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RESEARCH ARTICLE

VALORIZATION OF PLANT BIOMASS, SUGARCANE BAGASSE AND MILLET PODS TO PRODUCE A CEMENTITIOUS MATRIX COMPOSITE

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Abstract

The rising cost of fossil fuels and the environmental impact inherent in the manufacture of building materials have prompted the exploration of alternative sources of production. Plant biomass, a renewable resource, is now emerging as an attractive alternative for the production of building materials, as demonstrated by a number of studies. This study focuses on the use of sugarcane bagasse fibers and millet pods as reinforcements in lightweight cementitious composites. The formulation was carried out using the design of experiments method, in particular mix designs. Four essential factors were taken into account, notably the quantities of cement, water and each reinforcement. Based on the literature review, a Water/Cement ratio of 0.5 was assumed for the production of the test specimens. After the mechanical and physical characterization tests carried out on the composites, an interaction was established between the fiber content and the three-point bending tensile and compressive strengths. As a result, the form of composite with a fiber content of 3% achieves a maximum flexural strength of 9.542 MPa, while another with a fiber content of 1.5% achieves a maximum compressive strength of 25.978 MPa at 28 days. These findings showed that the fibers improved the flexural strength of the composites as a function of time, compared with the control material. In the compressive strength range, however, they do not provide any significant resistance, but on the contrary promote an increase in voids.

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Introduction:-

Sustainable development is now a central theme in all projects aimed at improving human life. For many years, fossil fuels were exploited for industrial, energy, transport, construction and other projects, with negative impacts on our environment. As a response, a number of studies have turned to new sources of production as an effective way of safeguarding the environment. Biomass, being a renewable resource, is an interesting alternative capable of providing an ecological and viable solution for the long term. This study considers the use of agricultural waste products, in particular sugarcane bagasse and millet pods, as reinforcements in the manufacture of composites. The goal is to develop a lightweight cementitious matrix composite that can be used as an eco-building material. Among the researchers who have carried out research into the use of plant fibers in the implementation of cementitious matrix composites, we have :

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A.K Bledzki(Bledzki, 1999)have studied composites reinforced with cellulose-based fibers. The physical properties of natural fibers are mainly determined by their chemical and physical composition, such as fiber structure, cellulose content, fibril angle, cross-section and degree of polymerization. Only a few characteristic values, but above all the specific mechanical properties, can achieve values comparable to those of conventional reinforcement fibers. This study has shown that fiber drying prior to processing is an important factor, as the water present on the fiber surface acts as a separating agent in the fiber-matrix interface. In addition, evaporation of water during the reaction process leads to the appearance of voids in the matrix.

S. Shibata and colleagues(Cao et al., 2006)investigated the mechanical properties of biodegradable composites reinforced with sugarcane bagasse fibers before and after alkaline treatment. In this study, biodegradable composites reinforced with bagasse fibers before and after alkali treatment were prepared and their mechanical properties investigated. The mechanical properties of composites made from alkali-treated fibers were superior to those of untreated fibers. Composites made from fibers treated with a 1% NaOH solution showed maximum improvement. There was an improvement of around 13% in tensile strength, 14% in flexural strength and 30% in impact strength, respectively. After alkaline treatment, the increase in fiber strength and aspect ratio contributed to the improved mechanical properties of the composites.

Olutoge Festusand colleagues(Olutoge et al., 2015) studied the strength of sugarcane bagasse-reinforced concrete using five different mixes with varying percentages and an E/C=0.5 ratio. Concrete without sugarcane bagasse fibers served as a control. Crushing of specimens at 7, 14, 21 and 28 days, respectively, to determine the concrete's compressive strength and flexural strength, showed that the incorporation of sugarcane bagasse fibers reduced the flexural strength of fiber-reinforced concrete by 24% and its tensile strength by 30%.

