*__Original Research Article__*

# MEASUREMENT OF THE THERMAL CONDUCTIVITIES OF CLAY MATERIALS STABILIZED BY A MIXED BINDER

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## ABSTRACT

This research work concerns the physical characterizations and the measurement of the thermal conductivities of clay materials stabilized by a mixed binder. At first, the different physical characterizations are carried out for the classification of the study material. Then, cylindrical specimens 7 cm in diameter by 7 cm in height are made with clay alone, specimens stabilized with 5% gum arabic, specimens stabilized with 5% cement, and also specimens stabilized with 5% cement and 5% gum arabic and finally specimens stabilized with the various binders mentioned above and reinforced with rice straw at a rate of 1%. The results of the thermal conductivity measurements vary from 0.6 to 0.9 W/m k.



*Keywords: clay material, stabilization, reinforcement, cement, gum arabic, rice straw.*




## 1. INTRODUCTION

The rise in temperature in homes has become a major concern for builders. For the search for comfort, the occupants are obliged to use electrical appliances, such as the ceiling fan. These electrical means consume enough energy and also cause diseases [1]. In Sahelian countries like Chad, electricity is extremely expensive and the temperature is very high, it can reach up to 40°C between March and June [2]. Most of the constructions in Chad are made from cement brick, concrete or fired bricks. These materials have very high thermal conductivity values [3] [2]. For the search of comfort, we offer local materials, economical and without environmental problems. It is stabilized clay with a low rate of gum arabic and/or cement and reinforced with rice straw at a rate of 1%. During the manufacture of the specimens, we opted for a compaction pressure of (20 ± 3) MPa. In previous research work, measurements of the thermal conductivities of materials stabilized by gum arabic and also by cement are carried out [1, 3][1;4]. We propose for this research work a new construction material based on clay, stabilized by a mixed binder (gum arabic and cement) and make measurements of thermal conductivities on cylindrical samples. The method used is hot wire. It is set up in the LERMAB Laboratory at the University of Nancy in France, the details are given in the publication by Jean LOUIS TANGUIER of January 2021 [4][5].

## 2. MATERIAL AND METHODS

In this work we carried out the thermal characterization of construction materials such as cement and clay mixed with biosourced additives such as gum arabic and rice straw.

The device used to determine the thermal parameters is that of the hot wire manufactured at LERMAB.

## 2.1 Study materials


**Fig. 1. (a-Clay; b-CPJ 42.5R cement; c- gum arabic; d- rice straw)**

### 2.1.1 Clay

Physical tests are carried out on the clay for its identification, namely the particle size by sieving and by sedimentometry, the Atterberg limit (the liquid liquid and the limit of plasticity), the density of the solid particles by the method of water pycnometer by referring to the standards respectively [6, 7, 8, 9]. These results made it possible to classify the clay as being “little plastic”.

### 2.1.2. gum arabic

Most of the gum arabic harvest comes from Sub-Saharan Africa (Egypt, Maghreb, Mali, Senegal, Sudan, Chad, etc.). It is marketed in the form of crystals or powder. Gum arabic is pale yellow to brownish yellow in color [10]. Thanks to its physico-chemical properties, gum arabic is used in several fields, namely in the food, pharmaceutical, cosmetics industries, etc. Gum arabic can be used as a binder thanks to its essential physical properties [11]. The use of gum arabic instead of mineral binders (cement and lime) respects the approach of sustainable development, it is a healthy product vis-à-vis the environment and renewable. Chemical tests have revealed the presence of sugar in the chemical constituents of gum arabic, which negatively influences the setting and hardening of materials stabilized by gum arabic [4].

The gum arabic used in this research work is of friable type coming from the “Sayal” tree, see figure 1c. All the characteristics are given in the work of (Abakar ALI et al, 2017) [12].

