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International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

http://ijpsat.ijsht-journals.org
Vol. 29 No. 2 November 2021, pp.512-533

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Abstract – Rice is the staple food in Madagascar. The rind of this rice is, therefore, a waste present in large quantities on the island. Some of these bark is used by brickmakers to bake clay bricks. A minimal amount of the ash produced by these burned bark is used to produce soap. The rest is released into the environment as agricultural waste. Our work aims to find another way of recycling this ash, which is mainly located on the large island. The studies carried out in this article have been directed towards mixing these ashes with cement dedicated to the construction of buildings. The idea is not new but provides a local solution to a specific problem in the country. The advantage of such an approach is twofold : it reduces the cost of construction but also enables the recovery of the agricultural waste produced in Malagasy state.

Keywords – Rice Husk Ash (RHA), Waste, Madagascar, Sustainable, recycling.

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I. INTRODUCTION

The objective of this work is to valorize the local materials, existing in large quantities in Madagascar island, which could replace part of the cement, thus reducing its cost and increasing the durability of the construction, which could allow Malagasy people to live in sustainable housing. Rice husk ash (RHA) and metakaolin (MK) are often used as additives in the manufacture of concrete based on cement, sand and rock. They have properties equivalent to those of cement (i.e. They contribute to the solidification of the mixture) and can, therefore, be used as a complement to the latter.

This article aims to demonstrate that partial substitution of cement using mineral materials such as RHA and/or MK can provide with similar properties than the original version, and, reduce the volume of cement required. The work described in this article also demonstrates the possibility to consideration of requirements related to sustainable development leading to the reduction of en- vironmental impacts throughout the life cycle of the works (production of raw materials, transport, construction site - implementation, the lifetime of the work, deconstruction, recycling).

This article focuses on three main areas: first, Madagascar's potential resources of RHA and MK; second, the chemical, physical and mechanical characterization of these materials (which standardized experimental tests on the new binders are presented) and; finally, the results and discussions of tests.

The materials used in this work are cement mixed with RHA and MK.

The recycling of specific waste in construction is practised in many countries. Generally used in the manufacture of cement, this waste is more environmentally friendly, economical and has physical characteristics that meet the needs and standards of the construction industry. In particular, RHA are a widely used materials as supported by cited research.

II. STATE-OF-THE-ART OF RHA VALORIZATION IN THE BUILDING CONSTRUCTION

Researchers [1], [2], [3] and [4] have shown that an addition of about 15% metakaolin confers a superior resistance capacity in aggressive environments, such as those of seawater and acid solutions. Others have analyzed the effect of hydration of cementitious materials with the addition of RHA

[5] and their properties [6].

In 2011, Kishore et al. [7] studied the physical strength of ash concrete from rice husk. The study on the mechanical properties of high-strength concrete with different levels of replacement of ordinary Portland cement by RHA proved that RHA could be replaced by cement at about 10% to form high-strength concrete.

In 2013, Sathawanne et al. [8] studied the physical effects of Fly Ash and RHA when the latter partially replace cement. Studies have shown that mixing fly ash, RHA (about 30 to 10

In 2015, studies by Chowdhury et al. [9] highlighted the usefulness of wood ash and incineration residue in construction. The authors studied the replacement of cement by these ashes in a defined proportion and showed that the results of the conformity tests met the construction standards in Civil Engineering.

It was only in 2016 that a study on agricultural waste came into being. Prusty et al. [10] used agricultural waste (specifically rice husk) as fine aggregate in concrete and compared it with self-placing mortar in terms of durability and thermal conductivity.

In the same year, Shatat [11] presented a study on the impacts of methacrylate and RHA on the hydration behaviour and mechanical properties of mixed cement. The results showed that the combination of MK and RHA has a positive effect on mechanical properties. Samples incorporating cement ternary mixtures with 20-15% MK and 5-10% RHA showed better compressive strength than the standard sample without RHA. These mixtures have proven to be the optimal combination to achieve maximum effect.

In 2017, Zareei et al. [12] studied the effect of the durability and strength of high-strength concrete containing RHA and of cement mixed with micro silica. The test results showed a positive relationship between 15% RHA replacement and an increase of about 20% in compressive strength. During the same year, Christopher et al. [13] produced a bibliography on rice husk mortars.

The conclusions that emerged from this work are:

- controlled incineration of RHA is necessary to mix this material with concrete;
- the use of RHA has increased water demand during concrete manufacturing;
- the replacement of the cement with RHA up to 10% results in the development of strength comparable to that of the control samples;
- the use of RHA in concrete will result in an RHA concrete microstructure impermeable to degradation agents such as sulfate attack, chloride penetration, and it has excellent shrinkage properties. The concrete based on the RHA also has a longer lifespan, and
- researchers did not yet explore areas of research such as bending and shear responses (and associated properties) of reinforced concrete slabs and beams containing RHA.

Samad et al. [14] produced a bibliography on the role of binary cement, including Supplementary Cementitious Material (SCM) such as Rice Husk Ash. The article summarizes the different physical and chemical properties of the RHA. The authors demonstrated that 40% addition of RHA to cement does not modify the physical properties of the concrete of this specific mixture.

Abu-Jdayil et al. [15] prepared the most recent bibliographic article (2019) in the field. The authors listed all existing techniques to insulating buildings with construction materials from a renewable waste. Among these techniques is the upgrading of rice husk.

There are no studies on the potential and characteristics of these building materials from agricultural waste located on the Madagascar island in the scientific reviews. However, this island is full of kaolin and MK, which could partly meet local cement needs. In this article, a characterization study of waste agriculture mixes with bricks dedicated to the construction of buildings specifically in Madagascar island are presented.

III. Opportunity of Madagascar to integrate agricultural waste in building construction

Since 2009, the Malagasy construction sector has been going through a difficult period due to the political crisis that had shaken the country. However, the building materials market experienced a major leap forward in 2014 despite a decline of almost -7.7% in 2013. It recorded an increase of

+7.5% according to the latest Economic Scoreboard (TBE) of the National Institute of Statistics [16].

Among the construction materials used in construction, cement remains a problem in Madagascar, a developing country. Only one plant is operating, but it is unable to meet the country’s needs. Indeed, it produces only 150 000 tonnes per year [17] whereas the local need is 500 000 tonnes [18].

Every year, the island suffers from a recurrence of natural disasters (hurricanes, heavy rains) and insufficient maintenance budgets lead to the destruction or damage of several existing infrastructure. It should be noted that the United Nations Human Development Report 2015 reports that Madagascar ranks 154^{th} out of 188 countries. Its GDP in 2014 was PPP 1459.3 (current in- ternational PPP (Purchasing Power Parity dollars) compared to PPP 39 678.0 in France and PPP 101 926.4 in Luxembourg. Thus, the poverty rate calculated by the World Bank is 68.7% and about 70% of the population is estimated to live from agriculture. Consequently, solid constructions are essential so that Malagasy people can live in decent housing.

In the building sector, concrete is the most widely produced material.

