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Effect of barley straw treatments on desiccation shrinkage and thermal properties of lightweight sand concrete

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ABSTRACT/RESUME

Abstract: *This experimental work focuses on studying the effect of different barley straw treatments on the dimensional variation due to desiccation shrinkage, as well as the thermal properties of lightweight sand concrete. For this purpose, four methods of barley straw treatments have been used, such as waste oil, hot water, varnish and gasoil. In previous work, the optimal composition with untreated barley straw with the content of 15 kg / m^3 has shown that the addition of straws alleviates the sand concrete and gives it acceptable thermal properties. Nevertheless, it has shown a remarkable increase in shrinkage. The objective of this study is to further improve the studied properties and therefore to target the best treatment. The results obtained showed an interesting reduction in the shrinkage in the case of hot water treatment, gasoil and varnish. Improvements in shrinkage have been achieved including a reduction of up to 21%. On the other hand, the treatment with the waste oil gave an increase of the shrinkage, compared to the concrete of sand based on untreated barley straw. It should be noted that even the thermal conductivity has been reduced where the reduction was about 40%. In fact, the straw treatments led to the increase of the Young's modulus and the tensile strength of the barley straw. Moreover, the study of X-ray diffraction (XRD) showed a slight difference between the concretes studied. Finally, a microscope visualization showed a good adhesion between the straw and the cement matrix.*

I. Introduction

In Algeria, the materials currently used do not cover the housing deficit as the demand for building materials is high at the moment. In this context, the idea of valorization of local materials in the construction has occurred. The valorization of the local materials touched even the industrial and artificial wastes. According to various previous researches, the introduction of certain wastes in concrete and mortar may still improve certain properties of these materials [1- 3].
Indeed, the inserting of barley straws into sand concrete has given remarkable results, especially in terms of lightness, resistance to bending and insulation. This material could be a good solution in terms of thermal insulation in local construction, especially in arid environments, such as southern Algeria where the climate is very hot in summer and very cold in winters. However, a remarkable increase in shrinkage has been recorded (close to the target value 1mm/m) [4- 6]. The shrinkage phenomenon generates significant stresses which can lead to cracking. Several studies show that the addition of fibers in the cementitious matrix has given a reduction in the desiccation shrinkage [7-9]. The use of straw as a building material has many advantages [10]. The use of straws in building construction is energy efficient, durable, attractive and even fire-resistant [11]. Several

studies have been carried out in this context and many lignocellulosic materials have been introduced into different matrices [4, 12- 20].

Through the various recent bibliographical references and related composites based on treated plant fibers, the following types of treatment can be menthionned: chemical treatments, coating treatments with a binder and impregnation treatments of certain liquid products, etc. [1, 21-27]. Virtually, all these treatments have led to good results.

In this study, four treatments were chosen, such as waste oil, hot water, varnish and gasoil; these treatments are considered as chemical treatments. In general, chemical treatments clean the surface of the fiber and increase its roughness [28], modify its composition, stop the process of absorption of moisture and improve interfacial adhesion [29]. Finally, the main objective of this work is to further improve the desiccation shrinkage and thermal properties of lightweight sand concrete by adding lignocellulosic material (barley straw) subjected to different treatments.

II. Materials and Methods

II.1. Raw Materials

II.1.1. Sands

The sand (RDS) used in this study is a mixture of two types of sands. The first type is dune sand (DS) and the second type is river sand (RS). The proportions of this mixture are prepared according to a specific mass ratio by correcting the granulometric curve of the river sand, in its thin part, by adding dune sand. This ratio is defined as follows: (RS/DS) = 1.7 [30].

Table 1 summarizes all the results relating to the physical tests carried out on the sand used. These results show that the sand used is very clean if refering to the sand equivalent values recommended by the standard NF P18 598. Moreover, the nature of the sand used is mainly siliceous. [2, 30].

II.1.2. Cement

The type of cement used in all the experiments is CPJ limestone Portland cement CEM/II A-L 42.5 R. The main physical properties and chemical characteristics of the cement used are presented in Tables 2 and 3 [3, 19].

II.1.3. Mineral Additions

To give more importance to the economic aspect, 10% of the mineral additions (1/3 limestone filler, 1/3 natural pozzolan and 1/3 hydraulic lime) were added by mass substitution to the cement. Their physical properties are summarized in Table 4 [3, 19].