### 2.1.3. Rice straw

Rice cultivation is well developed in Chad. It is mainly practiced in the Sudanian zone because of its requirement in terms of rainfall, and to a lesser extent in the Sahelian zone. The residue resulting from this culture is valued as energy, it is also used as food for animals and also for the construction of dwellings in the countryside. In this research work, rice straw is used as a reinforcement in the earth material to improve its mechanical and thermal characteristics. Physical and chemical tests are carried out on rice straw during the thesis work of [4]. This is the real and apparent density, absorption test and determination of its chemical constituents (lignin, cellulose, hemicellulose, ash and extractables). The results showed that rice straw has a very low density, it is around 460 kg/m3 [13]. Results obtained by Sun and Cheng (Y.Sun and Cheng 2002) on wood are close to the results given by rice straw [14]. An absorption test carried out shows that the rice straw has a too high absorption rate, that is to say at 5 minutes, the absorption of rice straw reaches approximately 200%. Tai Thu (T. Thu NGUYEN, 2010) [15] carried out an absorption test on hemp particles. It obtains results after 48 hours of immersion in water close to the results obtained on rice straw. For its use as a construction material, it must first be immersed in water until saturation before use. Otherwise, it absorbs all the mixing water and the material will be difficult to use. For our research work, we considered a rate of 1% rice straw and a size of 2 cm.

#### 2.1.3. Cement

The cement used in this research work is of the Portland Composite type, class 42.5R, manufactured in Cameroon (figure 1b). Currently, this cement is classified as the best hydraulic binder for its use in the construction of infrastructure in Chad. In addition, this material releases a huge amount of CO2 into the environment and consumes a high rate of energy during its manufacture [16]. For our research work, we use a rate of 5% to correct the problem of setting and hardening produced by gum arabic.

## 2.2 MEASUREMENT OF THERMAL CONDUCTIVITY

### 2.2.1 Preparation of specimens

The samples made for this purpose are made using clay, Portland cement compound (CPJ 42.5 R), gum arabic from Chad and rice straw also from Chad. Several formulations are prepared using a mass proportion of clay of 95 to 89%. Arabic gum and cement have a rate of 5% each and 1% rice straw. The different formulations are summarized in Table 1.

**Table 1. The different formulations for thermal conductivity measurements**

| | Nombre | Teneur en eau % |
|---|---|---|
| 100%A | 3 | 18 |
| 95%A+5%GA | 3 | 16 |
| 95%A+5%C | 3 | 18 |
| 99%A+1%P | 3 | 14 |
| 90%A+5%GA+5%C | 3 | 16 |
| 94%A+5%GA+1%P | 3 | 12 |
| 94%A+5%C+1P% | 3 | 14 |
| 89%A+5%GA+5%C+1%P | 3 | 14 |

A: clay; GA: gum arabic; C: cement; P: straw

The preparation of the test specimens followed the following procedure: The clay, the cement and/or the gum arabic are mixed dry, on the other hand for the rice straw, the procedure described in the thesis work of (Abakar ALI et al, 2017) [12] was followed, which consists of soaking the straw in water until saturation before putting in the mixture. Once the mixture is primed, water is added for sample making. The amount of mixing water is determined based on the so-called Proctor Normal method [17]. Once moistened, the material is placed in a plastic bag for about 2 hours for good impregnation. Subsequently, the homogenized and humidified mixture is placed in a cylindrical mold 7 cm in diameter by

7 cm in height, then a copper tube 10/12 mm in diameter is placed in the center of the mold. This copper tube receives the heating cartridge to diffuse the heat in the specimen. A pressure of (20±3) bars was exerted to obtain very compact samples, see figure 2. These were placed on the experimental bench for the determination of the measurement of the thermal conductivity after the stabilization of the temperatures (phase stationary temperature curves), see Figure 3. The experimental device is the same as that used in the research work of Jean LOUIS TANGUIER [5]. The difference lies in the dimensions of the specimens. Jean LOUIS TANGUIER used cylindrical specimens 16 cm in diameter by 32 cm in height.


**Fig. 2. (a-mold and accessories, b-press for manufacturing specimens; c - manufactured specimen).**

**<u>2.2.2 The drying kinetics</u>**

The different specimens are spread out in the open air until their masses have stabilized. We note that the “100%A” and “95%A+5%C” formulations have stabilized from the 4th day of drying. On the other hand, for the formulations which contain gum arabic, the drying was prolonged until the 7th day, this is the case of: ("95% + 5% GA and 90% A + 5% GA + 5% VS "). It is noted that the addition of cement at a rate of 5%, in the mixture containing gum arabic does not modify the drying time, see figure 3. It could be that the cement improves the water resistance of the material.