3.1. Rice husk and RHA

3.1.1. Rice husk

Madagascar is classified as the second largest rice consumer in the world. In 2004, annual per capita rice consumption in rural Madagascar[19] was estimated at 138 kg. Urban households eat 85% of their meals with rice [19]. Rice is cultivated throughout Madagascar [20] : 63% of Malagasy people cultivate rice and, in rural areas, 73% of households are rice farmers. The volume of national rice production amounts to 6 million tonnes of paddy per year, or about 4.2 tonnes of white rice on a total rice area of 1 250 000 hectares [20]. Rice is the main product obtained after threshing the rice plant. The grain of rice, also called straw rice or paddy rice, is a fruit called karyopsis surrounded by a protective envelope or husk, which is the protective layer or envelope of rice and constitutes on average 11% of the mass, according to CENRADERU (i.e. National Center for Applied Research for Rural Development), 2008.

In practice, to be returned for consumption after harvesting, the rice must be dried and peeled from its outer shell, which is the rice husk. Hulling can be done mechanically in a hulling factory or manually, by mortar and pestle. According to Houndékon [21], a person hulls an average of 5.13 kg of paddy parboiled in one hour and 7 kg for non-parboiled rice with an average yield of 65% including 5% small broken rice. In the passage of rice with its shell through a husker, one tonne of milled paddy produces 200 kilograms (20%) of RH after husking [22].

Industrial or artisanal processing units are, in most cases, located either in the major paddy production regions, in particular Lake Alaotra and Marovoay, or around production areas with a high population density such as Vakinankaratra, Antananarivo, Fianarantsoa etc. At the farmers' level, the treatment is still done with pestle and mortar. Pounding is the most widespread and used practice in rural Malagasy areas. Whatever the qualification of the paddy treatment, whether industrial, artisanal or family, the following steps remain the same:

- Cleaning - get rid of impurities;
- Hulling - remove the glumellae with two types of by-products (bullets and loud sounds), and
- Bleaching or polishing - final treatment before human consumption, whose by-products are broken rice and fine bran or low flour.

Statistical data indicate, that Madagascar produces about 4 000 million tonnes of paddy or rice not yet shelled, while about 160 000 tonnes (4%) of RHA can be obtained [23].

3.1.2. RHA

In Madagascar, RH are generally available in small quantities and distributed in tens of thousands of small rice mills. Since their transport is expensive, they are often reused on site to be used, in most cases, for firing building bricks if the appropriate clay is available in the area concerned. Once the cooking is finished, a tiny part of the residues of this fuel RHA are recovered by the Malagasy people to make pots and pans shine, and in a traditional way, to make manufacture soaps to cure certain skin diseases. The majority, is thrown into the wild, contributing to environmental degradation. The recovery of these combustion residues is necessary and desirable.

In order to test the effect of its partial replacement in cement, RHA was sampled from artisanal brickworks with a firing temperature of approximately 700°C. When the RH is burned in an oven,

the melting temperature of the RHA is 1439°C and it takes almost 5 hours to carbonize 1 m^3 of

RH.

3.2. Kaolin and Metakaolin(MK)

3.2.1. Kaolin

In hot and humid, tropical and equatorial climates, intense hydrolysis allows the formation of thick alteration mantle, forming amongst other minerals Kaolinite.

The Malagasy subsoil has large Kaolin deposits. This large quantity of kaolin is justified by the fact that, the warmer and wetter the climate (≥ 18 °C), the higher the production of Kaolinite.

With the limited tonnage assessment work that has been done, the GIS department of the Ministry of Energy and Mines was able to produce a map of the location of Kaolin deposits in Madagascar in Figure 1. After calculation, this Ministry argues that the Kaolin reserves is expected to be about 14 million tonnes from 10 identified deposits.

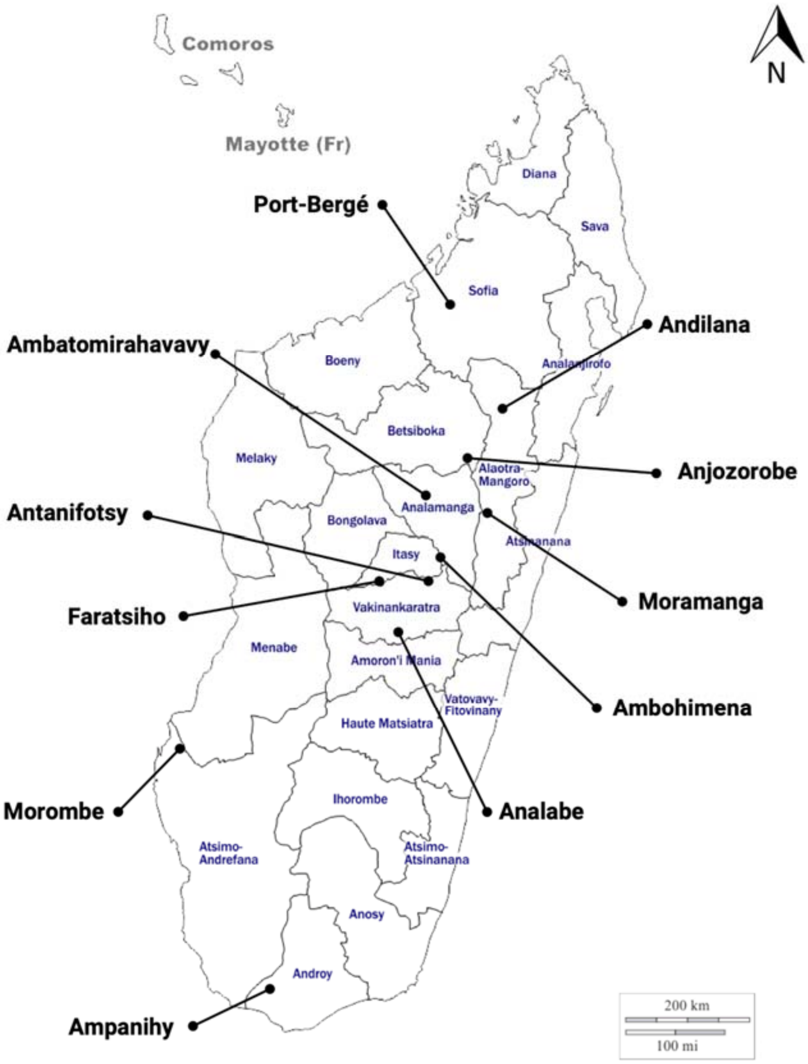


Figure 1: Kaolin site location map

Kaolin was collected from two specific locations: Antananarivo and Moramanga, designated K1 (white color) and K2 (salmon color) in this paper. Properties of K1 and K2 are provided in Table 1.

Antananarivo was chosen as:

- it is the capital of Madagascar;

- there are a significant number of small paddy processing plants;
- Kaolinite exists in large quantities in the subsoil of this region, and
- the largest consumption of cement in Madagascar occurs here, negating the need for long-distance transport of these materials.

Table 1: Chemical proprieties of K1 and K2

Percent (%)	K1	K2
SiO_2	63.98	65.19
CaO	<1	<1
MgO	0.12	0.11
Al_2O_3	17.11	17.30
Fe_2O_3	0.33	0.36
$enSO_3$	-0.01	0.00
Na_2O	-	-
K_2O	-	-

Moramanga was selected as:

- It is located near Madagascar's rice granary;
- According to surveys conducted by the Mines Service of Madagascar, Moramanga has good deposits of Kaolin with quantities in excess of 11 million tonnes;
- The Kaolinite outcrops extends several meters deep, and
- It is about 200 km from the capital.

3.2.2. Metakaolin

As there are two types of Kaolin (K1 and K2) (see Table 1), the MK are designated MK1 and MK2 in this paper [24].