Tamba S.Tamba S.(TAMBA, 2001)worked on lightweight concretes based on cellulose waste. A physico-chemical study of the materials used to make these lightweight concretes: aggregates (rice husks, wood chips) and fine materials (cement, dune sands and rice husk ash), is used to determine the feasibility of these mortars. Particular attention is paid to the composition of concretes in order to obtain specific physical and mechanical properties (density, strength, dimensional and weight variations). In this composition, the choice of the cement/aggregate weight ratio, among other factors, must be carefully considered. The study also considered the influence of fine material additions on mechanical performance. It was found that with such additions, lightweight concretes obtained can sometimes present mechanical strengths as good as those obtained with traditional concretes.

In his 2006 thesis on the development and characterization of composite materials, Bilba Ketty(Bilba, 2006)studied various plant fibers, notably sugarcane bagasse and banana trunk bagasse. The results showed that the mechanical strength of bagasse/cement composites was significantly improved, except in the case of basic treatment. In all cases, mechanical strength is double that of cement, except for the basic treatment, where it is lower. In addition, the more applied aspect of this work involved studying the setting of composites, in particular the influence of parameters such as fiber content, fiber pyrolysis temperature and water content. The conclusion is that these materials provide better working comfort for construction workers thanks to the reduction in hydration temperature and the set retarding effect.

In addition to the authors cited above, we have C. Baley(Baley, 1991a, 2004b), Chafi Nardjes(Chafi, 2005), Bilba(Bilba et al., 2003), Alida(Alida et al., 2011), Magniont C.(Magniont, 2010), Jonathan P.(Page, 2017)who have not remained on the sidelines of this research topic related to plant fibers with the possibilities of their exploitation as reinforcement in the characterization of various kinds of cementitious matrix composites.

Considering that sugarcane bagasse and millet pods are the main reinforcements of our composite, we will define here the proportions of the study factors: water, cement, sugarcane bagasse and millet pod for the formulation of the cementitious matrix composite. The formulation method adopted is that of experimental design, enabling us to optimize the strengths we wish to achieve through the basic hypotheses of: the study factors, their interactions, the context, the implementation conditions and the intended use of the composite.

Materials Et Methods:-

Materials:-

For the production of our composite, it should be noted that the study factors are also the inputs for the composite.

Based on the results of previous studies, we opted for CPJ 35 cement from the CIMBENIN cement plant.

The millet pods used in our study come from northern Benin, in the Alibori commune of Segbana.

Sugarcane bagasse is the fibrous residue obtained after sugarcane grinding.

Method:-

The formulation method for composites chosen in this study, and in particular the experimental designs, enable us to organize our tests in the best possible way. First of all, the experimenter seeks to determine one or more quantities. There are, however, a large number of variables on which these quantities depend.

In mathematical form, we can denote the quantity of interest by Y (the object of the study: load-bearing capacity, mechanical strength, thermal capacity, etc.), which we will also call RESPONSE, and by Xi all the elements likely to influence the response, which we will call FACTOR [5].

We then have:Equation 1 : $\mathrm{REPONSE} = \mathrm{f}(\mathrm{FACTOR1}, \mathrm{FACTOR2}, \mathrm{FACTOR3}, \ldots.)$

The study of the phenomenon then boils down to measuring the response as a function of the different values that can be given to the factors.Equation 2 : $\mathrm{Y} = \mathrm{f}(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3, \ldots \mathrm{x}_\mathrm{k})$

Determination high and low factor levels

The variable in our study are continuous factors. They are the various components of the composite material. These are sugarcane bagasse (BCS), millet pod (GM), cement and water. We defined high and low levels for each factor, while reducing the maximum fiber content to be incorporated into the composite to 6%. This gives us the following table:

Table1:- High and low levels of selected factors (source : Osmiel A.B, 2022).

Factors / Levels	GM (kg)	CIMENT (kg)	EAU (kg)	BCS (kg)
MIN	0	343	127	0
MAX	30	376	157	30

Among the experimental designs available, we have opted for the mixture design. Consequently, the factors of study are the proportions of the mixture's constituents. **As the sum of these proportions is always equal to 100%,** the percentage of the last constituent is imposed by the sum of the percentages of the first compounds in the mixture.

