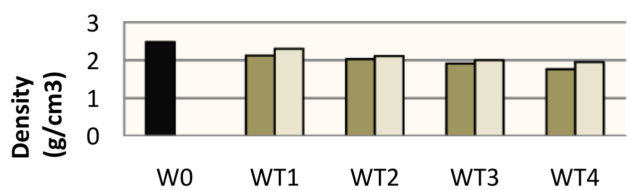
	W0	WT1	WT2	WT3	WT4
Df WI	2.56	2.19	2.13	2.05	1.82
Df WII		2.22	2.17	2.1	1.99

Figure 10: Density of fresh concrete with treated wood chips



	W0	WU1	WU2	WU3	WU4
Dh WI	2.47	1.94	1.71	1.46	1.29
Dh WII		1.99	1.85	1.58	1.32

Figure 11: Density of hardened concrete with untreated wood chips



	W0	WT1	WT2	WT3	WT4
Dh WI	2.48	2.12	2.03	1.91	1.76
Dh WII		2.3	2.11	2	1.95

Figure 12: Density of hardened concrete with treated wood chips

3.3. *Mechanical Properties*

3.3.1. *Experimental methodology*

Compression, bending and splitting tensile tests were prepared in accordance with international ASTM standards.

3.3.2. *Compressive strength*

Each compressive strength value reported is the average of six samples. The dry compression strength was determined using an Instron hydraulic press made in USSR, Marque: ZIM (ЗИМ) type n-10, N° 4577 with a capacity of 50t, with a loading speed of 5 mm/min.

2.3.3. *Bending tensile*

Each compressive strength value reported is the average of six samples. The dry compression strength was determined using an Zwick Roell Machine, made in Germany, with a capacitor of 20 kN and a loading speed of 5mm / minute.

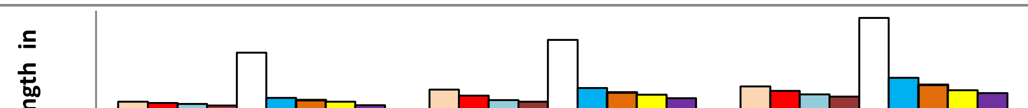
3.3.4. *Splitting tensile strength*

Are realized with a hydraulic press made in USSR, Marque: ZIM (ЗИМ) type n-10, N° 4577 with a capacity of 50t and an essay speed of 2 mm / minute.

3.4. *Analysis of Results*

Relatively little research is available from the current literature,compared to the tremendous amount of bending and tensile test results. If the composites are to be used for any application requiring compressive load carrying capacity, the effect of compressive strength changes due to fiber addition must be taken into account. Though it is difficult to compare various research studies due to widely varying experimental procedures, relative changes within studies can be directly compared.

The strength results in compression, bending and splitting tests for untreated and for treated wood chips based concrete at 7 days, 14 days and 28 days are presented in figures 13 ,14 ,15 ,16 ,17 and figure 18. These results are characterized by a significant dispersion. This scatter phenomenon is related to natural granular materials reinforced with fibers which are heterogeneous. This characteristic was reported by numerous studies reported in the technical and scientific literature [12][13][14][15]. It can be clearly noticed that the mechanical compressive strengths (Figure 13) decrease significantly. Indeed, after 7 days, the compressive stress values drop from 23.1 MPa to 2 MPa, while after 14 days, these values decrease from 28.3 MPa to 3.5 MPa. The values of the 28th day compressive stress, drops from 37.1 MPa to 5.5 MPa (Figure 14).

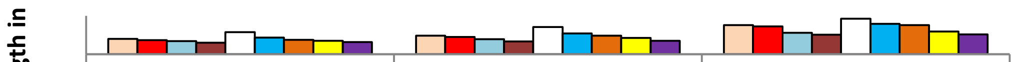


	7	14	28
WI U1	3.4	8.3	9.6
WI U2	3	5.9	7.8
WI U3	2.6	4.1	6.4
WI U4	1.9	3.5	5.5
W0	23.1	28.3	37.1
WII U1	5	9	13
WII U2	4.1	7.1	10.2
WII U3	3.5	6.3	8
WII U4	2	4.8	6.9

Figure 13: Compressive strength in MPa for untreated wood chips based concrete at 7, 14 and 28 days.

