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RESEARCH ARTICLE

Thermal Resistance of Concrete in Wood Safe and Scoria

[1] Eddie Franck Rajaonarison
[2] Alexandre Gacoin
[3] Bam Haja Nirina Razafindrabe
[4] Vincent Emile Rasamison

[1]Sciences of Materials and Metallurgy, Ecole Supérieure Polytechnique, University of Antananarivo, 101 Antananarivo, Madagascar.
[2]Search Group on Sciences for the Engineers, GRESPI/ Thermomécanique, University of Reims Champagne-Ardennes, Campus du Moulin de la Housse - BP 1039, 51687 Reims Cedex 2, France.
[3]Faculty of Agriculture, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa 903-0213, Japan.
[4]Researcher at the CNARP Department of Chemistry, B.P.702, 101 Antananarivo, Madagascar.

Corresponding author:
Eddie Franck Rajaonarison
franck_eddieee@yahoo.fr

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ABSTRACT

The wood is a valuable resource widely employed for industrial and household purposes, especially in joinery, carpentry and as a source of heating. However, the use of wood generates a lot of waste materials which bring about economic and environmental problems. As part of the valorization of such waste products, we carried out the present investigation which aims at the formulation of concretes from the combination of natural ingredients including sawdust and scoria. The optimal compositions of the composite concretes obtained have been studied. The results of the thermal tests showed that the sawdust based scoria concretes displayed excellent thermal behaviors. Moreover, depending on the quantity of wood and scoria, it is possible to obtain structural concretes, structure-insulation or insulation.

Keywords- Sawdust, Scoria, Lightweight Concrete, Thermal properties.

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INTRODUCTION

This work was carried out as part of the valorization of natural resources in the production of new composite materials which can be exploited for solving the problems of thermal insulation encountered in the field of construction. The use of such materials associated with the implementation of efficient techniques may contribute, from an economic standpoint, to minimize the cost of construction. In this regard, sawdust and scoria were chosen for in-depth studies in this research since the current trend is to promote the use of light products in individual construction.

The term "light concrete" encompasses all concretes whose density is lower than that of ordinary concrete (equal to about 2.4). Such a density can be obtained through the substitution of conventional aggregates (sand, gravel) by lighter, often artificial granules such as, inter alia, expanded polystyrene beads [1] and the coconut shell [2]. The performance of light concretes has been shown to be related to the characteristics of the aggregates [3].

In recent years, several works have been dedicated to various types of waste as a basis for the production of light concretes [4] [5]. For instance, wood waste has been incorporated to cementitious matrices [6] [7]. Meukam *et al.* [8] have investigated the effect of the addition of scoria or sawdust to laterite soil bricks.

The present communication deals with the study of the thermal behavior of the sawdust concrete from woodwork waste and the scoria, both of them were gathered from Antsirabe Madagascar. It particularly describes the specific characteristics of wood and scoria concretes as inferred from the physical properties of each constituent as well as the microstructure of the mixture thereof.

MATERIALS

Sawdust

Although plant woods have already found many applications in different fields for the benefit of mankind, their industrial use as the raw materials in concretes has not been well-known yet. The most common species in Madagascar are maritime pine, Scots pine, spruce, fir and eucalyptus. As long as the chemical composition of their sawdusts is favorable, they can be used as additions in the manufacture of cements and even as aggregates for the manufacture of concretes. We used sawdust with particle size distribution between 0.5 and 30 µm. The result of particle size analysis of wood chips is presented in Fig 1.

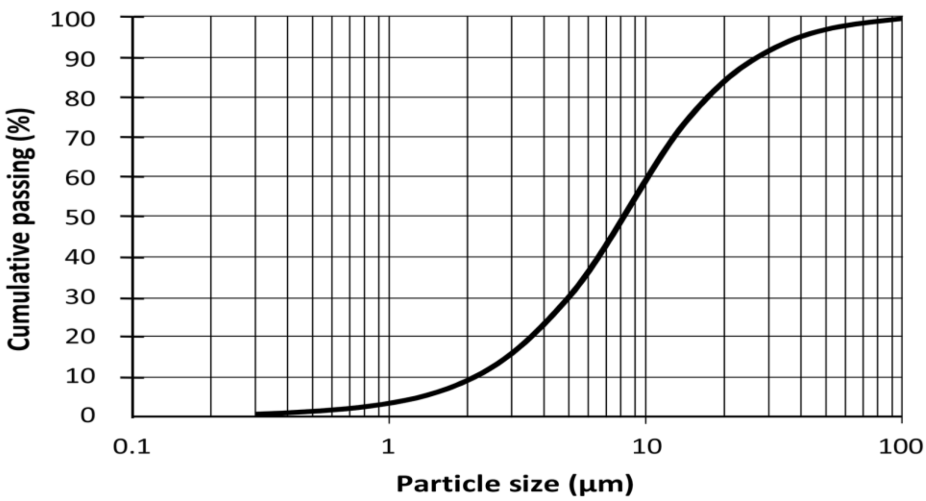

Fig.1 Grading curve of sawdust.