Experiment's matrix

Once the high and low levels of the factors have been inserted into the MINITAB 19 software, we obtain the matrix of experiments, i.e. the different formulations proposed by this software. The table below shows the matrix of experiments.

Table 2:- Formulations based on MINITAB software (Osmiel A. B., 2022).

Test order n°	MIL (kg)	CIMENT (kg)	EAU (kg)	BCS (kg)
1	30,00	343,00	127,00	0,00
2	10,00	353,00	127,00	10,00
3	15,00	358,00	127,00	0,00
4	0,00	373,00	127,00	0,00
5	10,00	353,00	137,00	0,00
6	0,00	358,00	142,00	0,00
7	0,00	343,00	142,00	15,00
8	0,00	358,00	127,00	15,00
9	0,00	343,00	127,00	30,00
10	0,00	343,00	157,00	0,00
11	7,50	350,50	134,50	7,50
12	15,00	343,00	127,00	15,00

13	0,00	353,00	137,00	10,00
14	10,00	343,00	137,00	10,00
15	15,00	343,00	142,00	0,00

Composite processing

From the results of the physical tests, we used the densities of each material (the study factors), i.e. 344.8 kg/m3 for millet husk, 3010 kg/m3 for cement, 1000 kg/m3 for water and 191.14 kg/m3 for sugarcane bagasse respectively, to determine the quantities of the materials in grams. Note that the density given by the literature review is 150kg/m3 to 200kg/m3. However, the context in which our bagasse is obtained is quite different from theirs, hence the difference.

As a result, the water/cement ratio adopted is 0.5, following extensive laboratory testing. This ratio is the same used by Festus Olutoge in 2015 in his study of the strength characteristics of concrete reinforced with sugarcane bagasse fibers (Olutoge et al., 2015). We used metal molds with dimensions of 4x4x16 cm3 to make the test specimens. The interior of the molds is first coated with a layer of oil to facilitate demolding after compaction using the impact table. In this case, we made the mixes mold by mold. Each mold is filled in two successive layers. The mold is then shaved and stored in the laboratory for 24 or 72 hours at 20°C±2°C.

The table below shows the quantities used to make the test specimens.

Table 3:- Formulations with W/C ratio=0.5 for each mould of 03 prismatic specimens 4*4*16 cm^3(Osmiel A. B., 2022).

Test order n°	MIL (g)	CIMENT (g)	EAU (g)	BCS (g)
1	93,669832	1071,0	535,5	
2	31,450043	1110,2	555,1	31,450043
3	53,067928	1266,6	633,3	
4		1522,2	761,1	
5	36,148227	1276,0	638,0	
6		1404,9	702,5	
7		1050,2	525,1	45,928894
8		1130,0	565,0	47,346998
9		882,7	441,3	77,204065
10		1296,3	648,1	
11	24,6205	1150,6	575,3	24,6205
12	42,321805	967,8	483,9	42,321805
13		1179,0	589,5	33,399282
14	30,817988	1057,1	528,5	30,817988
15	51,292845	1172,9	586,4	

The nomenclature proposed for the formulations in the test situation are :

MT-E4: Control Material-Test #4 = Cement + Water

MC-E2-CEGB1: Composite Material-Test n°2 = Cement + Water + Millet Pod + Bagasse
GM and BCS fiber content is equal to 2%.

MC-E11-CEGB2: Composite Material-Test n°11 = Cement + Water + Millet pod + Bagasse
GM and BCS fiber content equal to 1.5%.

MC-E12-CEGB3: Material Composite-Test n°12 = Cement + Water + Millet pod + Bagasse
The GM and BCS fiber content is equal to 3%.

Mechanical characterisation tests
The mechanical characterization tests include compressive strength and tensile strength.

Goal
The purpose of the test is to determine the mortar's tensile and compressive strengths, which will be measured in the laboratory on test specimens.

