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Mechanical characteristics of a classical concrete lightened by the addition of treated straws

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Abstract. This experimental work aims at developing and investigating a lightened concrete by the addition of treated straws. The used formulation is based on that of an ordinary concrete which is composed of sand and gravel as the main aggregates. The properties of the straws are improved by using one of two treatments before their use: the hot water and bitumen. Henceforth, the main objective of this study is to assess the mechanical characteristics of different formulations with different compositions and treatments on straws. The obtained results have shown that the addition of straws improves its lightness property. However, it decreases the compressive and flexural strengths as well as decreases the modulus of elasticity and increases the dimensional variations. Set into comparison to the concrete with untreated straws, the treatment of straws by hot water or by bitumen improves most of the characteristics.

Keywords: concrete; straw; treatment; mechanical properties

1. Introduction

In several countries, the reuse of various wastes has become necessary to avoid environmental problems and to ensure economic benefits. Agro-industrial waste, in particular the lignocelluloses material, increases manmade environmental effects, and their reuse affects beneficently the human health in general. Furthermore, sustainability has become one of the main interests in the current housing development strategies. Indeed, the use of the agro-industrial wastes to develop eco-materials in construction can reduce its cost, save natural resources, rise the comfort level and most importantly protect our health and environment.

Thus, numerous studies consider the incorporation of lignocellulosic wastes within a cement matrix, and exploit their renewable aspect and their thermal and acoustic good qualities. The idea of introducing a lignocellulosic waste into a sand concrete to improve its thermal performances has

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been investigated in many researches. In this context, sand concretes and mortar were already lightened by the addition diss, hemp, date palm fibres, bambo, alfa fibres and straws (Sellami *et al*. 2013, Benmansour *et al*. 2014, Gourlay *et al*. 2017, Mansour *et al*. 2007, Rokbi *et al*. 2017, Pacheco-Torgal and Jalali 2011).

On the whole, results have shown a significant improvement especially in lightness and thermal insulation. Nevertheless, other aspects were recorded such as high shrinkage and low mechanical strength. In order to minimize the loss in the mechanical strength of the composite, different treatments can be applied to the lignocellulosic waste before their use (Sellami *et al*. 2013, Khazma *et al*. 2014, Bederina *et al*. 2012, Sedan *et al*. 2008).

In fact, as one of the lignocellulosic wastes, straw represents an abundant economic material present in most countries and characterized by its lightness and its good thermal insulation characteristics. This is why straw is traditionally used in many countries for the construction of houses.

These constructions benefit from the low cost of straw and its excellent quality of insulation (Milutiene *et al*. 2007, Whitman and Holloway 2010, Cantor and Manea 2015, Helepciuc *et al*. 2016).

Recent works have investigated the reuse of this material in sand concrete (Belhadj *et al*. 2016, Bederina *et al*. 2016) and have studied the influence of the quantity of straw and its treatment on the physico-mechanical properties. But if sand concretes, that does not comprise any gravel, are able to replace the conventional concretes in certain structures, the traditional concrete remains the most used in constructions, and the addition of the straw in these concretes has remained unstudied.

The objective of the present work is on the one hand to elaborate a light-weight sand-gravel concrete based on a classical formulation added to it straw.

2. Materials

The considered concrete is a mixture of sand, gravel, cement and water. In this mixture, straw is used as inclusion.

2.1 Sand and gravel

The sand used in this study is of 0/2.5 mm and comes from Khelidia quarrie in the north-east of Tunisia. The gravel (4/12 mm) comes from Jbel-Ressas quarrie also in the north-east of Tunisia. The chemical characteristics of the two materials (Trabelsi *et al*. 2017) are shown in Table 1. Granulometric curves of gravel and sand are shown in Fig. 1. The obtained value of the Sand Equivalent (SE), equal to 76, shows that the sand is a clean one.

