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Experimental investigation of mechanical and thermal properties of a new biosourced insulation material

Rassim Belakroum, Abdelhafid Gherfia
Univ. Ouargla, Fac. des Sciences Appliquées, Lab. Dynamique, Interaction et Réactivité des Systèmes, Ouargla 30000, Algeria
(* Corresponding author: rassim.belakroum@gmail.com)

Youcef Kerboua, Mahfoud Kadja
Laboratoire d'énergétique appliquée et pollution, Université de Constantine I, Algeria

Ton Hoang Mai, Chadi. Maalouf
Groupe de Recherche en Sciences pour l'Ingénieur /Thermomécanique (EA 4694), Université de Reims Champagne-Ardenne, France

Brice Mboumba-Mamboudou, Michèle T'kint
UPJV/EPROAD 4-5, rue moulin neuf 80000 Amiens, France

***Abstract*— In this paper, we present the mechanical and thermal proprieties of a new eco-material made from date palm fiber and lime. By its composition, the new material is biodegradable and therefore reduces environmental impact. Also given the availability of palm date fiber in large quantities and lime at low prices in the countries of North Africa, the implementation of an effective insulation material based on such components will have an interesting impact on building industry.**

The confectioned material is a light concrete which can ensure both thermal and acoustic insulation. For preparing this material, we were inspired by the techniques used for the production of hemp-concrete. This last is widely used especially in Europe for the thermal insulation of buildings. The analysis carried out shows that this bio-composite: has a good thermal insulation properties and acceptable mechanical resistance. The thermal conductivity and specific heat capacity are sensitive to the variation of the composition ratio (fibers / lime) and the compaction of the material during its manufacturing process.

Keywords*— *palm fiber, thermal insulation, mechanical properties, thermal properties, biosourced composite.

I. INTRODUCTION

Nowadays, our society is facing major problems of energy and environmental aspects. Rationalizing our energy consumption and promoting the use of materials with low environmental impact are measures to be taken to slow the degradation of our environment as well as early exhaustion of available energy resources.

The building sector has over 40% of global energy consumption and 56.7% in carbon dioxide emissions, which is considerable [1]. Therefore, the use of reliable insulation materials and the integration of passive air conditioning systems are two measures to be taken among others in order to mutate to a more rational energy model. From an environmental point of view, it is very advantageous to use natural fibers as an alternative to synthetic and mineral fibers. The construction industry should gradually adopt new methods and new vegetable fiber materials. This will contribute to reducing the use of energy in its primary form as well as CO_2 emissions.

The need to develop new effective materials for thermal and acoustic insulation with a very low environmental impact has prompted researchers to invest in this area. Several types of vegetable fibers have been extensively investigated as hemp, flax, and bamboo [2]. Vegetable fibers are cheap, available in most parts of the world and their cost is minimal contribution to the total cost of the composite construction. The abundance of date palm fiber in North Africa and the Middle East presents an opportunity to develop green building materials at low prices. The annual world production of date palm fiber is estimated at 1.13 million tones [5].

Compared to steel fibers, because of their flexibility the plant fibers are easy to handle especially when a large percentage of fiber is used [3]. Composites based on vegetable fibers have advantageous properties in terms of thermal and acoustic insulation and an ability to regulate the humidity inside buildings by absorption and / or desorption of water vapor depending on the relative humidity of the air [4].

In this work, we focus on the characterization of a new insulation material made from date palm fiber. For developing the material in question, we use only the fiber layer that surrounds the trunk of the palm tree. This fibrous sheath reduces thermal stresses due to changes in ambient temperature and thus protects the palm against severe weather. By appropriate experimental techniques, we tested the mechanical

behavior for different compositions 50%, 40%, 30% and 20% fibers. We also measured the thermal conductivity and specific heat of the new bio-composite using transient plane source method.

II. EXPERIMENTAL

The material in question is a bio-based building material manufactured essentially based on date palm fibers and lime. This study investigates mechanical and thermal proprieties of samples of different compositions, that is to say, we have evaluated the sensitivity of the material for the variation of the ratio of fiber/ lime.

A. Composite preparation

Mixed with a binder such as lime, fiber of the date palm allows making a composite material with interesting features. Beyond its thermal conductivity, the concrete base palm date fiber has a porosity related to the nature of the fiber, the lime-based binder and the unevenness existing between the aggregates that are sensitive to the compacting operation. Performance palm fiber mortars are directly related to dosage of the various components. The material properties are always a compromise between mechanical, thermal, hydric and acoustic performances.

The achievement of the specimens is manual. After dosing of the components, the mixture is needed in a tray. The mixing process is important because it is only with a homogeneous mixture which ensures good contact between the components. The amount of water absorbed by the fiber during the implementation was estimated based on the fiber in water absorption rate. Before adding water, the mixture is kneaded dry for about 5 minutes. Finally, the mixing water is poured gradually. During kneading, pellets can be formed according to the size of the fibers. These pellets must be broken to ensure homogeneity. It remains to note that the drying operation, which took place in the open air lasted 90 days.