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The highly hygroscopic nature of the wood chips does not allow their direct use as light granules in concrete. In order to improve the physical characteristics of the composites studied, including their water sensitivity and their high dimensional variations, the hygroscopic chips have to undergo a water saturation treatment for 24 hours, before mixing them with the cement. Thus, it must be avoided that the water designated for the hydration of the cement is absorbed by the chips and accordingly it no longer ensures the complete hydration of the anhydride cement.

In previous study on light bales made from rice husks [9], it has been found that the presence of amorphous silica in the bales had a beneficial role on the cement paste - ball bond. By analogy, it is expected in the present research that a treatment of sawdust in a silicate solution would lead to a similar result. As silica is slightly soluble in water, a solution of sodium silicate was used. Therefore, the sawdust was treated with a solution of sodium silicate at a concentration of 100 kg.m^{-3}. After that, the wood chips undergo a bleeding before mixing with the cement.
Infrared spectra of untreated and treated sawdust samples are shown in Fig 2.

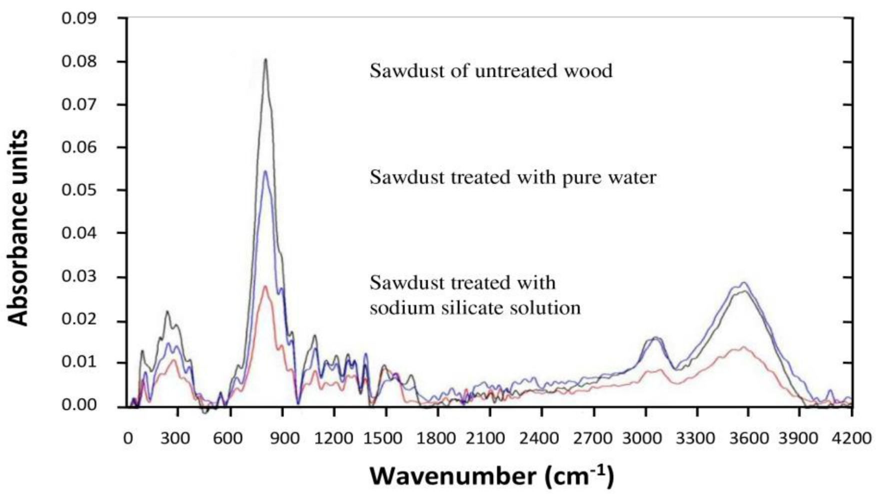

Fig. 2 Infrared spectra of sawdust.

At first sight, the Infrared spectra of untreated and treated sawdust showed the same profile. However, a decrease in the intensity of absorption was observed especially in the case of sawdust treated with sodium silicate.

Cement

The cement used in this study was type I (ASTM C 150) [10] where its physical properties and chemical composition are shown in Table 1.

Table-1: Chemical compounds and physical properties of cement.

Chemical compounds	%	Physical properties	%
SiO_2	21.01	Specific gravity (g/cm^3)	3.12
Al_2O_3	5.39	Specific surface (Blaine) (cm^2/g)	3350
Fe_2O_3	3.23	2 days compressive strength (MPa)	21.0
CaO	62.11	7 days compressive strength (MPa)	28.0
MgO	1.98	28 days compressive strength (MPa)	42.0
Na_2O	0.21	Initial setting time (min)	157
K_2O	0.74	Final setting time (min)	235
SO_3	3.1	Soundness (mm)	1.0