Test principle
The specimens are loaded in compression and bending using a press until they break. The force causing failure in each case is used to determine the mortar's mechanical strengths.

Material:-

1. A testing machine which is a press complying with the requirements of standards (EN 196-1) ;
2. A standardized mixer;
3. Standardized molds to produce 3 square prismatic specimens 4×4×16 ;
4. A shock device capable of applying 60 shocks to the molds by dropping them from a height of 15mm±0.3mm at a frequency of one drop per second for 60s ;
5. A bending strength testing machine capable of applying loads of up to 10KN at a loading speed of 50N/s.

Operating mode
A 4×4×16 mold is filled with the prepared standardized mortar. The mortar is clamped in this mold by introducing the mortar twice and applying 60 shocks to the mold each time. The mold is then levelled, covered with a glass plate and stored in the wet room or cabinet.

A few hours after mixing has begun, the specimens are removed from the moulds and stored in water at 20°C ± 1°C until the time of the fracture test.

On the scheduled day, the specimens are broken in flexion. The flexural fracture of each specimen is carried out according to the procedure described in the figure below.

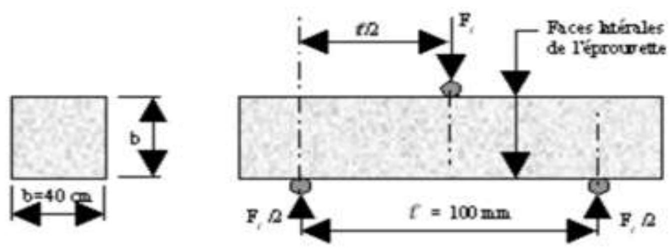


Fig. 1:- System for bending strength test.

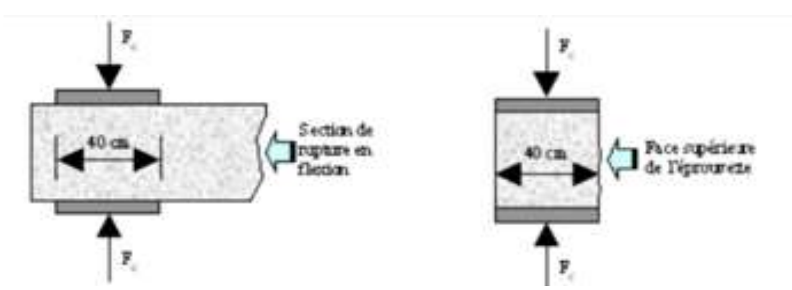


Fig. 2:- Compression fracture device.

Results:-

Determination of flexural tensile strength
If F_f is the breaking load of the specimen in bending, the breaking moment is a quarter of the breaking load times the specimen length ($\frac{F_f * l}{4}$). The corresponding tensile stress on the underside of the specimen is :

$$R_f = \frac{1{,}5\ F_f \times l}{b^3}$$

Tensile bending tests are performed on three (03) prisms; the results obtained on each prism are averaged. If one of the three results differs by ±10% from the mean, that result is discarded and the remaining two results are averaged. If two results differ by ±10% from the mean, all three results are discarded.

Determination of compressive strength
If F_C is the breaking load, the breaking stress will be :

