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Study of The Influence of Storage Media on the Thermo-mechanical Behavior of Concrete and Cement Blocks

Benjamin Kiema [a*], Ousmane Coulibaly [a] and Emmanuel Ouedraogo [b,c]

[a] Laboratory of Environmental Physics and Chemistry (LPCE), Department of Physics, Joseph KI- ZERBO University, 03 BP 7021 Ouagadougou, Burkina Faso.
[b] Laboratory of Thermal and Renewable Energies, Joseph KI-ZERBO University, 03 BP 7021 Ouagadougou, Burkina Faso.
[c] Department of Physics and Chemistry, University of Ouahigouya, 01 BP 346 Ouahigouya 01, Burkina Faso.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Once all construction materials have been formulated, it is necessary to find a suitable environment in which to store them before using them in the building. Generally speaking, in developing countries, materials are not preserved under the real conditions of temperature and humidity and are exposed to often severe climatic conditions. This has an impact on the behaviour of these materials. With this in mind, we conducted our study on concrete and cement bricks, the two materials most commonly used in building construction in Africa. The overall objective of our study

**Corresponding author: E-mail: benjaminkiema03@gmail.com;*

is to analyse the effect of storage environments, particularly ambient conditions of temperature and hygrometry, on the thermal and mechanical properties of concrete and cement bricks in a dry tropical climate. To achieve this objective, we first analysed the quality of the materials used to formulate the concrete and cinder block samples. Next, we chose a formulation method that would enable us to obtain the optimum proportions of aggregates. Finally, the thermal and mechanical parameters were measured using the KD2-Pro device and a mechanical press, respectively. The concrete and cinder block samples were stored for 28 days and 10 days respectively in the open air under ambient climatic conditions (35°C on average),in a water tank (29°C on average) and in a climatic chamber (20°C and 53% relative humidity). Results ranged from 1.126 (± 0.003) to 1.289 (± 0.023) $W.m^{-1}.\ K^{-1}$ for thermal conductivity. Mechanical test results ranged from 3.93 (±0.45) to 4.13 (±0.27) MPa for flexural strength and 16.42 (±0.17) to 17.95 (±0.21) MPa for compressive strength. The lowest thermal conductivity was obtained in the climatic chamber, with a value of 1.126(±0.0032)$W.m^{-1}.K^{-1}$.The best compressive strength of concrete and the best flexural strength of cement blocks were obtained for samples stored in the climatic chamber. For the best mechanical and thermal behaviour of these two materials, we recommend a temperature not exceeding 20°C as the storage environment in a dry tropical climate.

Keywords: Concrete; cement blocks; mechanical resistance; thermal properties.

1. INTRODUCTION

Burkina Faso has a hot, dry tropical climate. thermal amplitudes are subject to strong seasonal variations [1]. These variations tend to increase with climate change. conventional materials such as concrete and cement bricks are more resistant to these climatic variations. in the quest for thermal comfort in the home, these two materials are the least suitable compared with eco-materials, because their thermal properties are no better than those of eco-materials [2,3]. but in terms of mechanical strength, they remain enviable. These materials are heterogeneous, consisting essentially of a hydrated cement paste reinforced with aggregates. This paste is capable of changing its structure and properties under the effect of curing and storage conditions. In dry tropical climates, these materials are often subjected, from an early age, to very high temperatures accompanied by intense evaporation, which causes an early departure of the mixing water. This slows down or completely stops the hydration reaction of the cement and influences the quality of the hydrates formed [4]. This is why they must be cured before being stored in environments complying with standard norms [5]. In reality, when materials are not stored in accordance with conservation standards that reflect the actual climatic conditions in our countries, these conditions can influence their thermo-mechanical properties [6]. These properties change with age and are sensitive to ambient temperature and humidity conditions [7]. In order to determine the degree of influence of the storage environment on the materials, we first carried out a granulometric study on the aggregates.

