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MECHANICAL AND THERMAL PROPERTIES OF AN ECOLOGY LIGHTWEIGHT CONCRETE USING ALFA WASTE AS A VEGETABLE AGGREGATES

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ABSTRACT

In the present scientific work, we propose to use Alfa waste (Stipa Tenacissima) as a vegetable aggregates in the aim to design an ecology lightweight concrete with improved thermal properties. Actually, it is a prefabricated bloc made from a mixture of a lime as a binding agent, Alfa-waste as renewable lignocellulosic raw material and water. It could be used in numerous applications such as the production or renovation of floors, walls, insulation roofing and coatings for both domestic and industrial building. Thus different Alfa Lime Concrete (ALC) formulations basing on the weight ratio Alfa to Lime binder (0%, 5%, 10% and 20%) will be examined with regard to thermal and mechanical properties. Thermal conductivity tests were achieved by means of the transient Hot-Wire method. However, mechanical experiments were carried out via a universal hydraulic servo-controlled compressive testing machine. Results show that ALC specimens have a low bulk densities ranging from 833 to 950 kg/m^3 and a notable thermal performance ranging, respectively, from 0.180 to 0.220 W/m.°C. In the other hand, it has been concluded that ALC thermal conductivities have a linear behaviour as a function of bulk densities. However, mechanical results exhibit a low compressive strength ranged between 1.5 and 3.5 MPa. The above properties are very satisfactory compared to some others commercial products in the same category.

KEYWORDS

Alfa waste; lime binder; ecology lightweight concrete; mechanical properties; thermal properties; Hot-wire transient method.

1. INTRODUCTION

The conventional methods used in construction and building industries are responsible for high rates of greenhouse gases emissions and depletion of non-renewable natural resources (Pacheco-Torgal et al., 2011). As a result, the construction sector is more and more interested in finding out new alternative materials that respond to sustainable development criteria (Cerezo, 2005; Nozahik et al., 2012). In this context, using natural vegetable aggregates (also called lignocellulosic materials) to design lightweight concrete, could be a promising approach. Actually they are considered as one of the most important components for green (sustainable) building materials (Karade, 2010). They are classified as renewable and biodegradable materials, cheap and require only a low degree of industrialization for their processing and a

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low amount of energy for their production. Besides, they are readily available due to the large quantity of agriculture and industrials wastes (Karade, 2010).

Wood, hemp, flax, straw, sunflower, date palm and coconut are some few examples that have been till now used to design an efficient eco-friendly lightweight concrete with the aim to preserve the natural resources such as mineral aggregates whose extracting conditions become increasingly difficult (Bouguerra et al., 1998; Chandra et al., 2002; Wihan, 2007; Agoudjil et al., 2011). These untypical composite products are characterized by their important porosity, low bulk density, mechanical ductility as well as their low dry thermal conductivity. As a consequent, they are found to be used in many interesting practical applications especially in building composite materials such as wall infilling, floor and roof insulation, insulating plaster and renders, insulation boards and spray concretes such as the case for the Hemp-lime concrete (Arnaud et al., 2012).

Thus we aim through this scientific work to develop a prefabricated bloc of concrete called: Alfa Lime Concrete (ALC) made from Alfa waste particles as aggregate sand lime binding agent and determine their mechanical and thermal properties. This product could be used in numerous applications such as the production or renovation of floors, walls, insulation roofing and coatings for both domestic and industrial building (De Bruijn et al., 2009; Magniont, 2010; Arnaud et al., 2012).

Actually, Alfa (Figure 1) is a renewable raw material which is provided by a Tunisian pulping factory as waste materials. It is characterized by its availability, low cost and its interesting physical properties such as a low bulk density and a low thermal conductivity (Nadji et al., 2011; Marrakchi et al., 2011; Harbaoui et al., 2013). On the other hand, the binder used in the present application is a trademarked pre-formulated lime which has shown its effectiveness in numerous studies dealing especially with concrete using lignocellulosic material as aggregates (Cerezo, 2005; Magniont, 2010; Arnaud et al., 2012).