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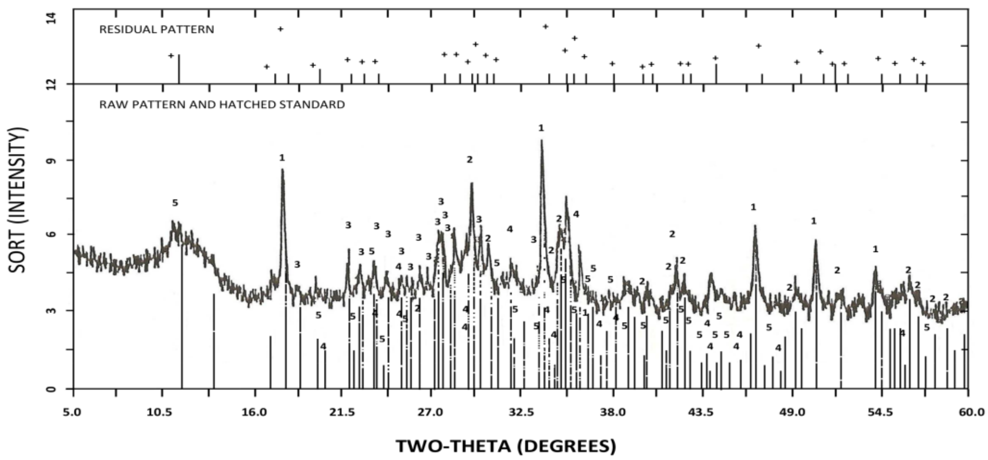
Scoria

The scoria used to prepare the specimens originates from the site of Antsirabe Madagascar. Its main mass, which has not been estimated, is formed by projection products, among which slags largely dominate. scoria samples were subjected to the identification and characterization tests. Chemical analyses of scoria powder samples were conducted. The X-ray powder diffraction method was performed on the samples using a monochromatic X-ray beam. A Siemens D500 diffractometer operating with a monochromatic CuKa radiation at a wavelength k = 1.7903 A˚, a voltage of 40 kV and a current of 30 mA was used. The results obtained are shown in fig 3.



	FRACT	STANDARD		I/ICOR	FOM	
1	28	4.0733	CA (OH) 2	1.4	0.703	Slaked lime
2	25	24.0202	CA (MG. AL. FE) S120	1.2	0.498	Pyroxen
3	15	9.0465	(CA. NA) (SI. AL) 40	1.0	****	Calcic plagioclase
4	13	21.1257	(MGO.6FEO. 4) 2SIO	1.0	****	Olivine (rich in iron)
5	17	14.0083	CA4AL2C09. 11H2O	1.0	****	Para-alumohydrocalcite

Fig. 3 X-ray diffraction analysis.

The results of chemical analyzes are given in Table 2 which shows the silica contents. Alumina and hematite fit perfectly within the limits set by the ASTM C618 [11] standard for scoria.

Table 2 Chemical composition of scoria.

Elements	%
SiO_2	45.79
Al_2O_3	15.68
Fe_2O_3	12.83
MnO	0.17
MgO	7.06
CaO	9.60
SO_3	0.02
Na_2O	3.54
K_2O	1.39
TiO_2	2.84
Cr_2O_3	0.11
P_2O_5	0.60
LOI	0.31
Total	99.94

Different densities of the considered sample were evaluated, as well as the water content of the aggregates in their natural state. The results are shown in Table 3 where ρh indicates the apparent density of the aggregates in the natural state, ρg represents the actual density of the pre-formed aggregates, ρvHg is the "true" density given by the mercury porosimeter, ρ Hg corresponds to the "apparent" density given by the mercury porosimeter, ρa refers to the absolute density of the grains given by the picnometer, w is the water content of the aggregates in the natural state and e is related to the porosity of the grains.

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Table 3 Densities and water content of scoria.

ρh	0.72
ρg	1.44
ρvHg	2.78
ρHg	1.46
ρa	2.85
e	0.49
W%	6

The particle size distribution of the aggregates is shown in Fig 4. The amount of dust increases near the soil surface and decreases with the depth. The medium density material of 1.15 taken from the main quarry of the quarry showed an average material proportion of less than 75 μm, ranging from 0.4% to 0.6%.