2.2 Cement

Table 1 Chemical composition of aggregates

Composition (%)	SiO_2	CaO	Al_2O_3	K_2O	Na_2O	MgO	Fe_2O_3	SO_3	PF
Gravel	0.44	54.9	0.035	-	0.049	0.436	0.53	0.192	-
Sand	98.2	0.08	0.34	0.17	-	-	0.11	-	-

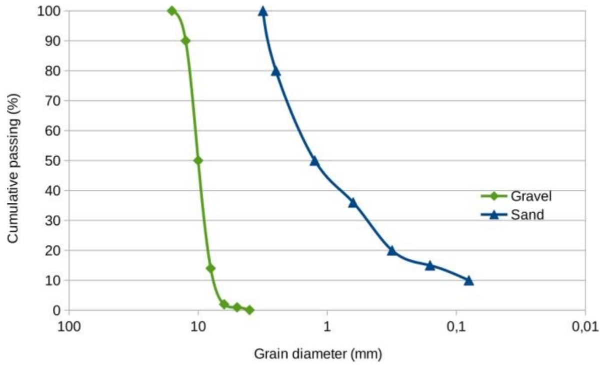


Fig. 1 Granulometric curves of gravel and sand

Table 2 Mineralogical composition of cement

C3S	*C2S*	*C3A*	*C4AF*
61%	11.85%	2.42%	13.75%

Fig. 2 Used oats straw

The used cement for the development of the concrete is the Portland cement CEM I 42.5 produced by Jebel Jeloud factory according to Tunisian Standard NT 47-01. It is characterized by a compactness of 0.574 and a density of 3210 g/cm^3. Its Blaine specific surface is 346.6 m^2/kg. The mineralogical composition of the cement is indicated in Table 2.

2.3 Straw

In this paper, oats straw is used. The used straws are locally commercialized in bale, generally with a dimension of 35 cm×45 cm×115 cm, and with 110 kg/m^3 of apparent density. The individual straw diameter (Fig. 2) is lower than 5 mm.

The chosen length of straws to be used in the 70×70×280 mm samples is 2 cm. These pieces of straw are obtained by a manual cutting of the straw from the bale with the chosen length. This procedure, although slow, ensures the use of a constant length of straw in all samples.

The studies carried out by Bederina *et al*. (2016) have shown that the treatment of straw by hot water gives the most interesting mechanical performances, so it is chosen as one of the two treatments considered in this work. However, the bitumen has not been studied until now as a

Fig. 3 Untreated straws

Table 3 Chemical composition of aggregates

	Gravel (kg)	Sand (kg)	Cement (kg)	Water (l)	Straw (kg)
Ordinary Concrete (C_0)	1232	680.5	350	175	-
Straw without treatment (C_s)	1080.4	596.9	350	175	15
Straw treated with hot water (C_{sw})	1112.4	614.5	350	175	15
Straw treated with bitumen (C_{sb})	1176.2	627.8	350	175	15

Fig. 4 Straws treated with bitumen

straw treatment that is why it was chosen as a second treatment (Fig. 4).

The hot water treatment consists of a full immersion of the straws in a water heated to 60℃ for a 10 s before its use in the concrete.

The bitumen treatment is performed manually by a full immersion of the oats straws in a Bitumen Cutback 400-600, then the straw is mixed slowly until its outer surface is completely covered by the product. Once finished, the treated straws are taken out in the open air to proceed to drying.

Besides the two treatments envisaged to improve straws properties, straw in its natural state (Fig. 3) is also considered.

3. Elaboration of the composite

The C_s formulation is a concrete with straw without treatment. As in Bederina *et al*. (2016), a

Table 4 Slump test and densities of different concretes

Designation		C_0		C_s		C_{sw}		C_{sb}	
		Average	S_d	Average	S_d	Average	S_d	Average	S_d
Slump test (cm)		11.07	0.153	11.43	0.153	11.67	0.153	11.83	0.058
Density (g/cm3)	Fresh	2.49	0.016	2.34	0.023	2.39	0.010	2.3	0.013
	Hard	2.46	0.024	2.31	0.013	2.35	0.011	2.28	0.012

quantity of straw of 15 kg/m^3 of concrete is considered. In all mixtures, the introduction of the straws is made by a substitution with the same volume of sand and gravel aggregate, keeping the volumetric ratio sand/gravel.

The realization was done using a low speed mixing in all steps in order to ensure a good homogeneity of the mixture. The following method, inspired from Belhadj *et al*. (2016), is applied: Firstly, a dry mixture of cement, sand and gravel is performed until a perfect and homogeneous mixture is obtained. Then, straws are introduced into the dry mixture and the blending is continued for at least three minutes. Finally, and without breaking the mixing process, the water is gradually added to the mixture.

After mingling, the material is introduced into moulds of 70×70×280 cm for tensile tests and 150×150×150 cm for compression tests. The demoulding is done after 24 hours.

4. Results and discussions

In order to study the different properties of the elaborated concrete, an experimental program was conducted. For each property, three measurements have been considered and the average value was calculated.