The Dreux-Gorisse method was used for the formulation. Finally, the thermo-mechanical parameters were measured respectively with the kd2-pro apparatus and a mechanical press. This enabled a comparison to be made between the mechanical and thermal strengths of concrete and breezeblock formulated and stored in three different environments.

2. MATERIALS AND METHODS

In this part of the work, we specify the various tools used, as well as the procedure for formulating and carrying out the tests.

2.1 Nature and Origin of Materials used for Sample Formulation

2.1.1 Aggregates

In this study, we used a mixture of two common classes of gravel: class 5/15

crushed gravel and class 15/25 crushed gravel. This mixture of two classes enabled.

2.1.2 Mixing water

Us to improve. Workability and avoid concrete segregation. We opted for class 0/4 sand, given its quality and technical performance. These aggregates come from the SOGEA SATOM base located on the Donsin airport site (Ouagadougou).

2.1.3 The binder

Cement is the binder used. We used CEM II 42.5 R "ELEPHANT" cement produced by CIMFASO. It is manufactured in compliance with Burkinabe standard NBF 02-013:2009. This choice was made in view of its availability on the Burkinabe market and its technical performance.

The mixing water we used was tap water, from Burkina Faso National Water and Sanitation Office (ONEA)

2.2 Sample Composition

2.2.1 Concrete samples

The method chosen for determining concrete composition is that of Dreux-Gorisse [8].

- ✓ A sag test is equal to 5.4cm; W/C(Water/Cement) =0.6;
- ✓ G/S(gravel/Sand) =1.93;
- ✓ SE (sand equivalent) =70.30.

The material dosages obtained for 1m^3 of concrete are shown in Table1.

2.2.2 Cement block samples

The cement block samples were formulated in accordance with standard [9]. W/C=0.5; SE= 70.30.Dosages for 1m^3 of cement block are shown in Table 2.

2.3 Specimen Preparation

Two types of specimens are used in this work (Fig. 1):

- ✓ Cylindrical specimens (16x32) cm^2 for compression testing.
- ✓ Prismatic specimens (4x4x16) cm^3 for bending tests.

Specimens are prepared in the laboratory at a temperature of between 25 and 33°C.They are kept in this environment for 24 hours until demolded. They are then stored in the desired environment for up to 28 days for concrete and 10 days for cinder blocks. The resistance and thermal conductivity values of the samples are the average of three tests.

2.4 Sample Curing

In dry ,hot climates, the difference in moisture content between the materials and the surrounding environment means that the latter is always out of equilibrium.

To avoid this situation, materials are cured immediately after demolding. Curing ensures that the materials maintain a favorable temperature and sufficient humidity in the space occupied by water in the cement paste. Many different methods can be used for this treatment. In our case, we proceeded by spraying the materials. The recommended curing time depends on the type of curing, the characteristics of the materials and the conservation environment. Several normative documents [2] give minimum durations depending on storage conditions and cement type. Numerous studies [10,11,12] insist on curing for at least the first seven days. Neville [13] suggests the same duration for CPO cements (Ordinary Portland Cement**)**. For slow-hardening cements, he recommends a long cure. We cured our materials for three (03) day.

2.5 Storage Conditions

Three environments were adopted. In environments and III, we used a temperature and relative humidity (RH) sensor for data acquisition.

- ✓ Environment I: Open air under actual climatic conditions. Temperature (T) between 33 and 42°C and relative humidity (RH) below 30% (RH< 30%).
- ✓ Environment II: In a water tank. We have: T=29±1.45°C and RH =100%.
- ✓ Environment III: In a climatic chamber. T= 20 ± 1 °C [14] and RH = 45± 2.25%.

2.6 Experimental Set -Ups

2.6.1 Thermal parameters

Thermal parameters were measured using the KD2-Pro device (Fig. 3).