Furthermore, lime is a traditional binder that has been used for centuries due to its positive characteristics. Actually it is soft, absorbent and flexible and has high capillarity allowing moisture to easily evaporate from the surface of lime-based materials. Besides, it has a lower embodied energy and enables low energy sustainable materials to be used (Roaf et al., 2007).

According to the literature, multiple parameters may affect mechanical and thermal properties of this untypical concrete such as curing conditions, concrete age, binder content and lignocellulosic materials characteristics such as their nature, shapes and sizes (Arnaud et al., 2012). In order to simply the present study, only two main parameters will be taken into account namely:

- The Bulk Density (BD) of ALC specimens.
- The weight ratio Alfa to Binder (A/B) that is used to formulate ALC specimens.

However, after a set of experiences, the weight ratio Water to Binder (W/B) was chosen to be fixed at 0.6 in order to attain optimal compressive strengths of ALC specimens. Actually, W/B is a determined ratio in concrete formulations because if it is increased mechanical properties will be badly affected (Magniont, 2010). Thus, once W/B is fixed, the weight ratio Alfa to Binder (A/B) will be varied up to 20% because above this percentage the workability of the freshly mixed Alfa-lime concrete will be really reduced and its compressive strength will be greatly decreased.

In this paper, a comparison with others building lightweight composites within the same category such as Hemp Lime Concrete, will be discussed.

(a)

(b)

Figure 1: (a) Alfa as a raw material. (b) Alfa as a waste material.

2. MATERIALS AND METHODS

2.1. Alfa waste materials

After removing dust, Alfa waste was oven-dried at 60°C (Memmert Oven-UFE 800) and then they were ground into small particles (Figure 2) by means of Bosch crusher plant AXT 22 D Bosch (Figure 3). The physical and thermal properties of Alfa waste are already determined in detail through a previous scientific work (Harbaoui et al., 2013) and are summarized in Table 1. Additionally, the grading curve (Figure 4) was determined using a sieve analysis test in order to reveal the sizes and the distribution of Alfa particles. The shape of the grading curve of Alfa particles can lead to the following interpretations:

• The average size Alfa particles are between 0.5 and 30 mm.

• Alfa particles are low in fines elements.

• Less than 20% of Alfa particles are low than 4 mm.

• More than 50% of Alfa particles are greater than 10 mm.

Figure 2: Overview of a sample of Alfa particles.

Figure 3: Bosch crusher plant (AXT 22 D Bosch)

Table 1: Physical properties of Alfa waste material.

Parameters	Unit	Mean value	CV* (%)
Bulk density	Kg/m^3	99.42	1.16
Absolute density	Kg/m^3	1309.50	1.30
Thermal conductivity	W/m.°C	0.0565	3.59
Total water absorption coefficient	%	96.79	5.88
Water content	%	8.79	9.15
PH	-	6.4	4.36

* Coefficient variation (%)=100*Standard deviation/Mean

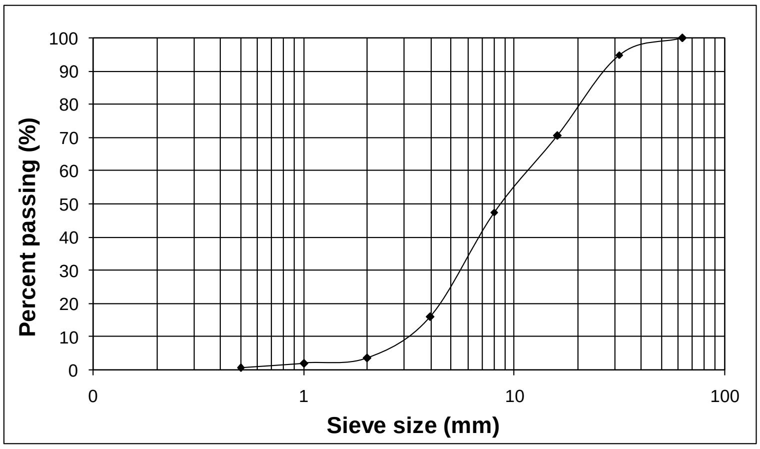

Figure 4: Grading curve of Alfa waste particles.