3.3. Local cement

Two types of cement were used, namely:

- C1, a cement from France, TEIL 52.5HTS-PM HTS from Martres, and
- C2, a CEM I 42.5 produced by the only local plant. this category of cement is the one most produced by the Lafarge-Holcim company because it gives the best results.

These two cement types were chosen because, for C1, it has been proven that it has regular and constant characteristics, and that the locally produced C2 is widely available and used by Malagasy hardware stores and moreover, the one most used by Malagasy manufacturers. C1 cement without any RHA was used as control for all experiments.

IV. Analysis methods of RHA and MK combination with local cement

In order to valorize Madagascar's RHA and MK manufacturing of mortars and concrete, the basic raw materials, (i.e. cement, RHA and MK) we initially characterized. The equivalent binder was analyzed to indicate the interest of combining these two basic raw materials in the partial substitution of cement. Standard mechanical tests were carried out on all materials.

4.1. RHA preparation conditions

The RHA were screened at 0.315 mm and passing material crushed with a RETSCH RS100 crusher with a tungsten carbide lining (see Figure 2). Only 2% of the RHA refused passing this sieve diameter.

4.2. Kaolins and MK preparations

Once extracted from their original site, the Kaolins were passed through a Dadaux homogenizer (see Figure 2) to obtain a sample, then crushed and passed through a RS100 mill and screened.

Figure 2: Materials for the preparation of addition materials

The Kaolins were calcined at temperatures ranging from 600 °C to 850 °C, that resulted in MK. The objective of calcination is to make pozzolanic materials less reactive by dehydroxylation. This dehydroxylation reaction of the material cause destruction of the initial crystal structure, leading to an amorphous material nature.

4.3. Analysis methods of the mixtures tests

A chemical and physical characterization of the raw materials were carried out (see Table 2 for more information).

The additives studied were used as a partial replacement for cement to form equivalent binders, depending on the dosage of a standard mortar [28].The control cement chosen is C1. The proportions used in the study are shown in Table 3.

V. CHEMICAL

-Chemical analyses [25] such as the content

of main elements, loss on ignition and SO_3content,

VI. PHYSICAL

- An evaluation of the granulometry with a laser granulometer as well as the determination of the fineness [26];
- A measurement of the actual density [27],
- An ATD / ATG measurement (Differential Thermal Analysis/Thermo Gravimetric Analysis);
- Mechanical strength [28] and manoeuvrability [29] and [30];
- Withdrawal and swelling [31];
- The setting time [32];
- The evolution of the hydration heat by the semi-adiabatic method [33];
- The determination of the bulk density and porosity accessible to water (see [34] and

[35] for more information) concerning vacuum saturation, hydrostatic weighing and drying to constant mass;

- And finally, from an observation with DRX (X-ray diffraction), SEM (Electron Scanning Microscope) with an analysis with

EDS (Electronic Data Systems).

VII. MATERIAL USED FOR THE MEASUREMENT

+ For chemical analysis: flame spectrometry, the NABERTHERM muffle furnace;

+ For microstructure: SIEMENS Röntgengenerator KRISTALLOFLEX 710D with cobalt anticathode for DRX and JEOL JSM-6380LV, energy dispersion spectrometer, EDAX PV 9100 and RONTEC Signal Processing Unit signal analyser for SEMobservation and EDS analysis;

+ For physical analysis: DADAUX homogenizer, electric sieve shaker, MALVERN laser granulometer for granulometry, desiccator, oven, RETSCH - RS100 grinder;

+ For mechanical analysis: the maniabilimeter, the bending-compression press adapted to the specimens used and controlled in force, the Mitutoyo Absolute withdrawal measuring device, the Chatelier needles, the calorimeter.

Table 3: Characterization of the studied compositions

Test number	Mixture under consideration
1	75% C1/C2 cement + 25% MK1
2	75% C1/C2 cement + 25% MK2
3	75% C1/C2 cement + 7.5% RHA + 17.5% MK1
4	75% C1/C2 cement + 15% RHA + 15% MK2

VIII. RESULTS AND DISCUSSIONS

the measurement results obtained during the experiments carried out on the sample tests in Table 3 are described in this paragraph.

8.1. Chemical and mineralogical analyses

The content of the main elements are shown in Table 4.

Table 4: Content of main elements in addition materials

Specimen	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	MnO	SO_3	**Loss on fire**	**TOTAL**
RHA	88.92%	1.98 %	0.77%	2.01 %	0.68%	0.43 %	0.10 %	0.13 %	0.11 %	1.29%	96.5%
MK1	84.46%	35.14 %	1.21%	1.05 %	1.15%	0.20 %	0.07 %	-	0.01 %	0.74%	98.80%
MK2	69.59%	17.99 %	0.40%	0.19 %	-	0.16 %	0.03 %	-	-	8.92%	97.5%
C1	20.07%	4.86 %	3.07%	1.00 %	64.25 %	0.95 %	0.18 %	0.85 %	3.55 %	2.39%	98.78%
C2	22.05%	4.55 %	2.85%	0.90 %	55.75 %	0.75 %	1.02 %	4.46 %	1.99 %	4.55%	98.87%

8.2. Physical analysis and microstructure

The graphs in Figure 3 indicate results of granulometer evaluation.

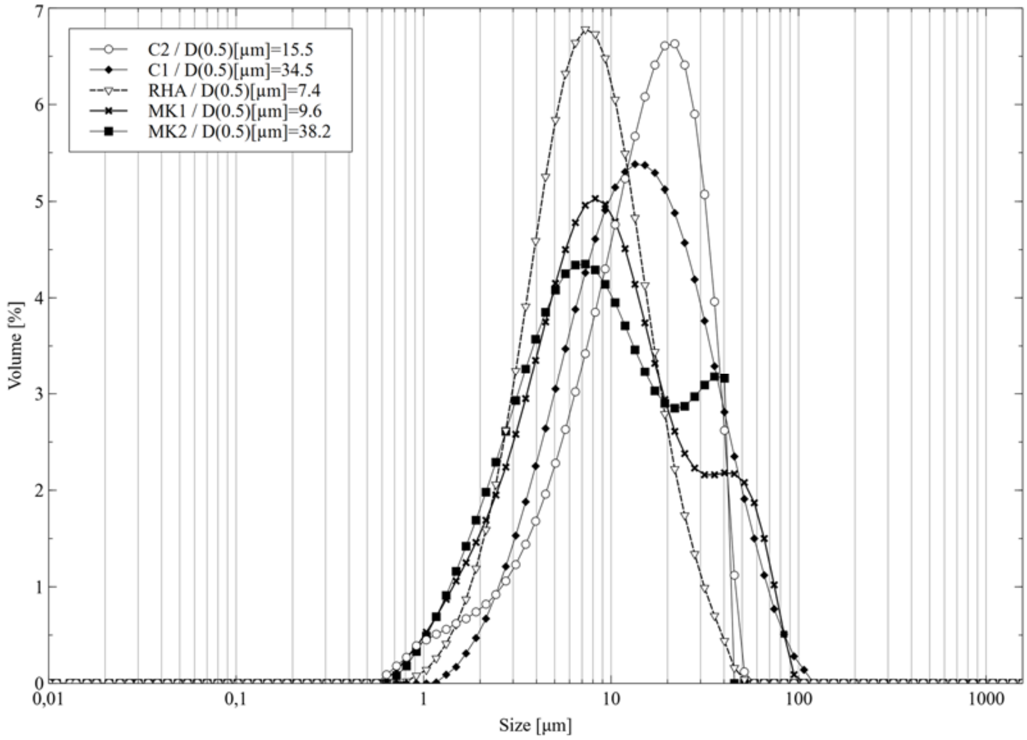


Figure 3: Granulometric curves of the addition materials obtained from the granulometer

The comparison of the evolution of the granulometry of our three materials is given by Figure 4.