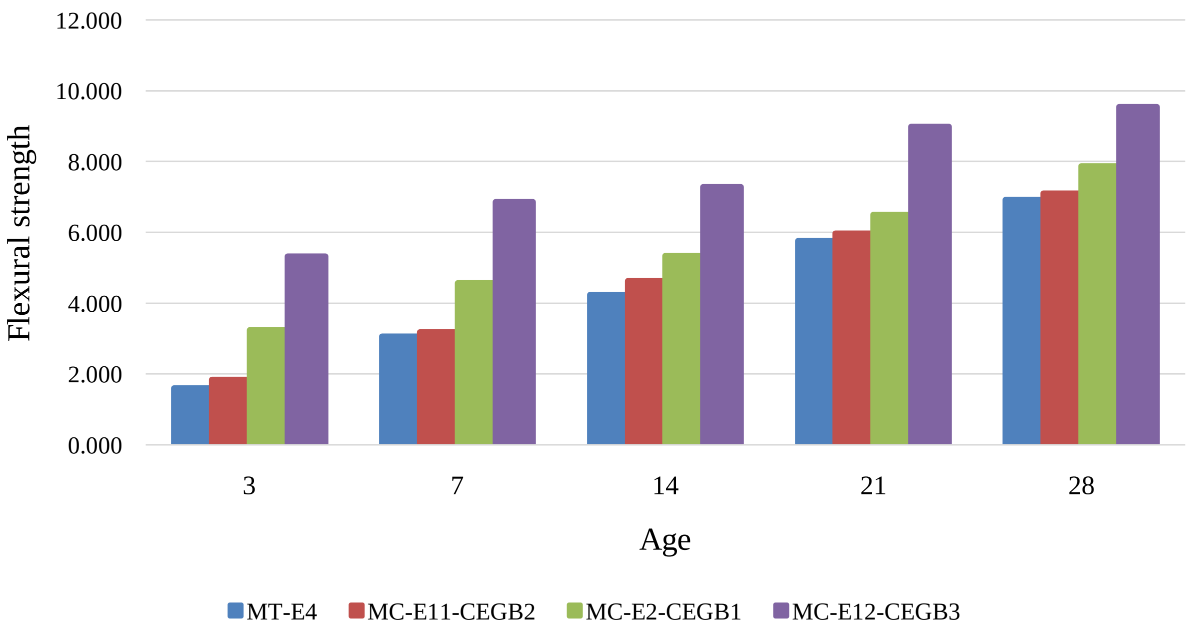
$$R_C = \frac{F_C}{b^2}$$

Compression tests are carried out on six (06) half-prisms. The average of the results obtained on each of the prisms is the compressive strength. If one of the six (06) results differs from the average by ±10%, it is discarded and the average is calculated from the remaining five (05). If one of the five (05) results again deviates by ±10% from the new average, the entire series of six (06) measurements is discarded. In this case, the reasons for the discrepancy should be investigated: mixing, placement, storage. When the strength is satisfactory, the average obtained is the strength of the material at the age in question.