Table 1. Concrete dosages by weight per 1m3 using the Dreux-Gorisse method

Constituents	Sand 0/4 (kg)	Gravel 5/15 (kg)	Gravel 15/25 (kg)	Cement (CEMII 42.5R) (kg)	Water (L)
Quantity	48	37.5	55.5	30	20

Table 2. Dosages by weight per 1m3 of cement blocks

Constituents	Sand 0/4 (kg)	Cement (CEM II42.5R) (kg)	Water (L)
Quantity	32	18	10

Fig. 1. Filling the specimens cylindrical

Fig. 2. Filling the specimens prismatic

Fig. 3. Measurement of thermal properties with KD2-Pro

This device uses the model for solving the heat transfer equation by the transient linear heat source propagation method in a semi-infinite medium, an equation published in IEEI standards [15].The measured quantities are:

- Thermal conductivity λ, which represents the material's ability to transmit heat under the effect of a temperature gradient;
- Thermal diffusivity α ,which characterizes the speed at which heat propagates by conduction in a body. It is given by equation 1

$$\alpha = \frac{\lambda}{\rho c} \tag{1}$$

C: amount of heat required to raise the temperature of the unit mass of the material by one (1) degree Celsius (1°C).

ρ: density of the material.

2.6.2 Mechanical parameters

The devices used to evaluate the mechanical parameters are shown in Fig. 4 and 5:

Fig. 4 shows a Class 1 manual concrete press with a capacity of 2000 kN and two pressure gauges. It is suitable for 16×32 cm^2 cylindrical specimens. The vertical distance between the 2 platens is 336 mm, and the diameter of the platens is 216mm.This device operates in accordance with the following standards:NFP18-411/EN772-1/ASTMC39/ BS1610,6073.

Fig. 5 shows an automatic bending testing machine with a capacity of 200 kN. It is suitable for reliable and consistent bending tests on standard concrete beams, 4x4x16cm^3 specimens. The device is designed and operated in compliance with the following standards: EN12390-5,EN 12390- 6,EN 1338,EN 1340,BS 1881, ASTM C78, C293 and C496.

We determined mechanical parameters such as compressive strength Rc (MPa)for concrete samples and flexural strength Rf (MPa) for cinder block samples according to NF EN 772-1 [16] by equations (2) and (3).

$$R_c = \frac{F}{S} \tag{2}$$

F : breaking force in kN.

S: surface area of 16 x 32 cm^2 test piece.

$$R_f = \frac{3FL^{'}}{2le^2} \tag{3}$$

F (N): breaking force
l (mm): material width
e(mm) : material thickness
L'(mm): length between two supports of the specimen

Fig. 4. Compression test

Fig. 5. Three-point bending test

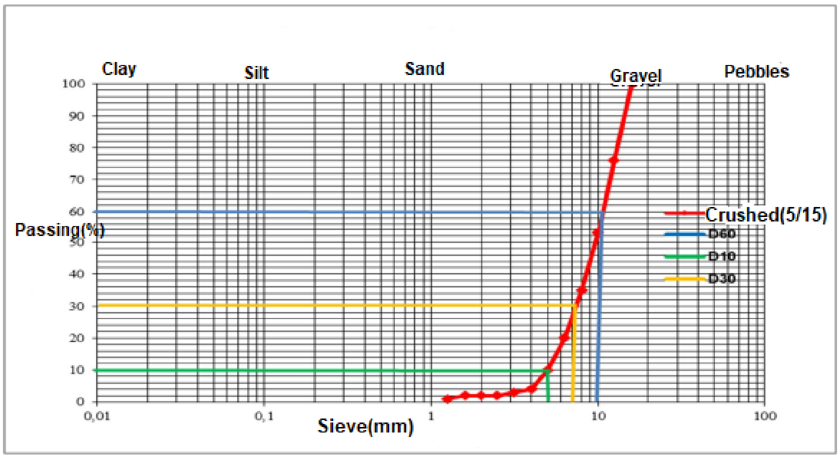

Fig. 6. Grading curve for 5/15 gravel

3. RESULTS AND DISCUSSION

The average numerical values obtained from the various tests are summarized below. An interpretation of the various results is also given below [15,16].