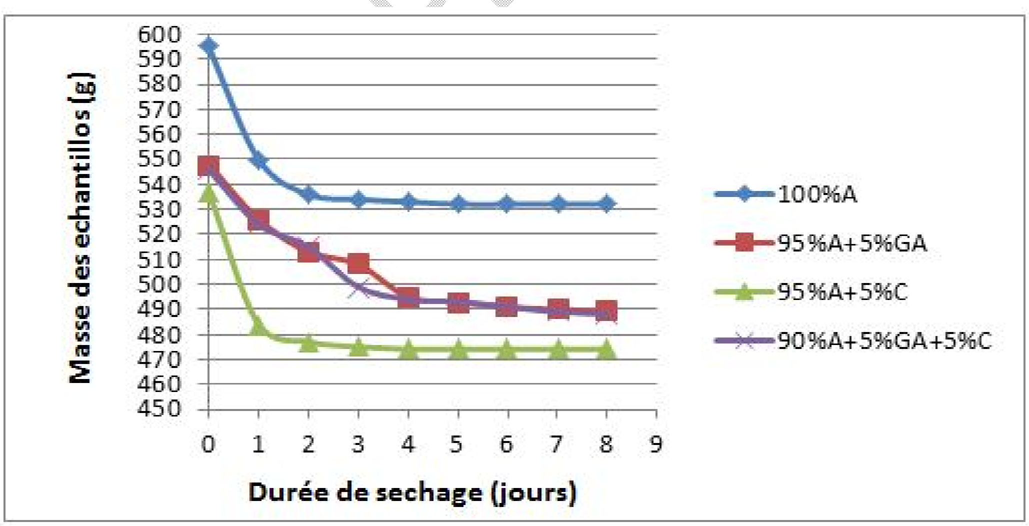


**Fig. 3. Sample drying curve**

**<u>2.2.3 Dispositif expérimental</u>**

*Experimental apparatus*

*The principle of the method for measuring the thermal conductivity of materials in cylindrical geometry is tested at LERMAB, in France and shown schematically in Figure 4. It illustrates the experimental device and indicates the positions of the various thermocouples. It consists*

*- A special ACIM JOUANIM stainless steel heating cartridge with 50 W power and 8 mm in diameter;*

*- A 10/12 copper tube*

*- Type K thermocouples, jacketed 0.5 mm in diameter with insulated hot junction. Data acquisition (temperatures) is done using an ALMEMO 2290-8 acquisition unit which has been calibrated beforehand.*

*- The voltage and the current are measured by a BBC M 2042 precision multimeter. The voltage is adjusted by a "Variac" type variable resistor.*

*For the determination of the thermal conductivity of our samples, the quantities such as the geometry of the samples, the variations of the temperatures and the flow of heat are taken into account, according to the equation:*

$$\lambda = \frac{\varphi \ln\left(\frac{r2}{r1}\right)}{2\pi L(T1 - T2)}$$

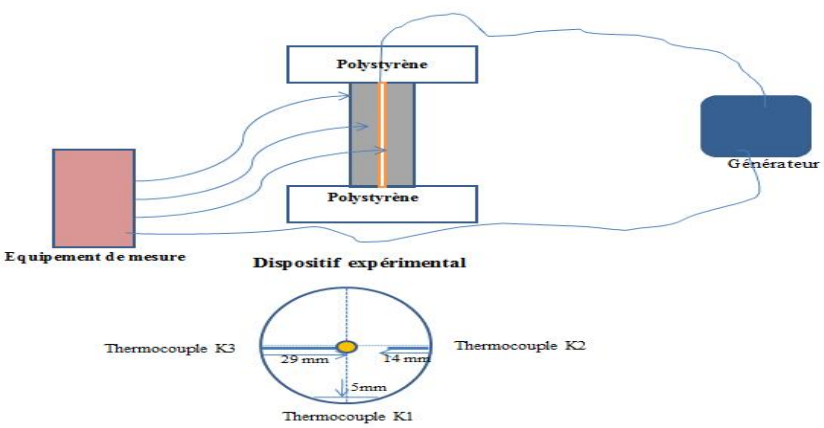


**Fig. 4. Experimental device for measuring thermal conductivity**

## 3. RESULTS AND DISCUSSION

Once the sample has been placed in the apparatus, the various temperature values are recorded to plot the curves of the variable phase and that of the stationary phase.
Figure 5 gives the different curves.