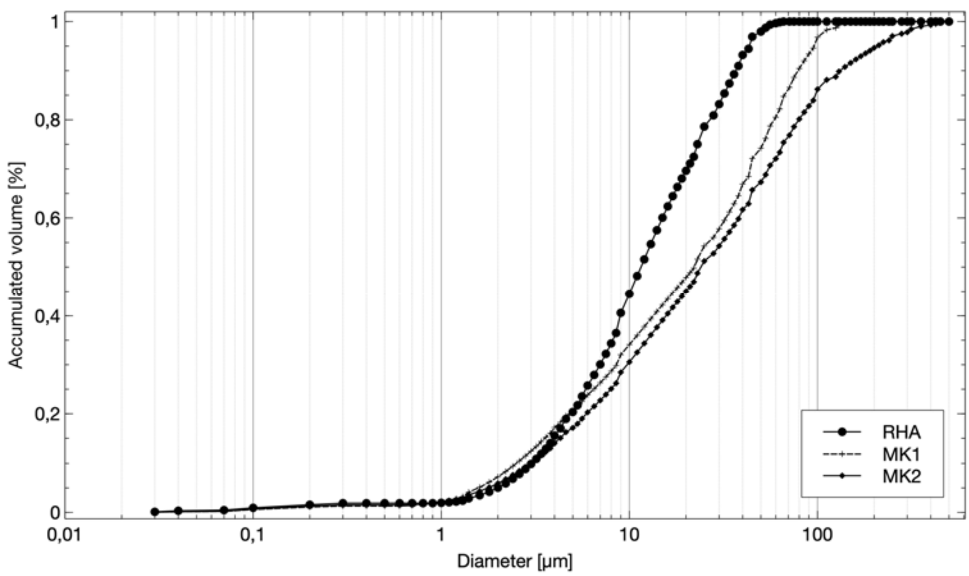


Figure 4: Particle size curve of addition materials

The densities of the materials are given in table 5.

Table 5: Density of addition materials

MATERIAL	**RHA**	**MK1**	**MK2**	**C1**	**C2**
DENSITY [*kg/m*^{3}]	2100	2600	2300	3100	2700

The ATD/ATG curves are given in the Figure 5.

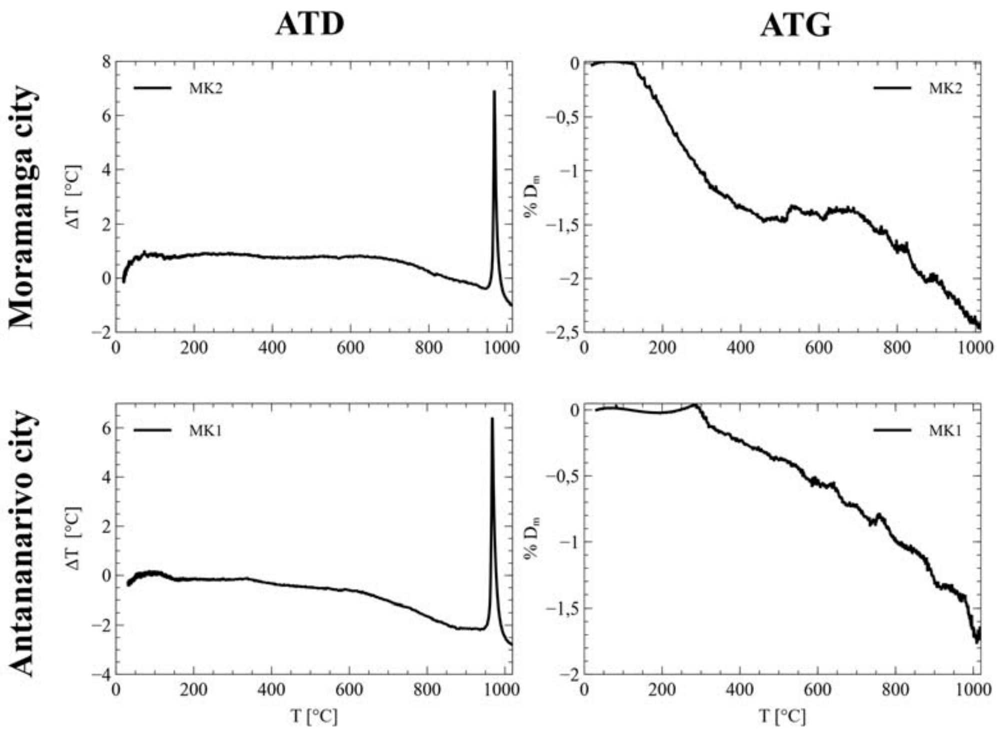


Figure 5: ATD/ATG curves

Diffractogram analysis of the materials are given by the Figure 6.