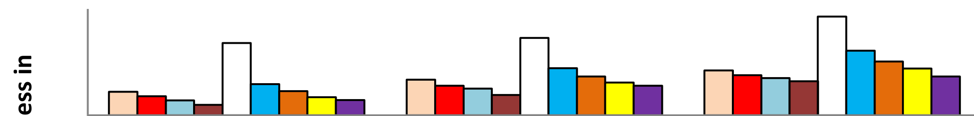
The mechanical strength for the Bending tensile strength varies between 9.5 MPa to 1.4 MPa and 2 MPa for the 7-days concrete based. It varies from 10.2 MPa to 5.3 MPa for the 14-days concrete while for 28-days concrete, it varies from 13 MPa to 5.75 MPa (Figure 15 and Figure 16). The splitting tensile mechanical strength decreases by almost 50% (Figure 17) for the two classes of wood chips based concretes. The splitting tensile mechanical strength varies from 4.1 MPa to 1.7 MPa for untreated wood chips and from 4.1 MPa to 2.25 MPa for the 28-days treated wood chips concrete (Figure 18).

Mechanical resistances for untreated red-wood WIU and untreated Steamed beech wood WIIU decrease significantly with the increase of chips rate that due to low adherence of concrete based wood chips: wet wood chips do not improve the mechanical strength of the concrete. The treated wood chips gives acceptable results because the cement paste envelopes the wood chips and increases the mechanical strength compared to concrete made of untreated wood chips.



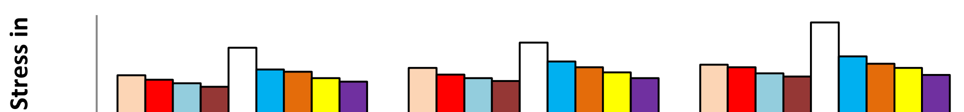
	7	14	28
WI T1	16	19.3	30.5
WI T2	14.5	18	29.1
WI T3	13.6	15.8	22.4
WI T4	12.1	13.3	20.2
W0	23.1	28.3	37.1
WII T1	17.3	21.7	31.8
WII T2	15.1	19.4	30.4
WII T3	14.1	16.9	23.5
WII T4	12.8	14	20.7

Figure 14: Compressive strength in MPa for treated wood chips based concrete at 7, 14 and 28 days.



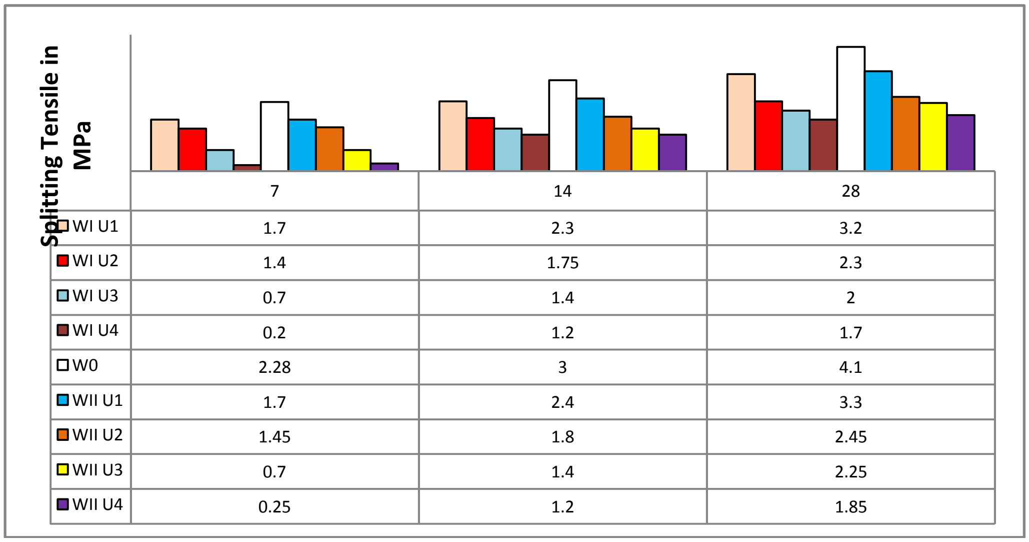
	7	14	28
WI U1	3.1	4.7	5.9
WI U2	2.5	3.9	5.3
WI U3	1.95	3.5	4.9
WI U4	1.4	2.7	4.5
W0	9.5	10.2	13
WII U1	4.1	6.2	8.5
WII U2	3.2	5.1	7.1
WII U3	2.4	4.3	6.15
WII U4	2	3.9	5.1

Figure 15: Bending tensile in MPa for untreated wood chips based concrete at 7, 14 and 28 days.