3.1 Material Particle Size Distribution

3.1.1 Gravel

The grading curves for 5/15 and 15/25 gravel are shown in Fig. 6 and 7 respectively. The Los Angeles Test gives a value of 30.2. this result is consistent with [17].

It can be seen that for this gravel the sieve openings are between 1 and 20 mm. the first point on the curve corresponds to the sieve with a mesh opening greater than 0.5 mm. the aggregate analysed is therefore of class d/d (minimum grain diameter/maximum grain diameter). the last point of the curve corresponds to 100% passing. this confirms that the aggregate analysed is class 5/15.

We can see that for this gravel the sieve opening is greater than 5 mm. The first point of the curve corresponds to the sieve with a mesh opening greater than 0.5 mm. In this case, the analysed aggregate is of class d/D (minimum diameter grain diameter). The last point of curve corresponds to 100% passing. This confirms that the analysed aggregate is Class 15/25.

3.1.2 Sand

The grading curve for the sand we used to formulate our materials is shown in Fig. 8.

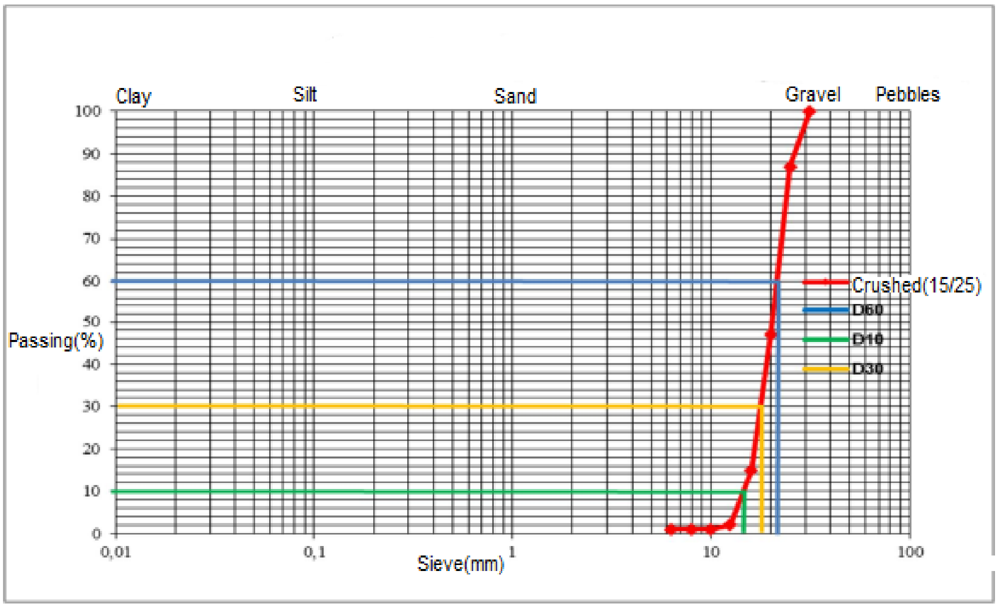

Fig. 7. Grading curve for 15/25 gravel

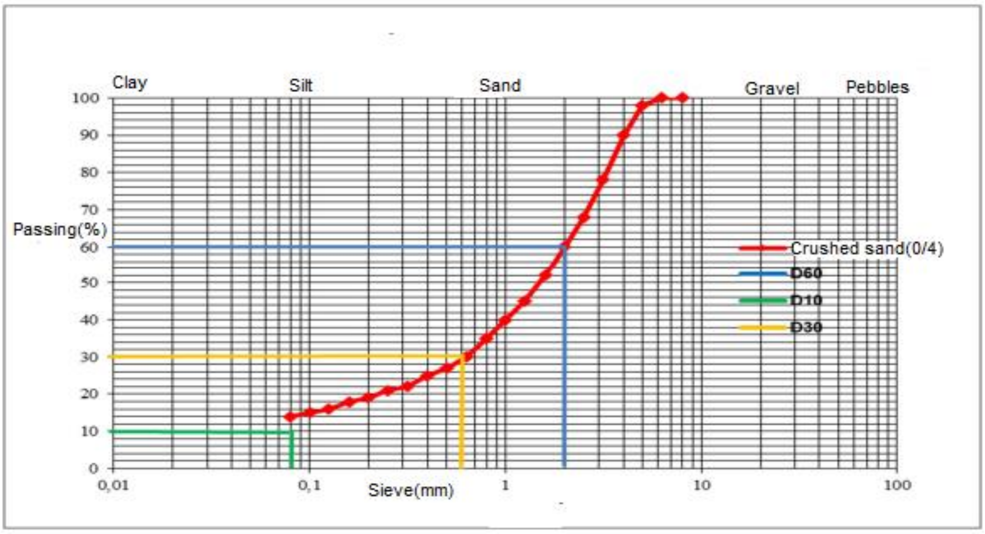

Fig. 8. Grading curve for 0/4 sand

On the curve, the first point corresponds to the sieve with a mesh opening of 0.08 mm in diameter, with a percentage of passers of around 14%. This first point shows that the minimum grain diameter (d) is less than 0.5 mm. The material analysed is therefore class 0/d (maximum grain diameter). The last point on the curve corresponds to the mesh sieve with a diameter d of around 0.9 mm, with 100% passing. this confirms the 0/4granular class of the sand. In addition, we determined the fineness modulus (FM) of the sand found FM=3.19. So, this is a coarse sand that will yield materials of good strength.