Table 1. *Physical properties used sands RDS.*

Characteristics	**RSD**
Maximum diameter (mm)	5
Apparent density (kg/m^3)	1590
Specific density (kg/m^3)	2485
Compactness (%)	0.66
Porosity (%)	0.34
Fineness modulus	2.81
Visual sand equivalent (%)	93.2
Sand equivalent (%)	80.3

Table 2. *Physical properties of used cement.*

Apparent density (kg/m^3)	1030
Specific density (kg/m^3)	3030
Blaine specific surface area (m^2/kg)	444.9

Table 4. *Physical Properties of Used Mineral Additions.*

Physical properties	**Limestone**	**Pozzolan**	**Lime**
Blaine specific surface area (m^2/kg)	280	388	650
Specific density (kg/m^3)	2700	2850	2750
Apparent density (kg/m^3)	1530	1005	666

II.1.4. Limestone Filler

The fillers were used to complete the granulometric curve of the sand in its fine part and fill its voids. The fillers used in this study are of calcareous nature. Tey were obtained by sieving the remains of crushed gravel (80 µm sieve). The use of the filler in the composition of sand concrete is essential [31, 32]. Table 4 shows the physical properties of the limestone filler used.

II.1.5. Admixture

The admixture used is a superplasticizer "MEDAPLAST- SP40" high water reducer to obtain concretes and mortars of very high quality. It is a liquid solution easily diluted in mixing water and brown color, in accordance with the EN 934-2 standard.

II.1.6 Barley Straw

The barley straw used in this study is a local crop and found in the form of a compressed bundle with a size of approximately 100×50×35 cm^3.This material is introduced into the matrix to develop a new lightweight concrete (Figure 1).

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Table 3. *Chemical analysis of used cement.*

Element	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	SO_3	K_2O	Cl	Na_2O	Free CaO	PAF	Ins
Quantity (%)	16.93	62.23	1.03	5.26	2.82	2.89	0.65	0.02	0.04	1.78	7.83	1.61

Different studies have shown the effect of fiber length on concrete behavior [33]. The choice of straw length in this study was not random; in fact, we thought about half the smallest size of the molds used. The straw lengths considered are 3.5 cm for prismatic molds (7×7×28 cm^3) and 2 cm for prismatic molds (4×4×16 cm^3). Regarding the straw mixture, the proportions of each of them were determined based on a series of preliminary tests. It has been found that the straw used consists of 70% tubular straws and 30% of covers and broken straws [3]. Its apparent density is about 59.8 kg/m^3. Chemical the barley straw is mainly composed of cellulose (40.4± 7.8), hemicellulose (25.6± 5.1) and lignin (12.7± 3.6) [34].

Figure 1. *General aspect of barley straw bundle form.*

II.2. Methods

II.2.1. Treatment Method

The products used are shown in Figure 2. The treatment preparations are carried out manually under climatic conditions of temperature T=20°C ± 5°C and relative humidity RH=50% ± 10%.

For hot water, the preparation of this treatment is carried out by heating the water up to 60°C using a thermometer. After that, the barley straw is immersed in this water for 10 seconds. The conservation of treated straws is done in the test room. The drying time of these treated barley straws is about 48 hours (Figure 2a).

For waste oil, varnish and gasoil: barley straw is introduced into the container containing a quantity of treatment product, then mixed slowly until the outer surface of the barley straw is completely covered by the product. The time required to dry the barley straw treated with the oil, the varnish and the gasoil is 20 days, 24 hours and 24 hours respectively (Figure 2b, c, d).

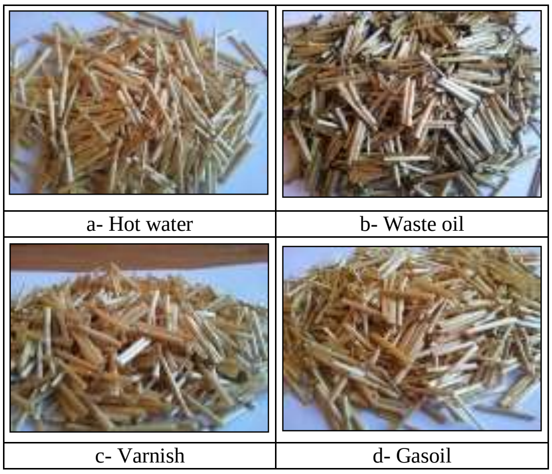

Figure 2. *Treated straw preparation (3.5 cm).*

II.2.2. Experimental Techniques

- The composition of sand concrete with barley straw is inspired by previous work [19]. This composition, which is taken as a reference, is shown in Table 5.
- The density is measured on prismatic specimens of dimensions (7×7×28) cm^3 with three test specimens by composition.
- The shrinkage measurement is carried out on specimens (4×4×16) cm^3 according to standard NF P15 433. Δl (t) is obtained by averaging the three specimens from the same block of molds.
- The thermal properties are measured using a Hot Disk TPS 500 Transient Plane Source probe which is a proposed technique for thermal transport studies of solid materials [35] (Figure 3).
- The tensile test of barley straw was determined by a universal "Shimadzu" type test apparatus. The length of the barley straw used is 12 cm.