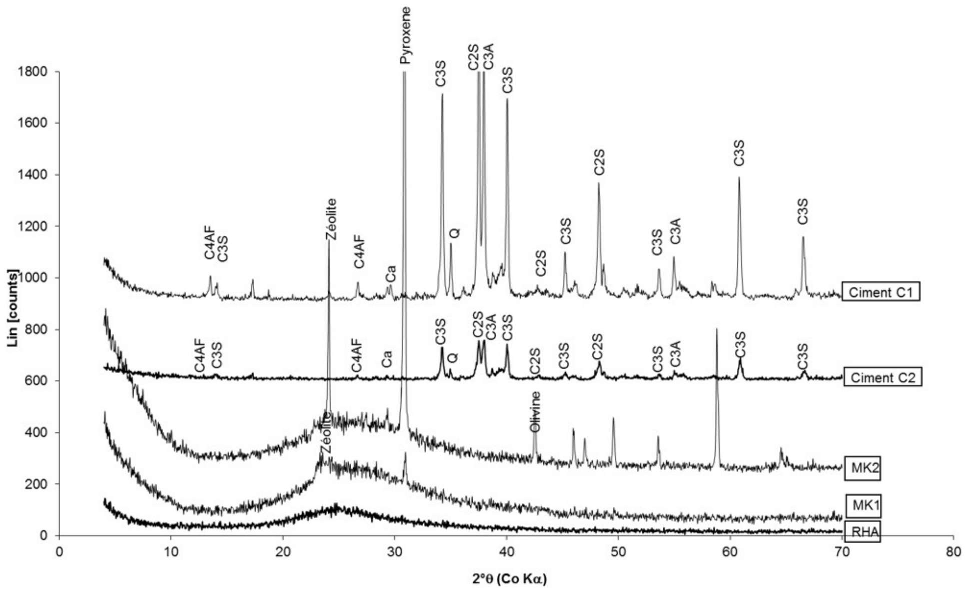
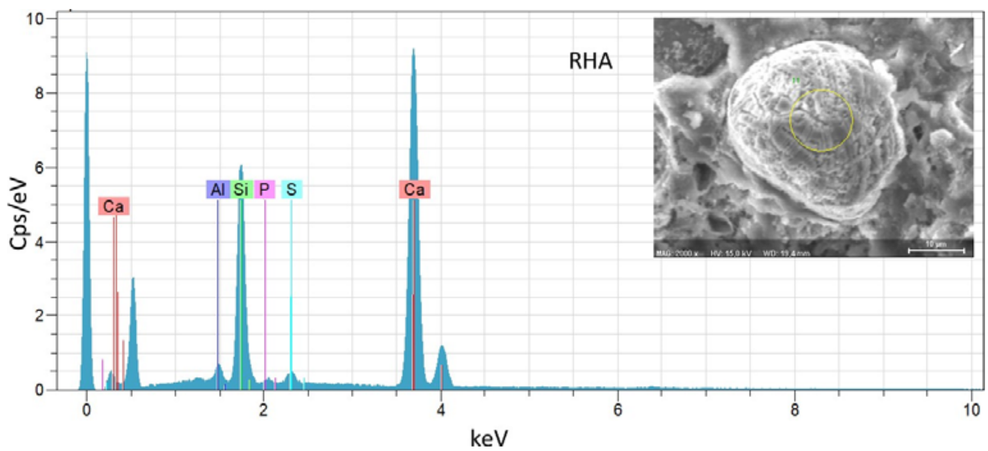
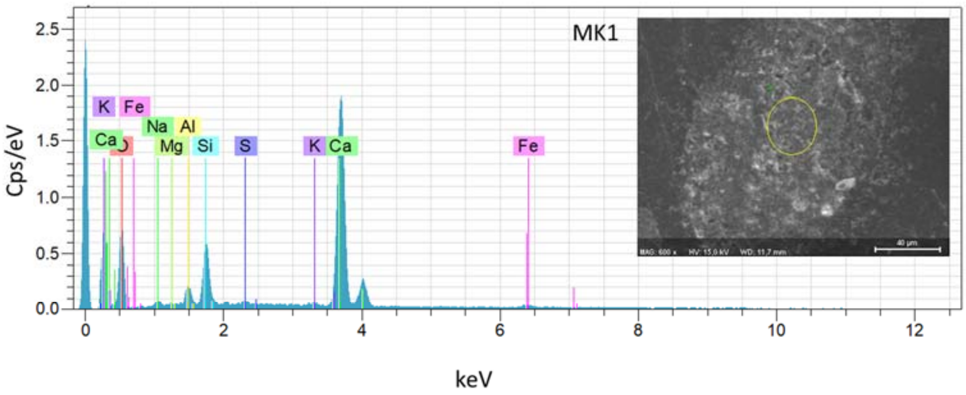
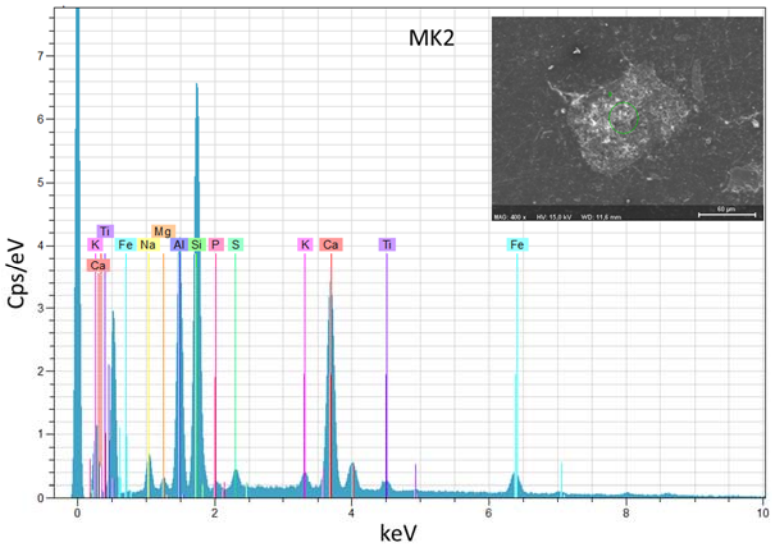


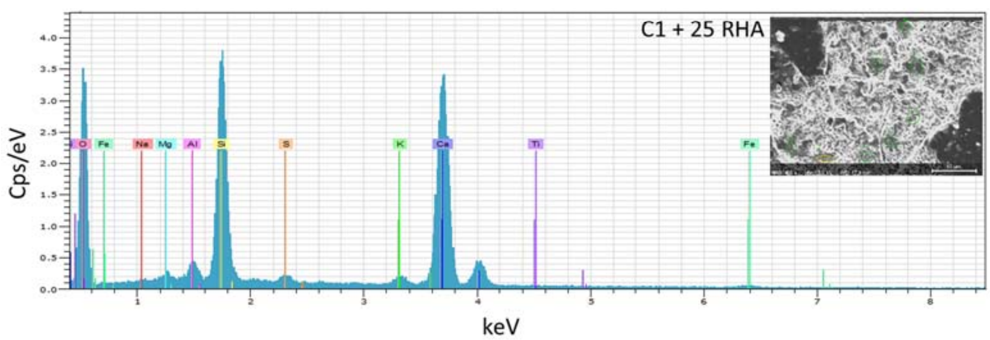
Figure 6: Diffractogram of materials

The samples were analyzed using a Scanning Electron Microscope (SEM) in secondary electron mode. The acceleration voltage is 15 kV. The observations were supplemented on an ad hoc basis by Energy dispersive X-ray spectroscopy (EDS) analyses. The results of the observations are shown in the Figures 7.