B. Water Absorption capacity

To determine the water absorption capacity of date palm fiber and the absorption kinetics, measurements were performed on samples of 100 g of completely dry fiber. They were dried first at 50 ° C for one day before being immersed in water for various times: 1, 2, 4, 10, 30 and 60 minutes, 24 hours and one week. The sample mass at a time t allows us to determine the water absorption rate A(t) which is expressed as the ratio between the sample mass gain at time t and its initial dry mass.

$$A(t) = \frac{M(t) - M(0)}{M(0)} \quad (1)$$

Where:
t – Time weighing
M(t) – sample weight at time t
M(0) – sample initial mass (dry mass), M(0) = 100,3 g

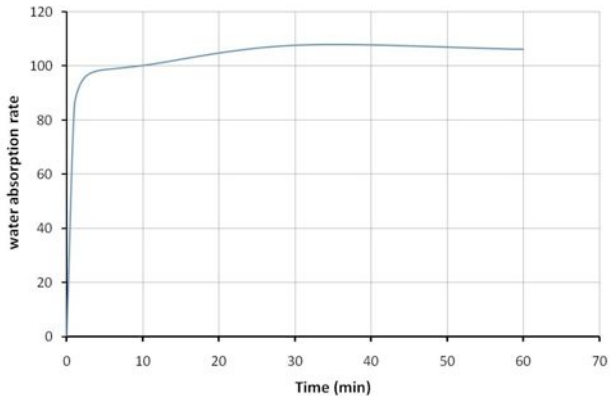

Figure 1. Water absorption rate

M_f mass of date palm fiber
M_L mass of binder (lime)
M_{eg} mass of mixing water
M_{ab} the mass of water absorbed by the palm fibers after 30 min

$$M_{eg}=0,6 \,.\, M_l+M_{ab} \quad (2)$$

C. Mesurment methods

For the mechanical characterization, bending tests in three points (Figure 2) were performed using a constant rate of 0.01 mm / s.

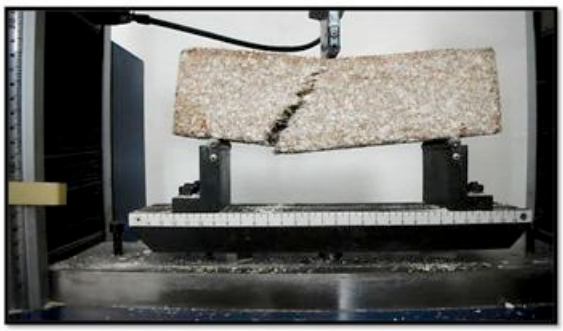

Figure 2. Experimental devices (bending test)

The thermal conductivity and the specific heat measurements were performed using a device based on the transient plane source method. It enables measurement of thermal conductivity range at least 0.01-500 W/m K° and can be used for measuring various kinds of materials. The technique of the transient plane source uses two identical samples, between which enters a sensor. The choice of a suitable sensor size is importance to maximize sample penetration.

III. RESULTS AND DISCUSSION

A. *Bending test and flexural strength*

In order to determine the water ratio that improves the material resistance, three samples of pure lime with different ratios water/lime have been tested to bending. The obtained results are shown in Figure 2. We can clearly observe that the best performance is obtained for a ratio of water/lime equal 0.6.

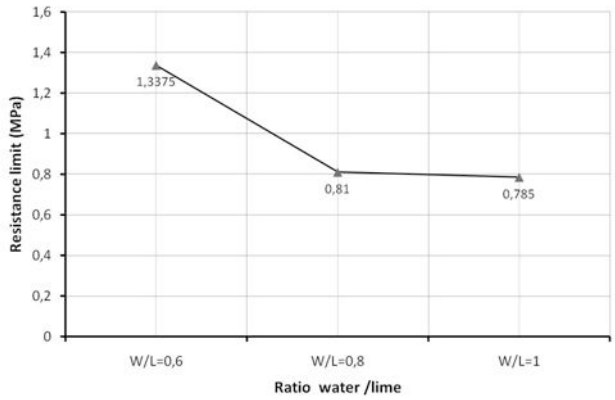

Figure 2. Resistance limit vs water/lime ratio

Concrete samples of date palm fibers have undergone bending characterization. The evolution of the normal stress versus strain is shown in Figure 3. It possible to note that the specimen becomes more resistant by increasing the lime content (W/L = 20%). It is also noted that for high contents of fiber, it is remarked a larger plastic zone.