- The structure of the concretes studied was carried

Table 5. *Optimal Composition of the Studied Matrix (Sand Concrete).*

Sand (kg/m^3)	Cement (kg/m^3)	Mineral additions (kg/m^3)	Limestone filler (kg/m^3)	Barley straw (kg/m^3)	Water (l/m^3)	Superplacticizer (% of cement weight)
1245	315	35	135	15	180	2

out by image analysis using a "ZEISS" type optical microscope.
- X-ray diffraction analysis was carried out using a "Brukers D8 Advance" type diffractometer on samples crushed and sieved at 80 µm (Figure 4).

Figure 3. *Method of testing the TPS Hot Disk probe.*

Figure 4. *Brukers D8 Advance.*

III. Results and Discussion

III.1. Influence of the Treatments on the Mechanical Properties of the Straw

According to Table 6, it is noted that there is an improvement in all the mechanical properties studied of treated straw compared to the case of untreated straw, which shows the positive effect of the treatments on the structure of barley straws. The rates of increase in the elasticity modulus of the treatments with gasoil, hot water, varnish and waste oil are respectively about 28%, 23.29%; 14.62% and 9.43%.

Table 6. *Evolution of the mechanical properties of the barley straw according to treatment types.*

Types of treatments	Elasticity module (MPa)	Maximum strength (N)	Maximum stress (MPa)
Without treatment	2380.72	64.95	11.54
Hot water	2935.18	121.24	27.03
Gasoil	3047.68	109.75	27.79
Waste oil	2605.14	93.86	19.74
Varnish	2728.82	102.75	25.91

III.2. Study of Sand Concrete Based on Treated Straw

III.2.1. Lightening Study

Density can be considered as the main characteristic of lightweight concretes. The treatment of straws certainly varies their masses, which makes it necessary to study the influence of different treatments on the density of sand concrete. From Figure 5, it is clear that the density of concrete has increased in all cases of treatment compared to the case of untreated straw. The rates of increase recorded vary from 1.42% (hot water case) to 9.55% (varnish case).
The treatment with varnish therefore gives the composite studied a density a little larger than that obtained by the other treatments.
However, the percentages of increase in the case of gasoil and waste oil treated composites were 7.44% and 8.68% respectively, compared to untreated straw concrete.
The main reason for the increased densities of concretes made with treated barley straws is the nature of the treatment products. According to standard NF EN 206-1, the density of lightweight concrete is greater than or equal to 800 kg / m³ but less than or equal to 2000 kg / m³. In the present case, it has been found that with all the treatments used, the density of sand concrete always remains in the range of lightweight concrete.

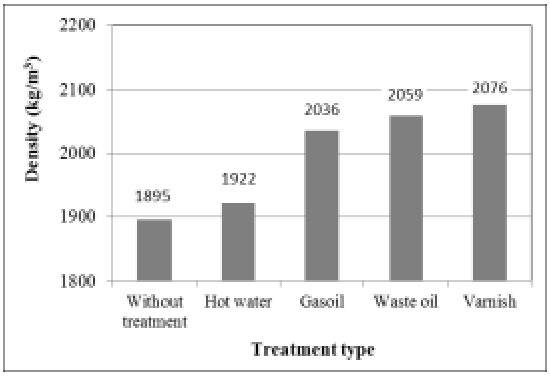

Figure 5. *Concrete density according to the treatment type.*

III.2.2. Shrinkage Desiccation

The average curves of three test samples of the free shrinkage of the composites studied as a function of time are presented in figure 6.

From the results obtained, the following conclusions can be drawn:
- It was noted that the treatments were marked on the shrinkage of the composites studied.