2.2. Mineral binder

The binder used in this study is a trademark, pre-formulated lime-based binder made up of air-lime (75%), hydraulic-lime (15%) and pozzolanic-lime (10%) (Magniont, 2010; Cérézo, 2005). It is considered as an eco-friendly binder characterized by its low bulk density, 650 kg/m^3.Themechanical strengths of the lime-based binder are ranged between 3 and 4 MPa at 28 days (Cérézo, 2005). The strain levels of the pure binder are higher than those composite made with cement binder, which enables it to fit better to the compressibility of vegetable aggregates (Arnaud et al., 2012).

2.3. Concrete formulations

Alfa Lime Concrete (ALC) is a lightweight composite building material which is a mix of lime as binding agents, Alfa-waste as a vegetable aggregates and water. In the present work, the ratio water to binder was fixed to be W/B=0.6 (by weight). However, in order to study the influence of Alfa material on the thermal behavior of the ALC samples, the ratio Alfa to Binder (A/B) is varied to be respectively: 0%, 5%, 10% and 20% (Figure 5). As a consequence, weight compositions of freshly mixed ALC, and proportions of each ingredient are summarized in Table 2.

Table 2: Weight composition of Alfa Lime Concrete (ALC).

ALC types	Binder, ***B*** (%)	Water, ***W*** (%)	Alfa, ***A*** (%)	***W/L*** (%)	***A/B*** (%)
ALC0%	55.55	44.45	0.00	0.6	0
ALC5%	54.05	43.25	2.70	0.6	5
ALC10%	52.63	42.11	5.26	0.6	10
ALC20%	50.00	40.00	10.00	0.6	20

The mixer that was used is a kind of 80L-capacity paddle mixer with a 20rev/min rotational speed. The mixing method was chosen according to many previous scientific studies dealing with the same type of concrete (Cérézo, 2005; Magniont, 2010) which is described as follows:

- Mixing of dry lime at low speed for 30 seconds.
- Adding water.
- Mixing of the mixture (lime and water) at low speed for 1min.
- Progressive addition of Alfa particles with mixing at low speed for 2min.
- Stop for a minute to homogenize the mixture and disperse clumps that tend to form during mixing.
- Final mixing for 1 min.

The fresh mixture is placed in two types of molds for the mechanical and thermal tests (11x22cm^2 and 7x7x28 cm^3). The samples were kept at temperature of 20 ± 1°C and relative humidity of 65±2%. These curing conditions are mentioned in the literature as the optimal condition to reach optimal mechanical properties (Arnaud et al., 2012). The name given to each mixture refers to the percentage of Alfa waste material used in each formulation. For example, ALC10% means: Alfa Lime Concrete using a ratio Alfa/Binder equals to 10% (by weight). In laboratory, we have used the French abbreviation (BLA) instead of ALC as can be seen from Figure 5.

(a) (b)

Figure 5: (a) ALC specimens for compressive tests. (b) ALC specimens for thermal tests.

2.4. Compressive tests

Mechanical tests were made on ALC specimens using a universal hydraulic servo-controlled compressive testing machine (IGM-NF EN 13286-34/53-Ref: I09 252) characterized by 100 KN-capacity and a crosshead speed ranged between 0.1 and 60 mm/min (Figure 6).

The compressive strength tests are carried out at three different ages (21, 28 and 90 days) basing in a crosshead speed of 0.5 mm/min. Preliminary tests have shown that mechanical results are independent of the different crosshead speed chosen to conduct these compressive tests (0.25, 0.5 and 1 mm/min), which is in agreement with results found in the literature (Cérézo, 2005; Arnaud et al., 2012). Mean values of the compressive strength are computed by testing two 11x22cm^2 specimens.

Figure 6: Example of ALC10% specimen during and after compression test.

2.5. Hot-wire method

Thermal conductivities of ALC samples were achieved using a transient Hot-Wire method (Figure 7). The apparatus consists of a Kapton probe placed between two identical samples of ALC and an electronic data acquisition unit equipped with interface software to control the experimental tests and processing data. The operating principle of the hot-wire probe is based on two steps. The first step consists of generating a low heat locally applied to the sample with a few degrees above room temperature. In the second step, the same hot-wire probe play the role of measuring the temperature variation of the sample as a function of time. The acquisition and the processing of temperature signal allow immediately determining the thermal conductivity for each type of samples.