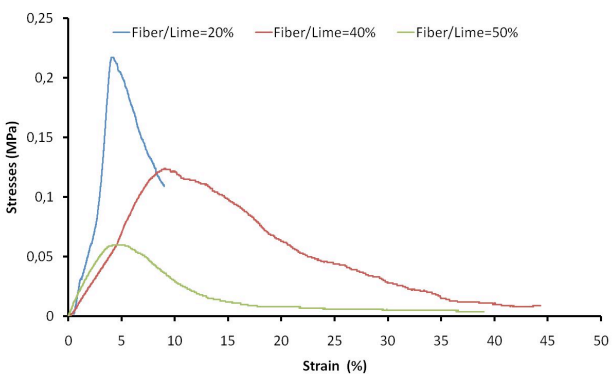

Figure 3. Resistance limit vs fiber/lime ratio

Figure 4 shows the variation of the resistance of the composite as a function of fiber/lime ratio. We can see that the Fiber/Lime ratio increase induces a net degradation of the resistance limit.

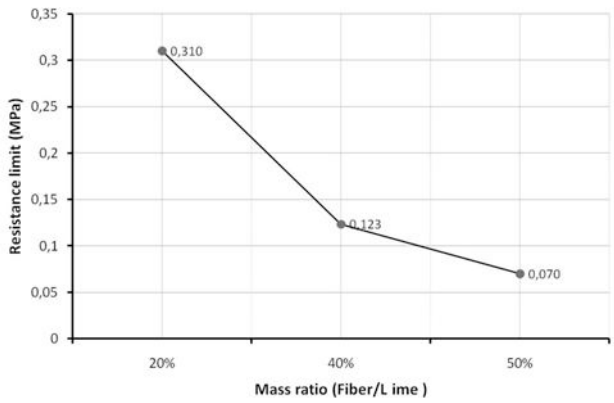

Figure 5. Resistance limit vs fiber/lime ratio

B. *Thermal conductivity*

The measurements of the thermal properties have revealed that values of thermal conductivity are very interesting and close to those of the hemp concrete. As we can observe in Figure 5, the thermal conductivity of the composite in question is sensitive to the fiber percentage. Lower values of the conductivity are obtained for samples of 50% fiber. The decrease in the amount of fibers leads to an increase of the thermal conductivity which reached 0.18 W/m.K for 20% of fibers.

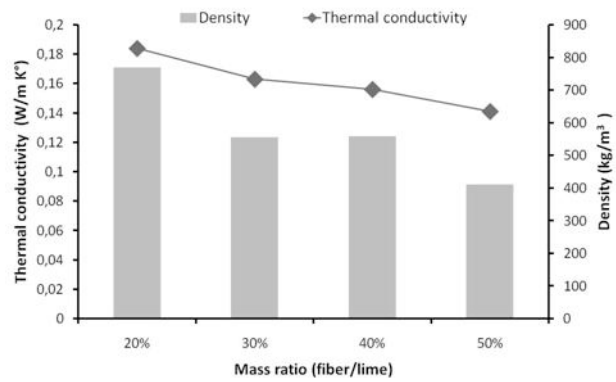

Figure 5. Thermal conductivity vs fiber/lime ratio

From results shown in Figure 6, it is noticed that by increasing the rate of the fiber from 20% to 30% in the bio-composite, we obtain samples of greater specific heat values. For fiber percentages between 30% and 40%, the specific heat remains the same. We also observed a tendency of lower specific heat values for the samples of 50% of fiber compared to 30% and 40%.

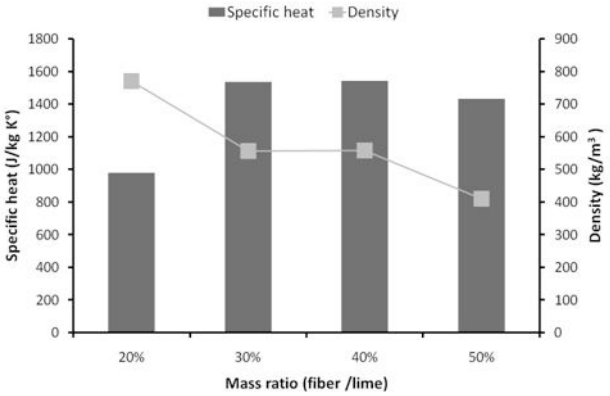

Figure 6. Specific heat vs fiber/lime ratio

IV. CONCLUSION

The objective of this work is the experimental investigation of mechanical and thermal proprieties of a new material based on date palm fibers. Considering the obtained results, we can note that the new material has satisfactory mechanical performances as well as very interesting thermal properties. The thermal conductivity of the bio-composite is comparable to that of hemp concrete. Indeed, all thermal and mechanical properties are sensitive to composition of the material (mass ration fiber/lime).

All these results lead us to believe that this material offers considerable advantages compared to the existing insulation materials. The development of the concrete date palm fibers probably requires further study and further work. It is also important to note that the material is commercially very competitor given the availability and the low cost of its components especially in a country like Algeria.

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