3.2 Thermal Properties of Materials

Figs. 9 and 10 show the thermal conductivity and thermal diffusivity of cement blocks as a function of the storage media.

For cement bricks exposed to the open air at room temperature, the thermal conductivity is of the order of 1.23 w/m.k (±0.028) which is close to that of A. chikhi et al. [18]. when the cinder blocks are stored in a water tank, the thermal conductivity increases by 4.88%. This increase can be explained by the presence of water, which activates the hydration of the mineral binder (cement) and eliminates pores or reduces the size of existing pores. This necessarily influences the thermal conductivity of the material. On the other hand, when the materials are kept in a climatic chamber (20°C and 53% RH) the thermal conductivity of the materials drops by 8.33%. This drop could be due to the regulation of temperature and relative humidity in the enclosure. this condition of the chamber affects the binder and makes the material more compact.

It can be seen that the materials exposed to ambient temperature have a higher thermal diffusivity than the other two storage environments (water tank and climatic chamber). This higher value can be explained by the difference in temperature between the other environment (35°C on average) and other environments (29°C and 20°C on average) during the ten days of storage. This temperature difference influences the thermal diffusivity of the materials [19].

3.3 Mechanical Properties of the Materials

We show the compressive and flexural strengths of the materials. Fig. 11 shows the results of the compressive strengths of concrete and Fig. 12 the flexural strengths of breeze blocks as a function of the storage environments.