Before performing experimental tests, the different types of specimens (7x7x28 cm^2) were oven-dried at a temperature of 60°C for 7 days and dry densities are computed. The thermal conductivity was measured at a temperature of 21 ±1°C and a relative humidity RH=65%. Dry densities of ALC concretes are determined and summarized in Table 3

Figure 7: Hot-wire transient method.

Table 3: Dry densities of Alfa Lime Concrete (ALC)

ALC types	Dry density (mean value)	CV (%)
ALC0%	950	1.07
ALC5%	919	1.28
ALC10%	876	1.43
ALC20%	833	1.76

3. RESULTS AND DISCUSSIONS

3.1. Mechanical properties of ALC concretes

The mechanical properties of conventional concretes are linked to a large extent to their ages. In general, typical concretes made with cement binder reach their maximum compressive strength after 28 days. Since Alfa Lime Concrete (ALC) is considered as a non typical lightweight concrete, the stetting time as well as the ratio Alfa to Binder (A/B) will affect their mechanical and thermal properties. Effects of these two parameters are discussed hereinafter.

3.1.1. Effect of the age

Figure 8, shows the effect of the age parameter at 21, 28 and 90 days, on the evolution of the compressive strength for the different types of ALC concretes. As can be seen, the compressive strength curves have a growing trend over days. In fact, at early age, the binder hydrates are not able to form a connected a network, due to nature of the binder which is composed with lime, and also due to the presence of the vegetable particles that still retain absorbed water. Thus, ALC specimens seem having weak mechanical properties and therefore present a low compressive strength. Over days, especially after 28 days, the hydrates form a continuous network and Alfa vegetable particles are more coated with binder. As a function of the setting time, the characteristics of the binder become dominant in all types of ALC specimens. As a consequent, ALC concrete can support high levels of stress in comparison with early ages. Thus, the compressive strength values are better at 28 and 90 days than at 21 days.

3.1.2. Effect of the ratio A/B

The ratio Alfa to binder (A/B) is the second key parameter which may affect the mechanical properties of ALC concrete. As shown inFigure 9, four different ratios are used, namely: 0%, 5%, 10% and 20%. ALC0% which refers to the pure binder is considered to us as a control sample. When the ratio Alfa to binder (A/B) increases, the compressive strength decreases nonlinearly depending on the age of specimens with respect to the compressive strength of ALC0%. Actually, when the amount of Alfa particles increases two main things occur. First, the binder concentration becomes not enough to permit the matrix playing a significant mechanical role. Second, due to the presence of Alfa particles, the porosity rate inside the matrix has to be increased as well the ratio A/B is increased. Thus the compressive strength of ALC concrete follows a declining trend as the ratio A/B increases.

3.1.3. Compressive strength values

According to the results presented in the both Figure 8and Figure 9, ALC samples have modest compressive strength values ranging from 1.5 to 3.5 MPa after 90 days of setting-time due to the special kind of binder that is used and to the high compressibility of Alfa particles. However, these strength values are sufficiently high that the ALC concrete can be adopted for various applications such as to build a sustainable and eco-friendly, load-bearing structure. Actually, the strength levels of ALC specimens that are determined in the present study seems in the same range, even better, than similar product found in the literature such as Hemp Lime Concrete. In fact, many previous studies show that compressive strength of Hemp Lime Concrete are ranged from 0.05 to 3 MPa respectively for a Hemp to Binder ratios (H/B) ranging from 0.21 to 1.02 and Water to Binder ratios (W/B) ranging from 0.8 to 2.04 (Arnaud, Gourlay, 2012). This is means that Ala properties and its morphology play a key role to obtain respectable ALC compressive strength values comparing to other concrete using lignocellulosic aggregates.