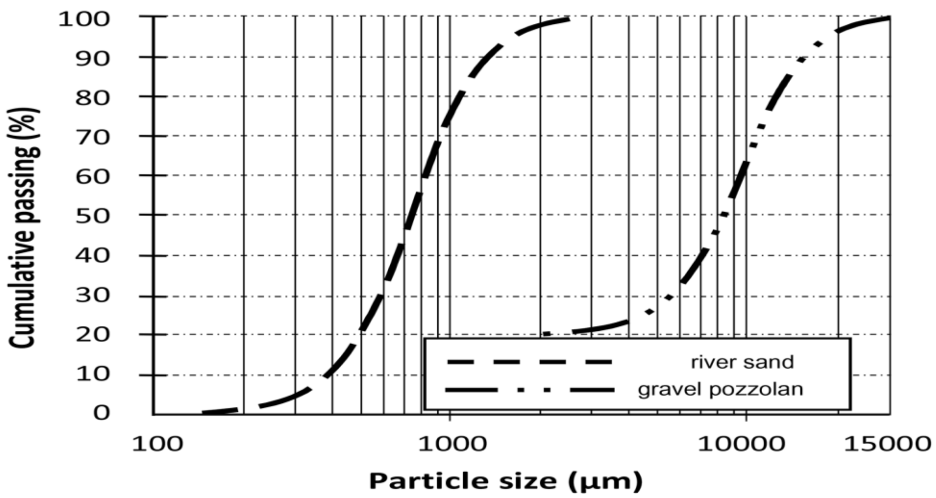

Fig.4 Particle size distribution of aggregates.

The investigation reveals that a large deposit of deeper slag meets the requirements of ASTM C-33 [12] for both the range and the average proportion of materials under 75 lm. The photographs of the samples used in this study are shown in Fig 5.

(a) Scoria quarry

(b) scoria

(d) sawdust

Fig.5 Samples used.

Formulation

From the theoretical and experimental considerations, many authors have studied the behavior of granular mixtures in order to obtain an optimal formulation of scoria concretes [13] [14]. The main objective for common concretes has always been to produce concretes with minimal porosity which logically offers the best mechanical resistance on a sustainable time scale. With regards to the lightweight aggregate concrete, the goal is slightly different and is directed towards rules of mixtures compatible with the composition of concretes which have acceptable

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mechanical strengths, a low density and good physical properties.
However, there is an incompatibility of these characteristics that prevents the optimization of the mixture. For each series given in Table 4, the rule of linear variation of the theoretical vacuum rate is governed by the aggregate mixture rule, expressed as follows [15]:

$$e = \alpha V_{abs} + \beta \quad (1)$$

where e is the void ratio; a and b correspond to the coefficients of the void fraction and the grain shape, respectively, and V_{abs} indicates the absolute volume of aggregates in 1 m^3 of concrete.
- On the one hand, for the A series, we did not use sawdust and gradually increased the amount of cement. For the B series, we have not used sawdust yet, but gradually increased the amount of sand related to the cement dosage.
- On the other hand, concerning the C series, we gradually increased the sawdust. This operation corresponds to the almost constant water content to see the influence of sawdust treated with pure water and with sodium silicate.
- Finally, as for the D series, the evolution of the composition was similar to that of the C series. It had no particularity excepted that the dosage of the concrete was kept constant at 450 Kg/m^3.
For each category, we prepared several samples with the different mass percentages of sawdust embedded in the concrete.

Table 4 Concretes composition.

Name	**A**			**B**			**C**				**D**			
Specimens n°	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***4***	***1***	***2***	***3***	***4***
Dosage (Kg/m^3)	250	300	350	350	350	450	400	425	350	450	450	450	450	450
Sand river	69	231	162	105	292	332	252	191	359	72	237	291	139	71
Cement	81	92	124	115	116	115	132	132	109	147	123	114	136	137
Sawdust	00	00	00	00	00	00	13	34	45	50	98	110	136	156
Water	120	120	160	160	155	160	172	173	175	173	187	136	221	216
scoria	537	493	537	537	357	300	384	469	259	537	332	231	401	465
Density (Kg/m^3)	1286	1396	1400	1330	1690	1748	1544	1522	1793	1463	1789	1780	1747	1732

The raw materials, previously dried, are introduced into a kneader. Dry mixing is essential to homogenize the mixture of river sand, sawdust, scoria and cement. These materials are mixed for three minutes at slow speed. The wood sawdust saturated with water are then added to the homogeneous mixtures by always keeping the mixing at a slow speed for three minutes. After that, the mixing water is gradually added. The homogenization of the material is ensured by mixing at low speed for three minutes and at high speed in one minute. After molding, the test pieces are kept in a humid room at 20 ° C. After 24 hours, they are removed from the mold and kept in a dry environment at 20 ° C.