4.1 Workability and densities

In accordance with the EN 12350-2 standard, the workability of concrete is tested using Abrams cone. The slump test results are presented in Table 4. The latter shows also the fresh and hard densities of the concretes. As all workability test values vary between 10 and 12 cm, it can be considered that the used concrete belongs to the S3 consistency class.

On the one hand, and again from the same table, it is also seen that the density of the concrete with straw treated with water is higher than that of the concrete with untreated straw or treated with bitumen, which might be explained by the fact that straws treated with water are heavier than the straws of the two other formulations.

On the other hand, the bitumen acts as a coating around the straw, thus preventing the absorption of water and cement inside the straw, hence a lower density of the concrete with bitumen treated straw.

Compared to the sand concrete (Belhadj *et al*. 2016), it is noted that the use of 15 kg/m^3 of straw in the mixture gives, similarly, a reduction of 6 to 7% in the density compared to the straw-free mixture.

4.2 Compressive strength

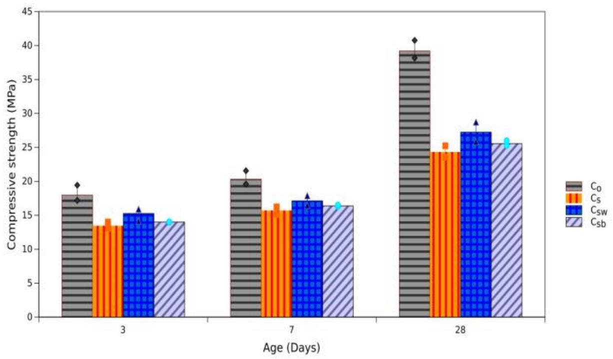


Fig. 5 Evolution of the compressive strength with time

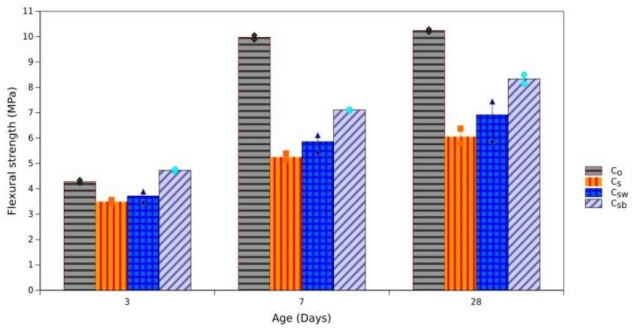


Fig. 6 Evolution of the flexural strength with time

The compressive strength remains always one of the most important characteristics of concrete. To determine it, compression tests were carried out on the various concrete formulations.

The compressive strength is measured at 3, 7 and 28 days. Fig. 5 indicates the variation of the compressive strength of concrete with time. At 28 days, the average value of the compressive strength of the concrete without addition of straws is 39 Mpa.

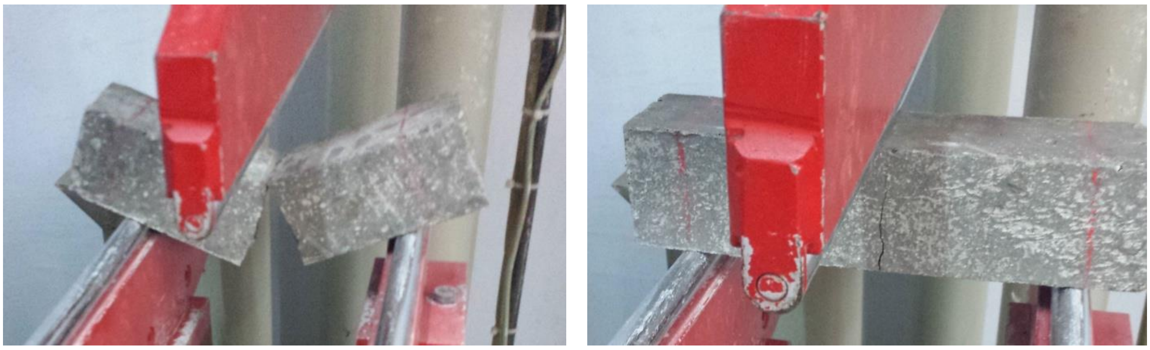
The addition of the straws decreases, as expected, the compressive strength value. An average value of 24 MPa is obtained with untreated straw. The treatment of the straws has improved the average value, but the result remains statistically very close. At 3, 7 or 28 days, the same effects are observed: a decrease in the compressive strength value with the addition of straws.