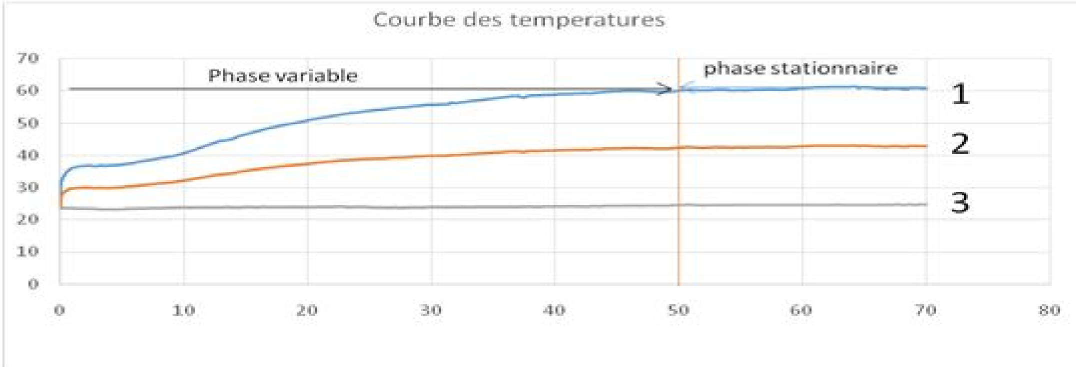


**Fig. 5. temperature curve**

The results, namely the measurements of the thermal conductivities and the densities, are presented respectively in figures 6 and 7.