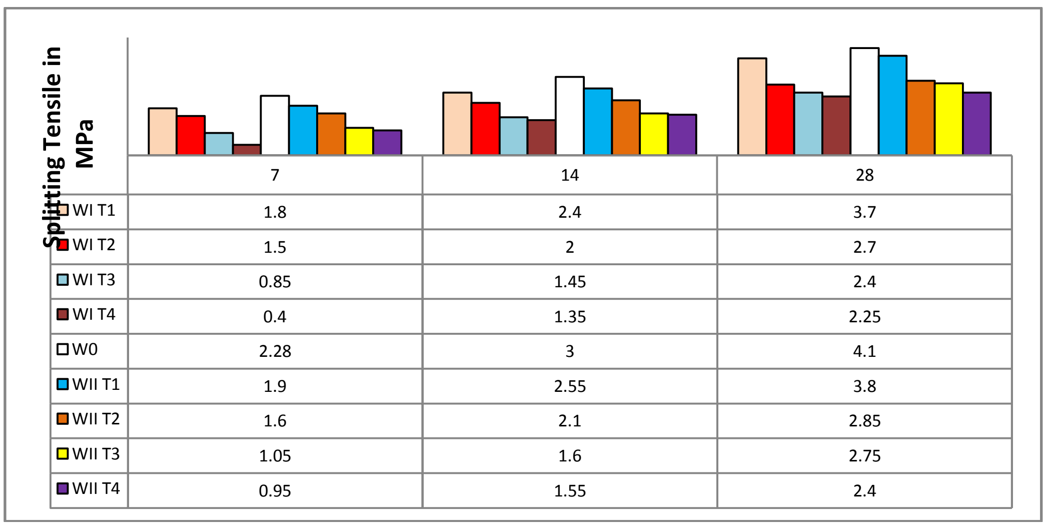
	7	14	28
WI T1	5.7	6.7	7.15
WI T2	5.1	5.8	6.8
WI T3	4.6	5.3	5.95
WI T4	4.1	4.9	5.5
W0	9.5	10.2	13
WII T1	6.5	7.6	8.3
WII T2	6.2	6.8	7.3
WII T3	5.3	6.1	6.7
WII T4	4.8	5.3	5.75

Figure 16: Bending tensile in MPa for treated wood chips based concrete at 7, 14 and 28 days.



	7	14	28
WI U1	1.7	2.3	3.2
WI U2	1.4	1.75	2.3
WI U3	0.7	1.4	2
WI U4	0.2	1.2	1.7
W0	2.28	3	4.1
WII U1	1.7	2.4	3.3
WII U2	1.45	1.8	2.45
WII U3	0.7	1.4	2.25
WII U4	0.25	1.2	1.85

Figure 17: Splitting tensile strength of untreated wood chips based concrete at 7, 14 and 28 days.



	7	14	28
WI T1	1.8	2.4	3.7
WI T2	1.5	2	2.7
WI T3	0.85	1.45	2.4
WI T4	0.4	1.35	2.25
W0	2.28	3	4.1
WII T1	1.9	2.55	3.8
WII T2	1.6	2.1	2.85
WII T3	1.05	1.6	2.75
WII T4	0.95	1.55	2.4

Figure 18: Splitting tensile strength of treated wood chips based concrete at 7, 14 and 28 days

In general, statistical analysis showed that the compressive property was significantly influenced by the addition of treated and untreated wood.