In the case of sand concrete (Belhadj *et al*. 2016), adding 15 kg/m^3 of untreated straw causes a drop in the compressive strength at 28 days of 40 %, the resistance value becomes 13 MPa. With the conventional concrete used in this work, a similar drop (of 38 %) of the compressive strength is noticed.

4.3 Tensile strength

Measurements of the flexural strength are carried out on 70×70×280 mm^3 prisms. The results illustrated in Fig. 6 show that the addition of straw causes a decrease in the average value of the flexural strength.

If for sand concrete with 15 kg/m^3 of straw, the flexural strength is 6% lower than that of the basic composition (Belhadj *et al*. 2016), it is less than that of the basic composition of 40% for the



(a) specimen without (b) specimen with straws

Fig. 7 Rupture in the flexural test, specimen (a) without and (b) with straws

Fig. 8 Crack in the sample with straw after rupture

concrete of this study. The use of the treatment limited the decrease to 32% using water as treatment and to 18% using the bitumen.

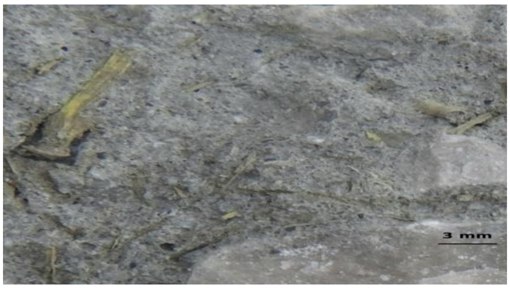
In the flexural test, and if brittle fracture was observed for the classical formulation of concrete (Fig. 7(a)), no brittle fracture was observed for the formulations of concrete with straws when the maximum stress is reached. Indeed, discrete crack appears in the test sample but the two parts of the specimen remain connected to each other as shown in Fig. 7(b). This is due to the presence of the straw that keeps this connection between the two parts of the concrete as shown in Fig. 8. This remark is also noted by Sellami *et al*. (2013) and by Belhadj *et al*. (2016) with the addition of vegetal fibre to a cemented matrix. Indeed, this addition confers the capacity to withstand loads beyond the elastic limits.

4.4 Macro structure

The macrostructure of the concretes is shown in Fig. 9. It represents the examination of the samples at the level of the crack.

For the sample with straw treated with hot water, the figure shows that the straw is well coated with cement and with a good adhesion between the straw and the matrix, a remark also found for sand concrete (Bederina *et al*. 2016) and explained by the fact that hot water seems to be the best treatment that easily dissolves the sugar contained in plant elements, which increases the compatibility between the two materials. In addition, there is also a penetration of the matrix in the

(a) Concrete without straws



(b) Concrete with untreated straws

(c) Concrete with straws treated with bitumen

(d) Concrete with straws treated with water

Fig. 9 Aspect of the concrete for different formulations (same scale used)

straws, which has the effect of stiffening the straw and increasing the compressive strength of the concrete.

In the case of straw treated with bitumen, it is observed that a layer of bitumen still appears on the straw, and that it clearly prevented the water from being absorbed by the straw.

Also a ring-shaped pores can be observed, which can be explained by the decrease in the matrix straw adhesion, due to the bitumen layer, which induce the extraction of the straw during the rupture of the sample.

4.5 Shrinkage study

The shrinkage measurements are performed according to NF P 15-433 Standard on prismatic specimens 70×70×280 mm^3. The tests show that the C_0 formulation (that does not contain straw) has the smallest shrinkage value (Fig. 10), and that the addition of the lignocellulosic material has the consequence of increasing the average value of the shrinkage. The work developed by Bederina *et al*. (2009) shows a similar behaviour in the case of sand concrete based on wood shavings. Indeed, shrinkage values are greater than those of classical sand concrete.

Many studies note that treatments of wood shavings (Bederina *et al*. 2009, 2012) or of straw (Bederina *et al*. 2016) before their use decreases the shrinkage values. Fig. 10 shows that in this study, treatments do not have a similar effect.