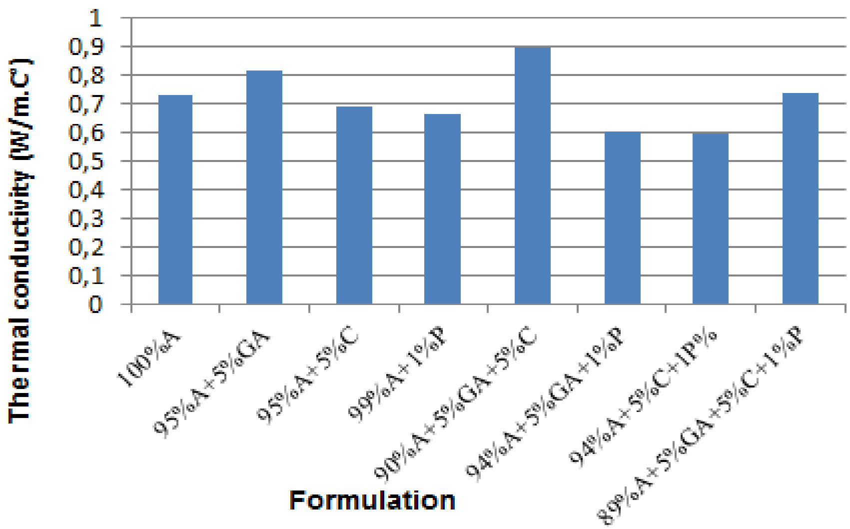


**Fig. 6: the results of the thermal conductivities according to the formulations**

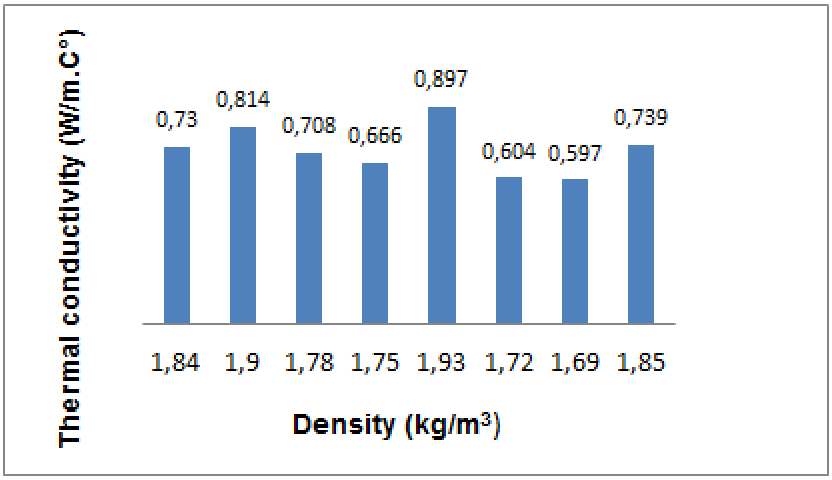


**Fig. 7: values of the thermal conductivities obtained as a function of the density**

Different formulations are prepared for the measurement of their thermal conductivities. The results are presented in figures 6 and 7. The values of the thermal conductivities vary from 0.6 W/m.K to 0.9W/m.K . The 90%A+5%GA+5%C formulation which gives the highest value of thermal conductivity. This formulation also gives the highest density. The increase in conductivity can be explained by the fact that the presence of cement can improve the bond between the different constituents of the specimen [1]. In addition, gum arabic helps retain moisture for a certain period of time. This will allow the cement to continue to hydrate. Thus, (CSH and portlandite) are formed to strengthen the bonds between grains and reduce porosity. Therefore, the internal structure becomes homogeneous and tight. This makes it possible to give high values of thermal conductivity [1].

The values of the thermal conductivities obtained with the samples stabilized by cement or by gum arabic are in the same orders of magnitude as the results obtained respectively by (Moro Olivier BOFFOUE et al) [1] and (Abakar ALI et al, 2018) [4]. Indeed, the presence of cement in the mixture gives a more compact and dense finished product. The phenomenon that increases the density is largely explained in the previous paragraph. The gum arabic in the mixture behaves like a glue that coats the grains and sticks them together to form a dense block [12]. This explains the increase in the value of thermal conductivity.

The stabilized or unstabilized samples reinforced with rice straw give low values compared to the other formulations. See the results which are summarized in Figure 6.

Furthermore, the presence of flakes in the mixture reveals the density of the samples. This can be explained by the density of the raw material. In general, straw has a very low density compared to granular materials such as clay and sand which have respectively 2450 kg.m-3 and 2700 kg.m-3 [4].

For materials reinforced with date palm fibers, the thermal conductivity decreased. This reduction is visible by the fact that plant fibers generally have a very low thermal conductivity. It is around (0.08 W.m-1. K-1) [18] for date palm fibres. In addition, the presence of fibers in the composite increases the porosity, which reduces its density and also the value of its thermal conductivity. (Aouadja et al) [19] found the same behavior on fiber-reinforced concrete.

The thermal conductivity results obtained in this research work are proportional to their density. The higher the density, the value of the conductivity increases (see figure 6). The work of (Al Rim et al) [20] on composites of a mixture of clay and Portland cement also confirmed that the higher the density, the value of the thermal conductivity increases.

## 4. CONCLUSION

This research work has highlighted the advantage of local materials in construction. They are economical and have a low environmental impact. A new formulation consisting of clay, cement and gum arabic is invented for the measurement of its thermal conductivity. The combination of two binders such as cement and gum arabic, mixed with clay gives a dense sample. The addition of cement in the mixture did not reduce the drying time, but on the other hand, it could improve the water durability and the mechanical resistance. The conductivity measurement results showed that this material is not insulating. However, its thermal inertia will help improve comfort in the home. This method is implemented for the first time in the LERMAB Laboratory, at the University of Lorraine to experiment with thermal conductivity measurements on building materials. This new device solves some problems stated on the other methods. These are axial and radial heat leakage and “edge effects”. It is very interesting insofar as the atmospheric conditions are mastered.



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