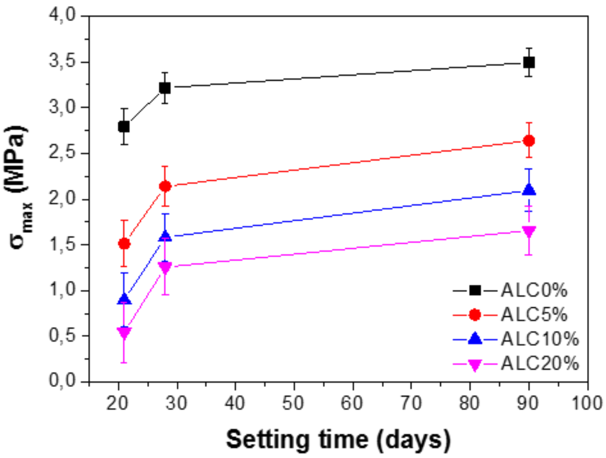

Figure 8: ALC compressive strength as a function of the setting time with corresponding coefficient variations.

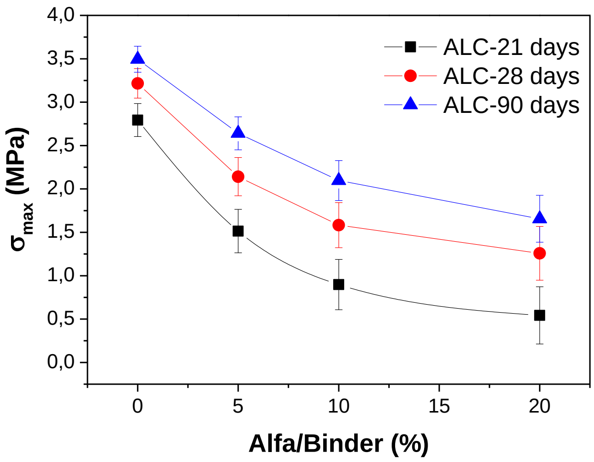

Figure 9: ALC compressive strength as a function of the ratio Alfa/Binder for three different ages, with corresponding coefficient variations.

3.2. Thermal properties ALC concretes

The thermal conductivity values, at a dray state, of the different types of ALC specimens are shown in Figure 10 as a function of their bulk densities. Immediately, it can be remarked two main points. Firstly, the thermal conductivity of ALC concrete has a linear behaviour as a function of bulk densities. This linear trend is in agreement with others scientific studies (Cérézo, 2005; Magniont, 2010; Arnaud et al., 2012) dealing with a lightweight Hemp Lime Concrete. Secondly, ALC has low thermal conductivities ranging from 0.180 W/m.°C (ALC20%) to 0.220 W/m.°C (ALC0%) respectively for a dry bulk densities ranging from 830 to 950 kg/m^3.

Based on comparison of bulk densities and thermal properties with similar common lightweight concrete (Table 4), Alfa-lime concrete has a low bulk density and a competitive low thermal conductivity, which allow to classify it as a new lightweight product with an outstanding thermal properties.

Table 4: Thermal conductivity values of most common lightweight concretes.

Lightweight concrete type	Dry density (kg/m^3)	Thermal conductivity (W/m.°C)	References
Expanded clay concrete	1600	0.46	Chandra, Berntsson, 2002
Aerated concrete	350-650	0.16-0.33	Chandra, Berntsson, 2002
Wood concrete	600-900	0.09-0.30	Chandra, Berntsson, 2002
Hemp-lime concrete	950	0.180	Arnaud, Gourlay, 2012
Alfa-lime Concrete	830-950	0.180-0.220	The present study

The physical and thermal properties of Alfa-waste material seem very helpful to formulate ALC concrete with enhanced thermal behaviour. Actually, Alfa material is characterized mainly by a low bulk density and a low thermal conductivity as can be seen in **Error! Reference source not found.**. Thus increasing the amount of Alfa-waste aggregates in the lime-based matrix will help to create more voids which lead to a low bulk density and low thermal conductivities values of ours ALC composites. Figure 11, explain this fact and shows at the same time a linear thermal behaviour as the ratio Alfa to Binder (A/B) increases. As a result, using more Alfa-waste allow decreasing the thermal conductivity of ALC and thus enhancing its insulation property which is acompanied, with a compressive strength decrease as mentioned in the previous section (3.1).