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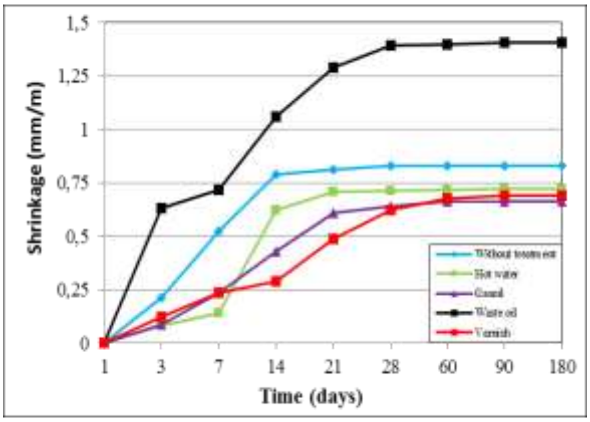


Figure 6. *Evolution of the shrinkage of the studied concrete according to time.*

- It has been noticed that, in the first 7 days, the shrinkage evolves with slow kinetics for all compositions, with the exception of the treatment with waste oil where wit has been noted a rapid increase in the value of shrinkage.

-Then, up to 21 days, a relatively increase in shrinkage to all the compositions was noted.

- Beyond 21 days, almost all the compositions tend to stabilize with a slight increase, with the exception of the treatment with the varnish, which continues with the same kinetics until the beginning of the second month where it begins to tend towards the stability.

- Although the waste oil treatment, in the case of wood chips, gave the best results with respect to shrinkage in Bederina et al. work, significantly reducing the dimensional variations of sand concrete [2], in the present case, this treatment gave the highest value, where the percentage increase over untreated straw is 67.34%. This was due to the smooth and oily nature of the outer surface of the straw which leads to a significant decrease in the friction between the straw and the matrix and the ease of sliding of the concrete on the straw. In fact, this decreases the adhesion between the straw and the matrix, especially before hardening, which is reflected in the significant increase in the first 21 days.

III.2.3. Thermal Characteristics

The average values of the results obtained with the TPS method are given in Table 7.

Based on the results obtained, there is a decrease in the value of the thermal conductivity in the treated straw compositions, compared to an untreated straw compositions; the percentage of reduction varies between 5.30% to 43.18%.

The treatment of the straw with the waste oil gave the greatest decrease in the value of the thermal conductivity, whereas the treatment with the gasoil did not improve the value of the thermal conductivity, compared to the case of the untreated straw by only 5.30%.

Moreover, it is noted that the thermal diffusivity evolves according to a direct correlation with the thermal conductivity; it increases in parallel with the thermal conductivity, except for the treatment with varnish; although this one gave a lower result compared to the gasoil treatment in the thermal conductivity: it has been found more of it in the thermal diffusivity with a percentage of 17.21%.

Contrary to what we have observed in thermal diffusivity, we note an increase in specific heat in all compositions with treated straws, compared to untreated straws; the increasing percentage sometimes exceeds 20%, except for the varnish treatment and the waste oil, whose specific heat has decreased by 14.73% and 24.69% respectively.

In general, it can be said that the values of the thermal conductivities are a little higher in comparison with the density; this is due to the fact that the thermal tests were carried out on samples that had not been pre-dried, i.e. in the climatic conditions of the test laboratory (temperature and humidity).

Table 7. *The thermal characteristics of the compositions studied.*

Types of treatments	**Thermal conductivity (W/m K)**	**Thermal diffusivity ((m^2/s) × 10^{-6})**	**Specific heat (J/kg.K)**
Without treatment	1.32	0.451	1560.25
Hot water	1.15	0.320	1880.84
Gasoil	1.25	0.366	1685.60
Waste oil	0.75	0.310	1175.01
Varnish	1.18	0.429	1330.44

III.2.4. Macro-Structure

In order to get an idea about the macrostructure of the studied composites and to visualize the matrix-straw link closely, images were taken by optical microscope with enlarged scales. Figure 7, shows the general appearance of the compositions studied. Note that these visualizations were performed on specimens resulting from the flexural test.

From the general aspect, it can be seen the presence of a good "straw-matrix" adhesion; the composite appears more or less homogeneous in the all cases, whether with treated straws or without treatment. It can be also noted the presence of concrete inside the tubular straws. On the other hand, it can be also noted that the orientation of the straws in the concrete was made randomly due to the vibration during pouring. Another well-chosen orientation could perhaps give a better improvement.

III.2.5. X-ray Diffraction Analysis

The results of the X-ray diffraction (XRD) analyzes of the studied compositions are shown in Figure 8.
From the diffractogram (Figure 8) that shows the comparison between the studied compositions, the following points can be observed:
- All compositions have given almost identical curves with difference in the peak intensity of chemical compositions.
-An increase in the intensity of the calcium oxide peak (CaO) which can be explained by the presence of CaO rich in cement.
- An increase in the intensity of the calcium carbonate peak ($CaCO_3$), since the limestone filler contains a high percentage of $CaCO_3$ [3].
- Several researches show that the nature of the sands, either dune sand or alluvial sand, is essentially siliceous; which confirms the presence of silica (SiO_2).