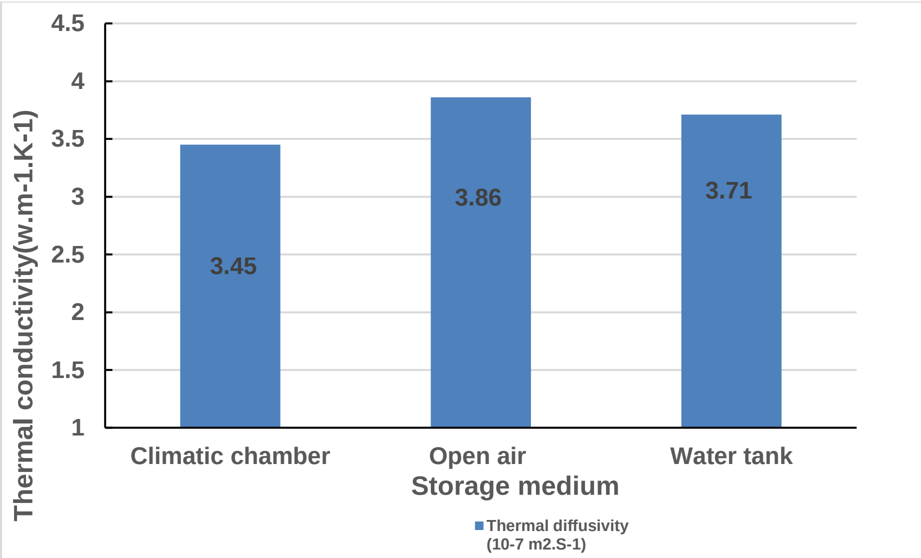

Fig. 9. Thermal conductivity values as a function of the storage medium

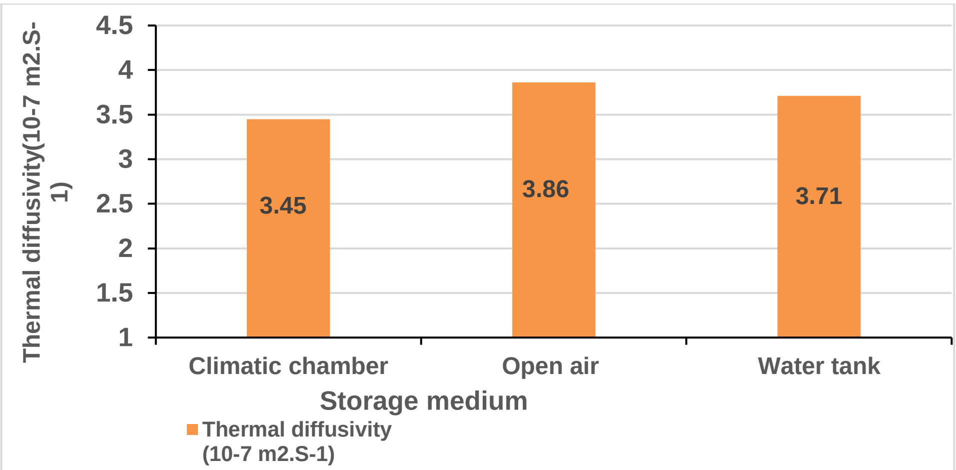

Fig. 10. Thermal diffusivity values as a function of storage medium

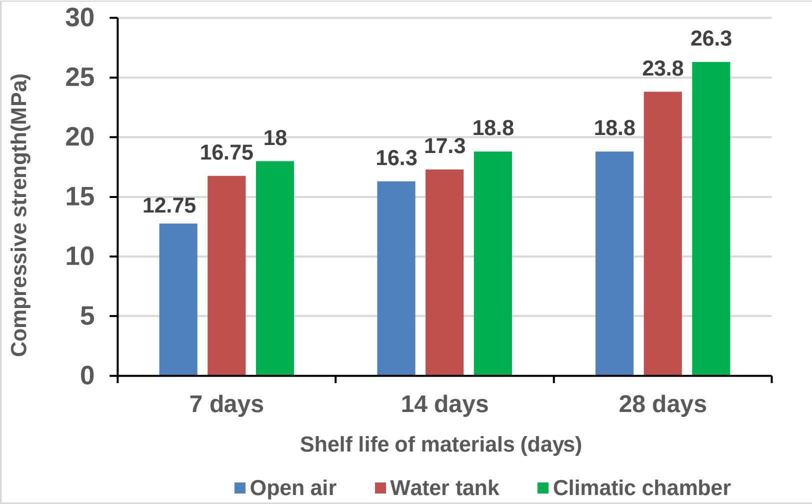

Fig.11. Compressive strength of concrete AT 7, 14 and 28 days

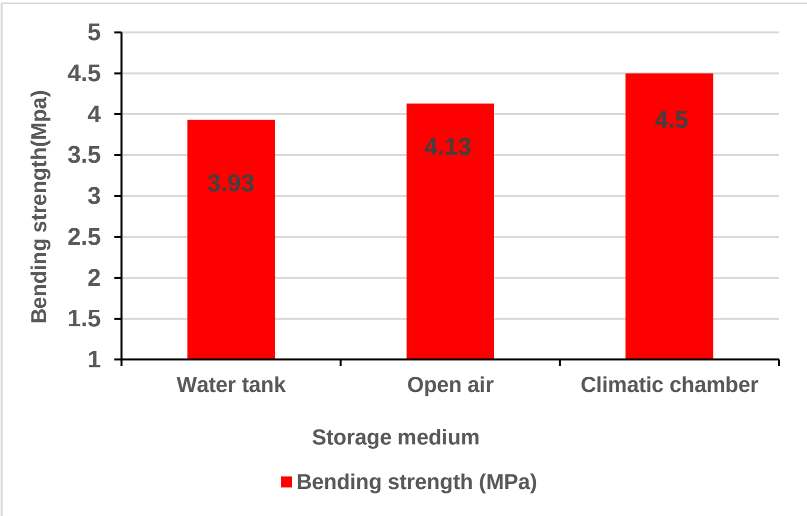

Fig. 12. Values of three-point bending strength of materials

Most of the values obtained are well above the minimum tolerance values, which are 4 MPa for hollow blocks and 8 MPa for solid blocks [20,21]. Up until the seventh day, the concretes matured at the same rate in the different storage environments. however, the compressive strength of the concrete in the room at 20°c was clearly better than that of the concrete stored in the open air and in the water tank. at fourteen (14) days, the strength in the open air had increased considerably compared to that obtained at seven (7) days due to the very high temperature, which activated the hydration of the cement. However, in the water tank, the strength dropped due to climatic variations during the day. this variation leads to a difference in temperature between the surface of the water and the inside of the tank in which the samples are immersed. the difference in temperature can cause significant thermal shock. However, the compressive strength in the chamber at 20°c is still better than in the other media. It can be seen that at 28 days the strength changes significantly in the water tank and in the 20°C chamber compared with 14 days, because the cement hydration reaction has had time to complete. However, in the open air, the strength is considerably lower than at 14 days. This drop in strength can be explained by the fact that up to 28 days of exposure to the open air without protection, the effects of temperature become controversial and lead to excessive departure of mixing water, which can completely stop the hydration reaction, and compressive strength is significantly lower. these results are in line with those found by verbeck et al. [22]. When the age ratio of the strengths in the three media is calculated, we obtain [23].

- Open air: 80.75%
- Water tank:70.37 %