3.5. *Thermal Conductivity*

The objective of this section is the development of the analysis of the thermal insulating capabilities of the wood chips based concrete. The conventional method to estimate the conductivity involves the measurement of the heat flux through the specimen in adiabatic conditions. This requires a specific and complex experimental system. In the context of this research, the thermal conductivity is estimated using the lime wire method, as shown in figure 19 [16], [17]. The analysis is made for a composite with a constant volume fraction of 2% of wood chips. Four classes of concretes have been investigated. On Figure 20 are reported the thermal conductivity of the concrete composite based on wood chips in dry, wet and saturated states at ambient temperature /21°C). To avoid the evaporation-condensation phenomenon should save it at temperature around 40°C. Depending of the state configuration, the obtained experimental results revealed an increase of the thermal conductivity.

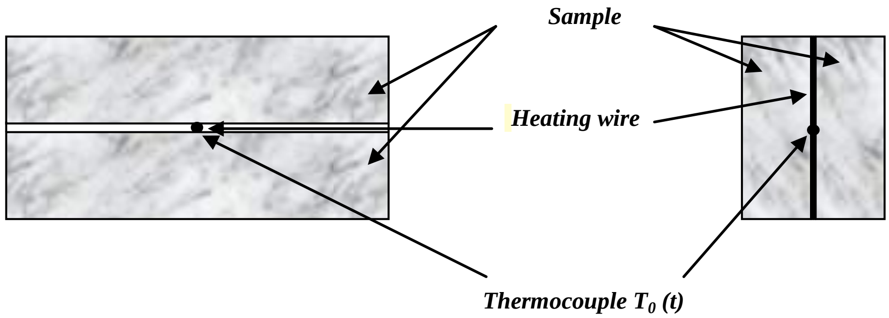
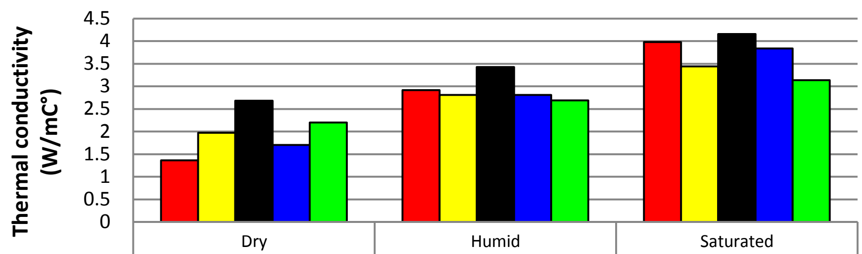


Figure 19: Sketch of the lime wire method assembly for the lime wire method.



	Dry	Humid	Saturated
WI U2	1.36	2.92	3.98
WI T2	1.97	2.81	3.44
W0	2.68	3.43	4.16
WII U2	1.7	2.81	3.84
WII T2	2.2	2.69	3.14

Figure 20: Values of the obtained thermal conductivity.

The thermal conductivity varies from 0.18 to 0.49 in the dry state. In a humid state with a saturation about (Sr = 0:5), it varies from 0.15 to 0.21. In a saturated state, the conductivity varies from 0.04 to 0.24. On Figure 20, one can notice the effect of an increase of humidity (saturation rate) which negatively impacts the thermal performance of the concrete. Indeed, the thermal conductivity varies according to the state of the concrete. These results indicated that the apparent thermal conductivity varies almost linearly according to the rate of water saturation.

Conclusions

Influences of volume fraction as well as treatment of wood chips surface on thermo-mechanical characteristics of concrete based on treated and untreated wood chips have been analyzed. The used methods show that concrete based on untreated wood chips has good thermal characteristics than treated wood chips. Vise versa for mechanical characteristics, however the concrete based on chips of Steamed beech wood has a good mechanical characteristics than the concrete based on red-wood chips. On other hand, the concrete based on Red-wood chips has good thermal characteristics than the concrete based on chips of Steamed beech wood. The obtained results of experimental study for mechanical characteristics confirm the superior performances of concrete based on treated chips of Steamed beech wood, and obtained thermal characteristics confirm the superior performances of concrete based on untreated Red-wood chips. Untreated wood chips reduce the slump and the density than the treated wood chips.

Dry concrete gives low thermal conductivities compared to humid and saturated concrete. However, the dry untreated Red-wood gives a better insulation compared to all the other types. Therefore, untreated Red-wood can be used as a concrete of insulation.

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