Generally, the results obtained are confirmed with the chemical analyzes of the materials used.

Without treatment (G = 20)

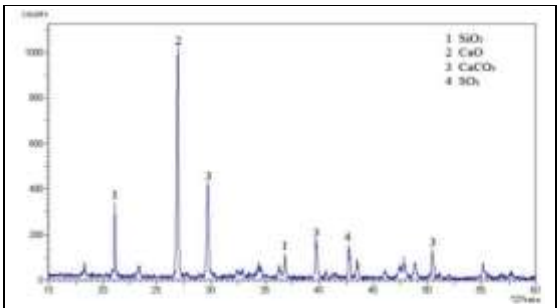
Barley straws treated by Gasoil (G = 10)

Barley straws treated by Hot water (G = 10)

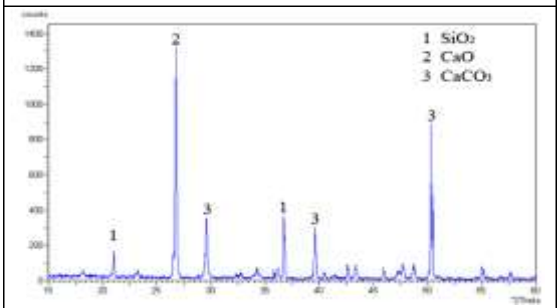
Barley straws treated by Varnish (G = 10)

Barley straws treated by Waste oil (G = 20)

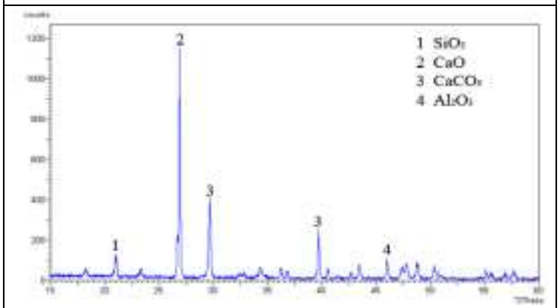
Figure 7. *Microscope visualization of the studied sand concretes.*



Case of without treatment



Case of barley straws treated by Hot water



Case of barley straws treated by Gasoil

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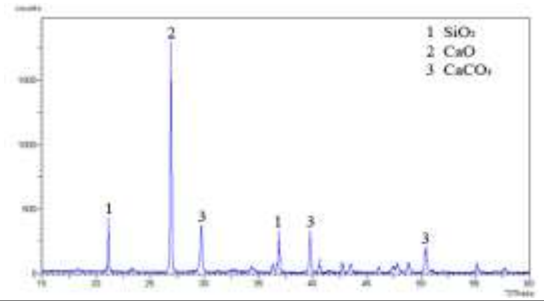
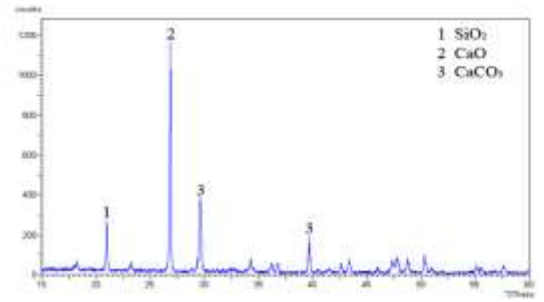


Case of barley straws treated by Waste oil



Case of barley straws treated by Varnish

Figure 8. *X-ray diffractogram analysis of the compositions studied.*

IV. Conclusion

Based on the results obtained, the following points were concluded:

- The treated barley straw gave a significant improvement in the tensile strength in all treatment cases, compared with untreated straw.

- Generally, the adhesion between "straw-treatment product" seems to be good.

- Due to the types of treatment used, the densities of the compositions increased by a certain percentage, compared tot he case of untreated barley straw. This increase in the densities is accompanied by a decrease in porosity.

- The desiccation shrinkage study of the compositions showed that the treatment of the straw by the gasoil gave a notable reduction compared to the others, but the treatment with the waste oil presented a higher value.

- Thermal conductivity is an important property for knowing the thermal insulation of materials. The study of this property showed that there was a good improvement in all cases of treatment compared to untreated straw, especially in the case of treatment with waste oil which gave a decrease of about 40% compared to the case "without treatment".

- The macro-structural study showed that the straws are well adhered to the matrix and the homogeneity appears relatively good.

Finally, it can be said that the treatment by hot water can be considered as the best one that ensure the best compromise between the studied properties.

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