MK1
Cps/eV
keV
K
Fe
Na
Al
Ca
O
Mg
Si
S
K
Ca
Fe


MK2
Cps/eV
keV
Ti
Mg
K
Fe
Na
Al
Si
P
S
K
Ca
Ti
Fe
Ca


C1 + 25 RHA
Cps/eV
keV
O
Fe
Na
Mg
Al
Si
S
K
Ca
Ti
Fe

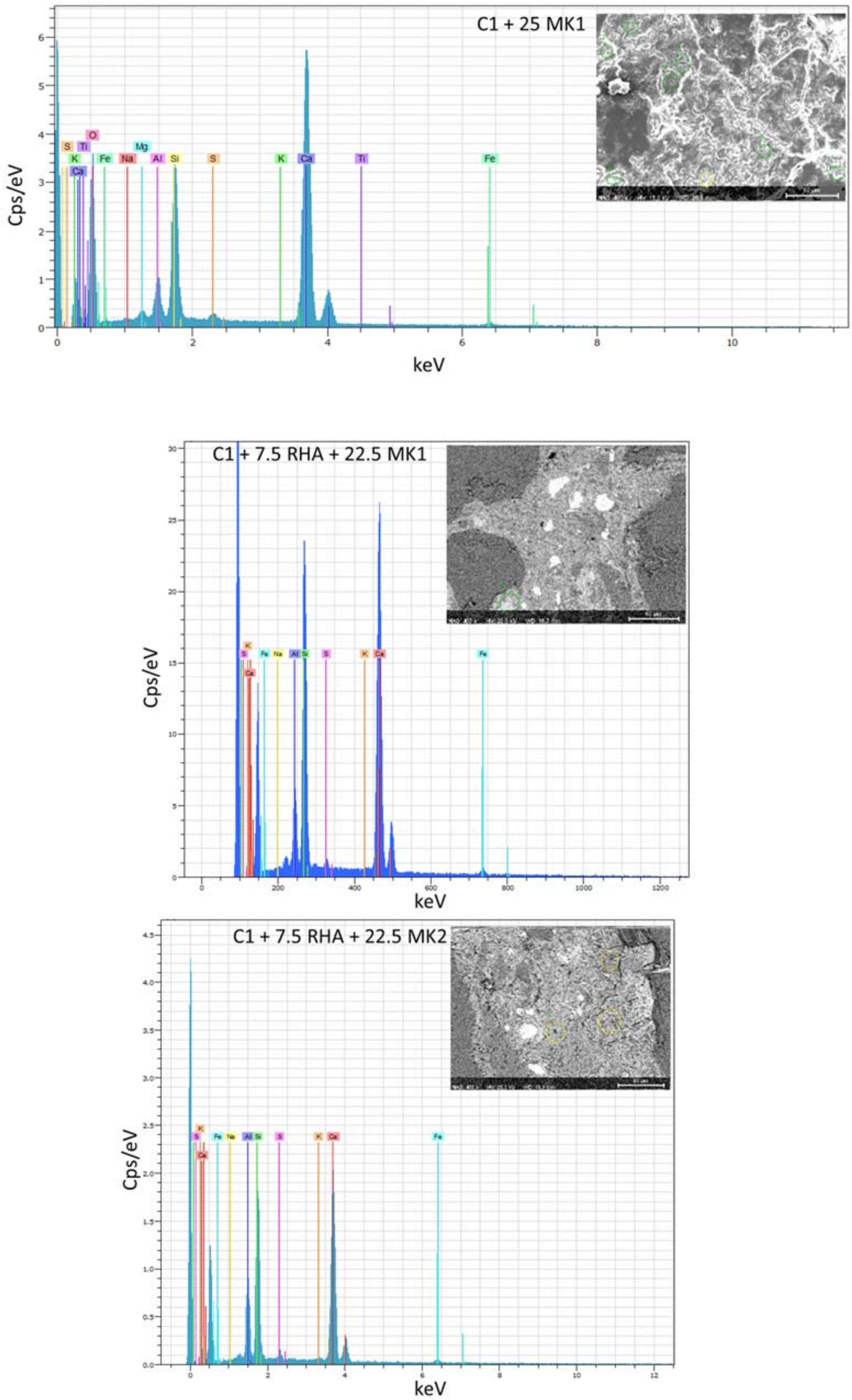


Figure 7: MEB and SEM observation of respectively RHA, MK1, MK2 and mixtures

The compositions chosen for this study (i.e. from Test 1 to 4) are given by Table 3. Table 6 give the composition obtained after analysis at the EDS.

Table 6: Composition results after EDS analysis

	Test 1	**Test 2**	**Test 3**	**Test 4**
Sodium Na_2O	0.39%	0.15%	0.12%	0.00%
Potassium K_2O	1.29%	0.06%	0.22%	0.22%
Calcium CaO	52.22%	61.75%	54.56%	8.82%
Aluminium Al_2O_3	2.73%	6.21%	11.07%	38.20%
Silicon SiO_2	38.74%	26.22%	30.27%	51.42%
Sulfur SO_3	1.90%	1.86%	2.11%	0.45%
Iron Fe_2O_3	1.38%	2.28%	1.65%	0.89%

- Apparent density and porosity accessible to water

The apparent density and porosity accessible to water obtained with the created compositions is given by the Table 7.

Table 7: Apparent density and water-accessible porosity of the compositions

		Apparent Volumic Mass[g/cm^3]	Porosity accessible to water[%]
1	C1	2,161	15,8
2	C1 + 25 rha	2,036	19,9
3	C1 + 25 mk1	2,054	18,8
4	C1 + 25 mk2	2,059	19,5
5	C1 +7,5 rha + 17,5 mk1	2,047	19,5
6	C1 +7,5 rha + 17,5 mk2	2,038	19,7
7	C2	2,067	20,2
8	C2 + 25 rha	1,986	22,0
9	C2 + 25 mk1	2,022	21,6
10	C2 +7,5 rha + 17,5 mk1	2,012	21,2

The setting time of the stability is 28 days. The calculation of the hydration heat by adiabatic calorimetry allowed us to obtain in Figure 8 and 9.

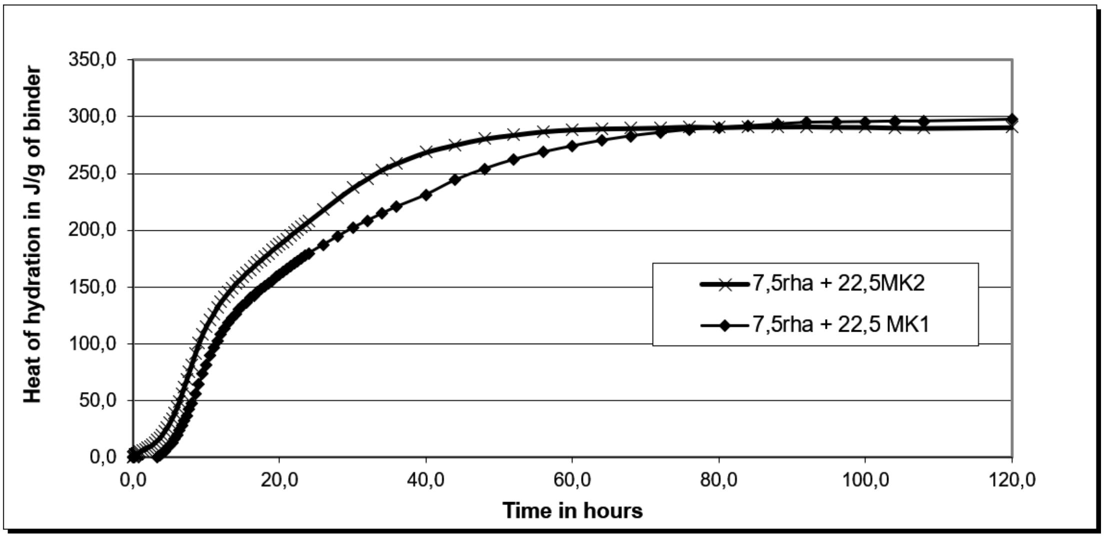


Figure 8: Hydratation heat of C1 + 7.5RHA + 22.5MK1/22.5MK2 mixture

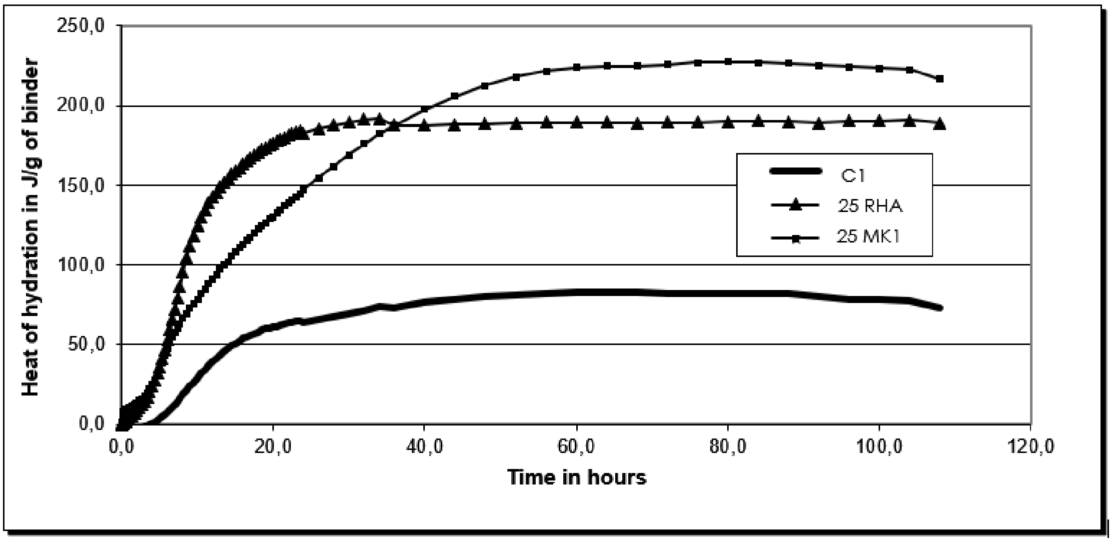


Figure 9: Hydratation heat of C1 + 25 mixtures RHA/25MK1 mixture

The compressive strength are given by the Table 8.