Thermophysical characterization
To measure the thermophysical characteristics, our samples were dried in an oven at a temperature of 50 ° C. An unidirectional heat flow passed through the samples (E) which were placed between the cold and constant isothermal heat flux sources. The thermal gradient that evolved between these two faces was measured. Once the stationary state is established, the apparent thermal conductivity [16] can be expressed by the formula:

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$$\lambda a = \frac{e}{S(Tc - Tf)}\left[\frac{V^2}{R} - C_1(Tb - Ta)\right] \quad (2)$$

where:
λa: apparent thermal conductivity;
V: voltage applied to the terminals of the heating plate;
R: plate resistance;
C1: coefficient of heat loss;
Ta: ambient temperature of the experiment room;
Tb: temperature inside the box;
Tc: temperature of the hot face of the sample;
Tf: temperature of the cold side of the sample;
S: surface of the sample;
e: thickness of the sample.

For temperature readings to calculate the thermal conductivity, it is essential that the steady state is reached. In our experiments, this was achieved six hours after the beginning of the test. The device used to measure the thermal diffusivity is the same as that of the box method for the measurement of thermal conductivity. The sample is placed in a box with reflective faces and thermally well insulated. It receives a thermal pulse from a source of constant flux radiation consisting of a 500W incandescent lamp.

RESULTS AND DISCUSSION

The results of the measurement of thermal conductivity and thermal diffusivity of samples are shown in Table 5. According to these results, the thermal conductivity increases with the amounts of sand and added binder material. In fact, the addition of sand fills the pores created by large particles.
The results of c1 and c2 clearly show the decrease in the thermal conductivity with the increase in the sawdust content, as also reported by Bederina *et al.* [17]. This decrease is due to the air holes between the small pieces of sawdust. This observation is also normal since wood has a much lower thermal conductivity than a concrete. Therefore, the values obtained make it possible to provide a very good thermal insulation according the proportion of sawdust incorporated into the material. A rapid decrease in thermal conductivity was noted when 0.5% of sawdust was added to the reference sample. Indeed, when an insulating material was mixed with a conductive material, the thermal conductivity will be reduced. This may explain the decrease in thermal conductivity whenever a percentage of sawdust is added.
It seems that the shrinkage is directly proportional to the proportion of sawdust and scoria. It should be also mentioned that open-air C-series concrete itself is characterized by higher shrinkage than Series A or B concrete, and the addition of wood increases it further.
In terms of values, it ranges from 790 µm / m for A et B series concrete to 1850 µm / m for C and D series concrete with 156 kg / m^3 of sawdust and 465 kg / m^3 of scoria.
By treating sawdust prior to use, the water absorption is greatly reduced when wood is added. In the case of concrete D1, 90 kg / m^3 of wood, the measured value is almost 7 times less, that is to say 2.8% before the treatment against 19.1% after the treatment.

Table 5 Values of the conductivities and thermal diffusivities of the concretes.

Name	λa [W/mK]	∂ [10^{-6} m²/s]
a1	0.257	0,271
a2	0.385	0,392
a3	0.380	0,390
b1	0.299	0,371
b2	0.524	0,530
b3	0.544	0,548
c1	0.480	0,503
c2	0.448	0,454
c3	0.652	0,550
c4	0.395	0,417
d1	0.609	0,521
d2	0.639	0,545
d3	0.556	0,478
d4	0.411	0,457

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The pore structure of a material plays a dominant role in the control of its thermal conductivity [18]. Hemp concrete manufactured by a projection process has a conductivity value up to 0.49 W / m K for a volumetric mass of 550 kg / m^3 [19]. Therefore, it is an excellent insulating material compared to scoria concrete whose thermal conductivity values ranging from 0.206 to 0.616 W / m K.

The variations in diffusivities are similar in appearance to those of conductivities following the introduction of sawdust and sand. Those heavily dosed in sand are the most diffusive concretes. This observation can be explained on the basis of the compactness of these grains.

CONCLUSION

In this research, we undertook the formulation of concretes by using the sawdust, a main waste product derived from the use of wood, as ingredient together with scoria and cement.

- The results obtained showed that the sawdust and scoria are reliable resources to produce lightweight concretes with excellent thermal behavior.
- The addition of sawdust significantly lightens the scoria concrete and considerably increases its insulating power.
- The thermophysical characteristics of the composite concretes obtained might compete with those of common concretes.
- The sawdust based scoria concrete should be further exploited at industrial level for the development of new insulating materials which are useful in the field of building construction.

This work contributes to the valorization of waste materials such as sawdust which are a matter of concern in most of countries worldwide in terms of environmental pollution.

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