4.6 Swelling study

The swelling phenomenon is studied on 70×70×280 mm^3 samples stored in water. Fig. 11

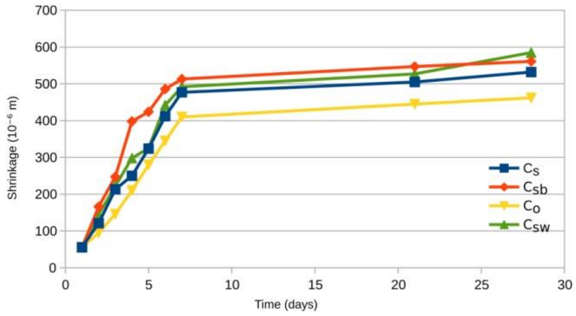


Fig. 10 Concrete shrinkage variation over time

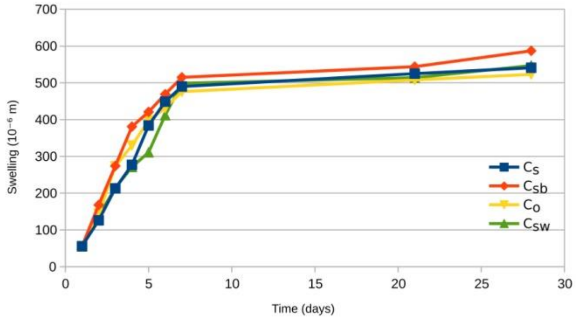


Fig. 11 Concrete swelling variation over time

shows the swelling as a function of time for the different formulations.

The presence of straw in the samples has a minimal effect on the swelling value. The latter is also not influenced by the treatment of straw with water. Contrariwise, the treatment with bitumen increases the average value of the swelling by 12% compared to the ordinary concrete.

4.7 Dynamic elastic modulus

The dynamic modulus of elasticity is determined using an Ultrasonic pulse velocity tester (UVP tester) according to BS 4408. The test procedure consists of generating a pulse in a concrete face by a transducer, the concrete transmits the impulsion into the other face, a second transducer receives the pulse and the UVP tester measures and displays the transmission time.

The velocity of the transmitted pulse V, is calculated from the measured transit time and the distance between the two transducers as in Eq. (1)

$$V = \frac{L}{t} \tag{1}$$

V is the velocity in km/s
L is the path length, in mm
t is the time taken by the pulse to traverse the length, in μs.

From the calculated ultrasonic waves velocity, the dynamic elastic modulus can be calculated as

Table 5 Dynamic elastic modulus

Formulation	T (μs)	L (mm)	V (km/s)	V_{av}	Q (kg/m^3)	E_D (MN/m^2)	S_d
C_0	16.2	70	4.321	4.295	2464	33758.5	292.9
	16.3	70	4.294				
	65.6	280	4.268				
	65.2	280	4.294				
C_{sb}	17.8	70	3.933	4.054	2283	27870.8	1155.9
	17.4	70	4.023				
	67.4	280	4.154				
	68.2	280	4.106				
C_{sw}	17.1	70	4.094	4.107	2353	29479.7	1006.9
	16.6	70	4.217				
	69.6	280	4.023				
	68.4	280	4.094				
C_s	17.1	70	4.094	4.079	2306	28508.0	122.7
	17.2	70	4.070				
	68.7	280	4.076				
	71.1	290	4.079				

$$E_D = V^2 Q \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \tag{2}$$

Where V is the velocity in km/s
Q the concrete density in kg/m^3
μ the poisson's ratio assumed equal 0.3
E_D the dynamic elastic modulus MN/m^2.

Table 5 presents the results of average modulus of elasticity and standard deviations S_d values determined on four samples for each mixture.

The results show that adding the straw to the concrete decreases the modulus of elasticity by 17%. The decrease of the average modulus becomes 13% with the use of the water-treated straw and 16% with the use of the bitumen-treated straw, but statistically, the effect of treatment can be considered negligible.

5. Conclusions

The straw is an ecological material that could be introduced into concrete to obtain a lightweight and an insulator one. Moreover, recycling straws lead to obtain a sustainable and low-cost material, and to reduce pollution.

If the effect of thermal insulation that can be obtained with the use of straw seems obvious, this work highlights on the mechanical properties of a conventional concrete obtained with the use of treated or untreated straw.

With the use of 15 kg/m^3 of straw in the mixture, some similarity with the sand concrete behavior can be noted as the reduction of 6 to 7% in the density compared to the straw-free mixture, and the drop in the compressive strength of 38%. But some differences are also noted, as there is a bigger drop in the flexural strength which reaches 40% for the concrete of this study. The use of the bitumen treatment helps in limiting the decrease at 18%.

The tests show that the addition of the straw results in an increase in the shrinkage value. The straw treatment slightly increases the obtained value. But for the swelling value, the presence of straw has a minimal effect.

Finally, results have shown that the addition of straw to the concrete decreases the modulus of elasticity by 17%.

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