Table 8: Compressive strength of the studied compositions

N°	COMPOSITION	COMPRESSIVE STRENGTH [MPa]				Flow[s]	Sagging[mm]
		2 days	7 days	28 days	90 days		
1	C1	28.4	44.4	56.2	68.7	6	18
2	C1 + 25 rha	23.7	44.5	65.0	71.7	8	4
3	C1 + 25 mk1	20.3	41.1	64.8	74.4	6	13
4	C1 + 25 mk2	18.6	37.1	59.3	71.6	8	12

5	C1 +7,5 rha + 17,5 mk1	21,4	46.1	67.6	74.8	6	12
6	C1 +7,5 rha + 17,5 mk2	22.1	43.2	64.3	73.6	8	10
7	C2	7.9	16.6	26.8	35.7	6	18
8	C2 + 25 rha	6.1	15.5	30.9	41.6	26	3
9	C2 + 25 mk1	6.4	16.7	30	41.4	21	0
10	C2 +7,5 rha + 17,5 mk1	6.3	16.2	30.7	39.6	12	7

The evolution of the resistance of these compositions is given by the Figure 10 and 11.

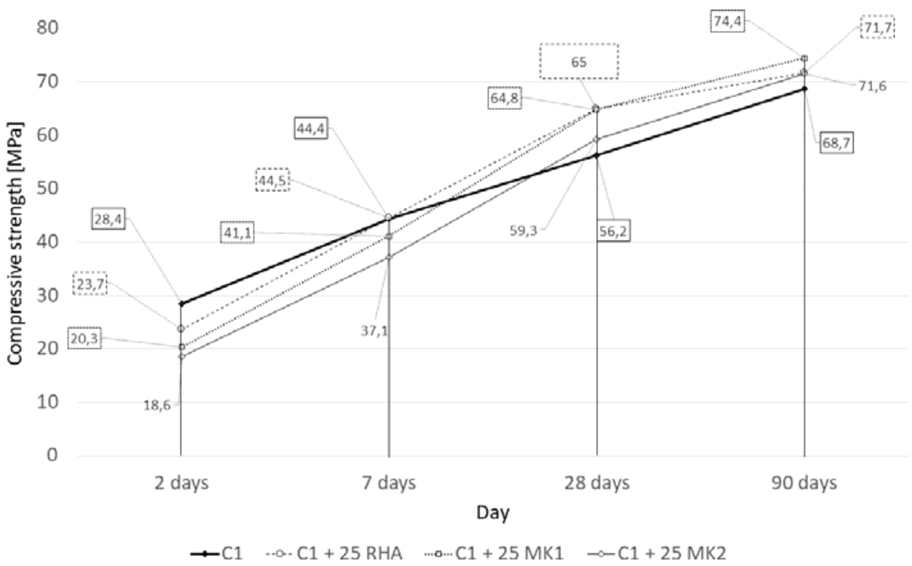


Figure 10: Compressive strength of compositions studied with C1 cement

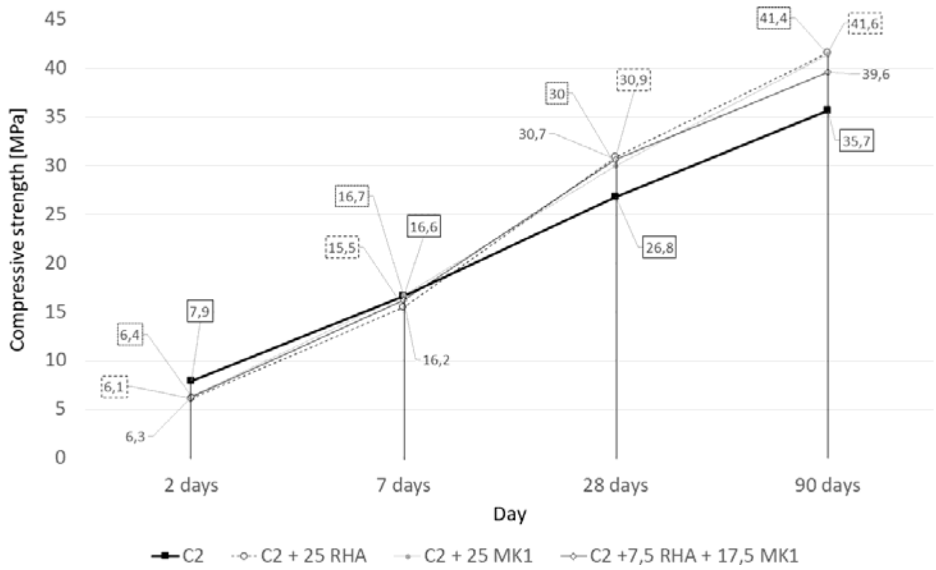


Figure 11: Compressive strength of compositions studied with C2 cement

- Endogenous retraction and desiccation of components

Figure 12 show the shrinkage measurements of the endogenous desiccation and retraction.

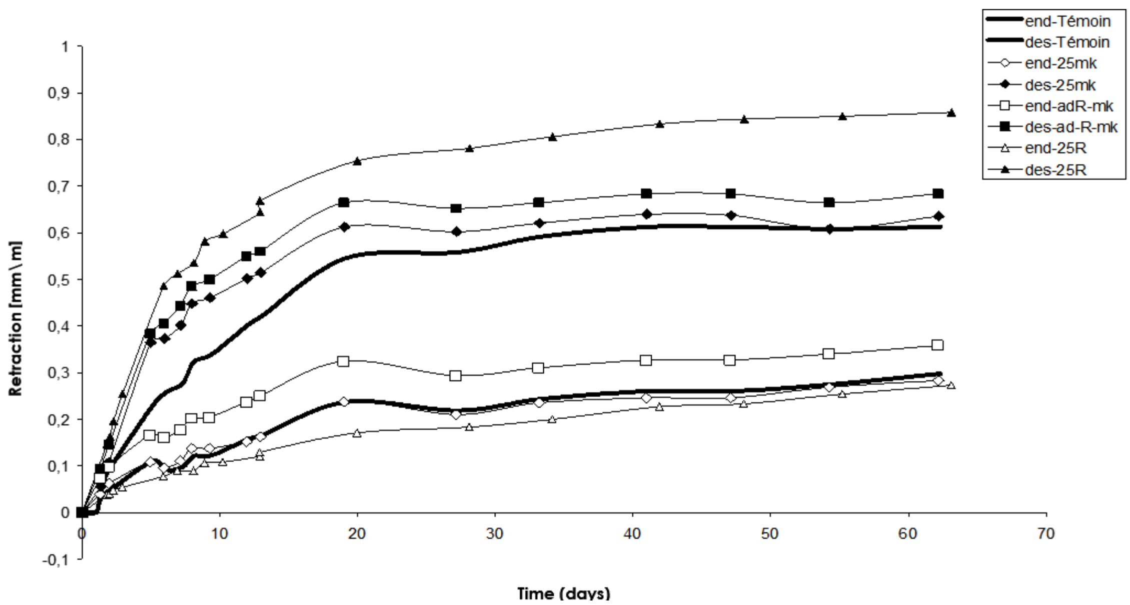


Figure 12: Endogenous retraction and desiccation of components

8.3. Results and discussion

The chemical and mineralogical analyses conducted in this study shows that:

- RHA is rich in silica (more than 85% by mass) and contains a significant amount of alkaline K2O (2.01%). RHA has a high silica content compared to MK. The curves in Figure 10 show that the RHA is essentially composed of a siliceous hump and a little more quartz (impurities) related to the recovery mode;
- MK has a higher alumina content and contains quartz and illite. The other elements that make it up are most often oxides of iron, titanium, potassium, sodium, etc.;

- C1 and C2 cements have the classic peaks of anhydrous constituents (presence of C3S, C2S, C3A and C4AF). C1 also contains some quartz (Q) and traces of calcite (Ca);
- It is well demonstrated, compared to the NF P 18-513/2010 standard, that the MK mainly contain silicon oxide and aluminium oxide;
- The iron oxide content of MK is slightly higher compared to RHA and the loss on fire. The fire loss of the RHA is associated with the presence of some unburned residues of the plant material, and
- Fire loss of C2 cement reveals the presence of limestone.

Concerning the physical analyses, it can be concluded that:

- The ATD/ATG analysis in figure 6 shows that there is no significant mass loss for MK, which is expected because it is already a calcined product. In addition, the exothermic reaction of the two MK occurs at the same temperature (just under 1000° C), i.e. there is a

  reorganization of the MK, particularly its transformation into mullite;
- although processed under the same grinding conditions, the three addition materials do not have the same grain size and it is MK2 that has a fine grain size according to Figure 3 where d(0.5)MK2 = 38.2 μm and MK1 has the highest density according to Table 5, where MK1=

  2.6 g/cm^3. It should be noted that the density of MKs reported in the literature is in the

  order of 2.5 g/cm^3 [36]. These values may vary depending on the mineralogical composition of the parent rock and the MK manufacturing process. This is proven because the two MKs

  have different densities;
- without addition, C1 and C2 cements have a higher density and porosity accessible to the lowest water level for cements without addition according to Table 7, and
- the addition of addition materials increases the heat of hydration but slightly less for the RHA according to Figure 8 and Figure 9.

The mechanical analysis (Table 8) revealed that:

- cements alone, without addition, have a high resistance at a young age (i.e. 2 day). From the 28th day, their resistance becomes the lowest compared to the compositions studied;
- the addition of 25% MK is not significant at an early age (2nd and 7th days), but is significant from day 28 onwards compared to the control cement;
- the addition of 25% RHA is particularly significant for C2 cement from day 28.Resistance at an early age (2nd2nd and 7th days) is very low, and
- the combined addition of 7.5% RHA with 17.5% mK1 significantly increases the strength of the mortar from day 7. It is the composition that shows the most significant improvements in terms of compressive strength.

Thus, it can be conducted that:

- the RHA contributes to making the binder lighter and less porous (see Table 6);
- the addition of RHA and MK helps to slow the flow of the mortar paste. The subsidence values clearly show the difficulty of working with cements with the addition of MK and especially RHA;
- with C2, a mass decrease of 4% for 25% of RHA addition was noticed against 2% with the addition of 25% MK;
- at 28 days, with the composition 7.5% RHA + 17.5% MK, compressive strength compared to other

compositions is the highest, which is proven at 90 days. MK1 appears to be a good additive, and

- The addition of 25% MK1 is beneficial because the loss of mass is not significant. However, the total withdrawal is a little more pronounced compared to the witness.

From Table 7, Figure 10 and Figure 11, the evolution of the compressive strength of the com- positions studied at 7, 28 and 90 days compared to the 2^{nd} day can be determined (see Table 6).

Table 9: Evolution of the compressive strength of the studied compositions compared to the 2^{nd} day

		INCREASE		
N°	**COMPOSITION**	**Between 2^{nd} and 7^{th} day**	**Between 2^{nd} and 28^{th} day**	**Betwe 2^{nd} and 90^{th} day**
1	C1	36%	49%	59%
2	C1 + 25 rha	47%	64%	67%
3	C1 + 25 mk1	49%	66%	70%
4	C1 + 25 mk2	54%	68%	71%
5	C1 +7,5 rha + 17,5 mk1	51%	69%	73%
6	C1 +7,5 rha + 17,5 mk2	50%	69%	74%
7	C2	52%	71%	78%
8	C2 + 25 rha	62%	79%	85%
9	C2 + 25 mk1	61%	79%	84%
10	C2 +7,5 rha + 17,5 mk1	61%	80%	85%

Thus, for C1 cement, the evolution of compressive strength is only 59% at day 90, whereas with the combined addition of 7.5% rha and 17.5% mk1, the increase can reach up to 78%.

IX. CONCLUSIONS

Madagascar island is a developing country with a very low GDP. Incomes in this country do not allow the population to easily acquire housing due to the high cost of building materials, especially cement. In this paper, an additive based on Rice Husks Ash (i.e. RHA) is proposed to replace part of the cement. The choice of this particular agricultural waste is because the Malagasy population produces and consumes large volumes of rice and that the waste produced from these rices bark is very little exploited on the island.

In this paper, data on RHA valorisation in the Madagascar building construction is presented. Results obtained show that additions of R.H.A and/or M.K in the composition of concrete and mortars will significantly reduce the cost of cement and subsequently improve the quality of the finished product. The addition of RHA and/or MK contributes to the reduction of the heat of hydration and has no effect on setting times. There is no risk of early and late expansion due to the hydration of free calcium and/or magnesium oxides (swelling of the Chˆatelier). The only disadvantage is the water demand in implementation.

The major advantages of adding RHA in combination with MK are:

- Allows in most cases to obtain resistances equivalent to a CEM I, from 7 days (Table 7);
- mechanical (see Figure 12): limited shrinkage, less cracking;
- physical: lower porosity (see Table 8) so resistance to freeze-thaw cycles increased, and
- the addition of RHA and MK helps to reduce the quantity of cement.

The bale, which constitutes nearly 4% of the weight of the grains, is not yet industrially val- orized. However, researchers have proven that rice husks are not very absorbent and rich in silica, which makes them relatively resistant to moisture and allows them to have breathable walls. It is inedible for rodents and insects. The small air space created by the fineness of the RHA grains gives it a retarding effect in the event of a fire.

The rice husk represents excellent potential for sustainable development of the construction sector through the use of a more ecological concrete. In addition to the environmental interests, this new sector offers the Malagasy territory an opportunity for development on economic and social aspects. A life cycle sustainability assessment is currently being carried out for the development of this sector in Madagascar. A first evaluation of the economic impact has highlighted a decrease in the overall cost. The cost drops from $92 to $75 per m^3 of concrete. Further investigations will accurately assess the economic impact of this rice husk based concrete in the building sector.

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