- Air-conditioned chamber at 20°C: 68.44 %

We compared these ratios with those found by L. Lachemat and al. [22]. In their work, they found that the resistance ratio in water was 70.68% compared with 79.15% in open air. These results are in agreement with our own. The same results were confirmed by Tsui leug-cho et al. [24] and A.F Abbast et al. [25].

Three-point bending tests were carried out 10 days after the blocks were made. Strength values ranged from 3.93(± 0.27) to 4.5(±0.25) Mpa. Flexural strengths vary according to the storage environment.T he specimens stored in the climatic chamber had higher strength values than the other two storage environments. this result can be explained by the fact that during the ten (10) days of storage in the chamber, heat exchange is low. In a controlled environment, the binder sets normally with a faster hydration reaction. On the other hand, in both environments, under unstable ambient temperature conditions, the cement hydration reaction is not rapid. The instability of the ambient conditions has an influence on the binder, which could lead to a drop in flexural strength in other environments.

4. CONCLUSION

The results presented in this article are based on the thermo-mechanical characterisation of conventional materials such as concrete and breeze blocks. This involved formulating the samples and determining the thermal and mechanical parameters. It emerged that the compressive and flexural strength of materials depends on the environment in which they are stored. Of the three storage environments, the best results were obtained in the 20°C air-conditioned enclosure. The difference in mechanical behaviour between materials exposed to a real climate and materials stored in a controlled environment is mainly due to the quality of the hydrates formed. Therefore, any instantaneous variation can lead to a change in the structure of these hydrates. As far as thermal parameters are concerned, the best results are also obtained in the climatic chamber. It should be noted that the behaviour of materials is greatly influenced by variations in climatic parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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