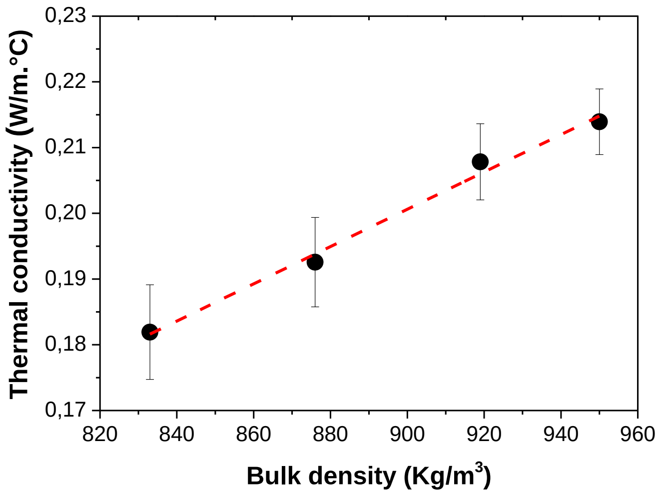

Figure 10: Thermal conductivity of ALC samples, at a dry state, as a function of a bulk density with corresponding coefficient variations.

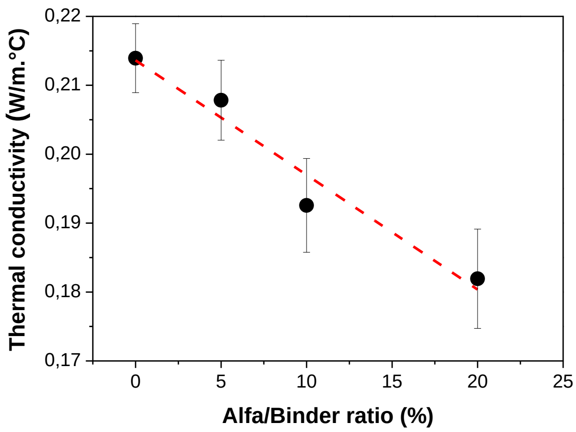

Figure 11: Thermal conductivity of ALC samples, at a dry state, as a function of the ratio Alfa/Binder with corresponding coefficient variations.

4. CONCLUSION

The result analysis of this study on mechanical and thermal characterization of Alfa Lime Concrete (ALC) highlighted the following key points:

- Due to its low density and low thermal conductivity, Alfa-waste material has successfully permitted to design an eco-friendly insulating bloc concrete.
- The compressive strength of Alfa Lime Concrete is ranging from 1.5 to 3.5 MPa, which indicates that ALC has a competitive mechanical properties comparing to similar composite found in the literature. As a consequent, it can be suggest to be used in combination with load-bearing structure.
- Setting time is a key parameter for ALC curing. After 28 days, ALC becomes a hardened composite but over days it will continue towards its high mechanical performance.
- Mechanical properties of ALC seem very dependant of the ratio A/B. In fact, more we use Alfa waste material, the compressive strength decrease towards low values. As a consequent, this ratio should be well determined to reach both optimal mechanical and thermal properties.
- Alfa Lime Concrete can be classified as a lightweight building composite. It is characterized by its low density ranging from 830 to 950 Kg/m^3 and its low thermal conductivity ranging from 0.180 to 0.220 W/m.°C.
- Thermal conductivities of ALC specimens have a linear thermal behavior as a function of BD and A/B. As remarked, more we increase BD values more thermal conductivities increase. However, if we increase the ratio A/B thermal conductivities decrease.
- Due to its improved thermal properties and acceptable compressive strength, Alfa Lime Concrete can be used as an ecology building materials which can make it in competition with other ecology composites such as the Hemp Lime Concrete.

Basing on these results, future research studies are needed in order to enhance the mechanical properties binder agent by using extra additives such as silica fumes or by using special treatment for Alfa particles such as epoxy and polyester resins or flax and paraffin oil.

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