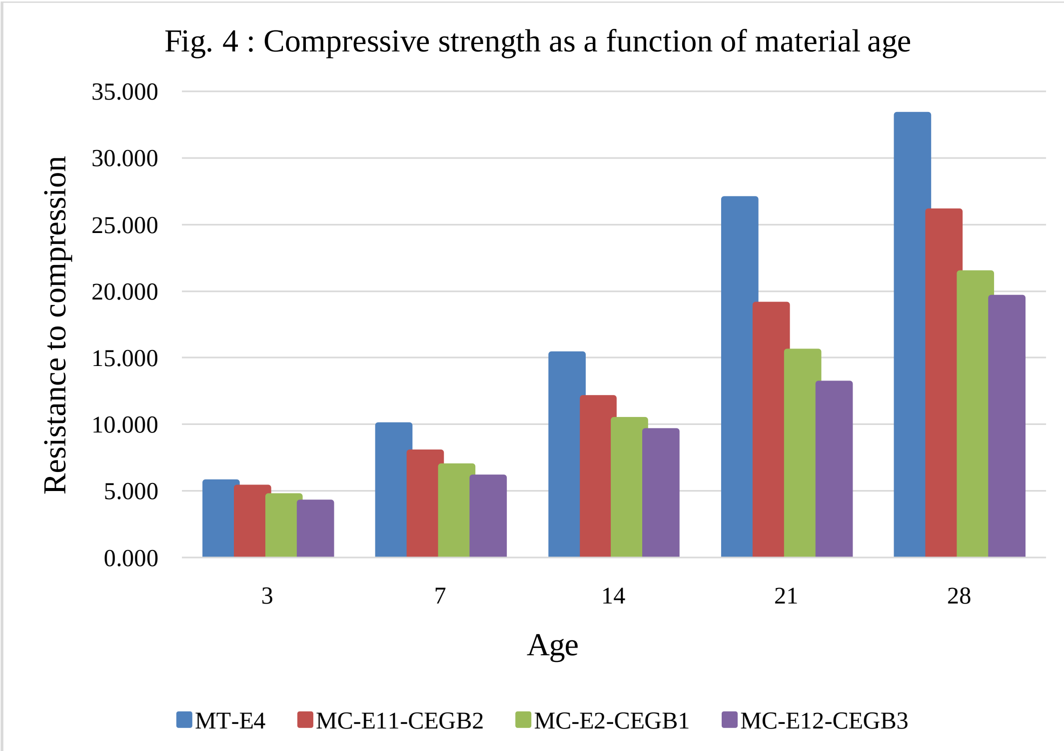
Results and Discussion:-

The following are the results obtained from compression and three-point bending tests on different days:

Fig. 3 : Evolution of bending strength as a function of material age



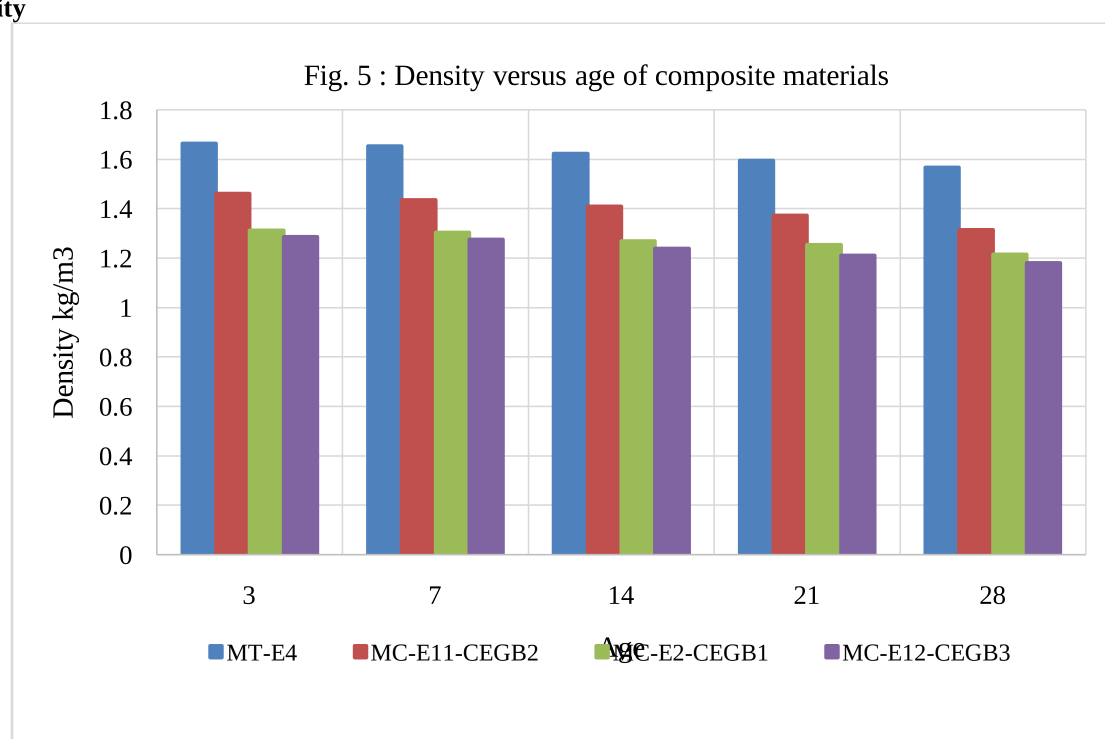
From the analysis and interpretation of the results we note that :
The flexural strength of composites is superior to that of MT because the presence of BCS and GM fibers gives the mortar the ability to resist the fractures that occur. These fibers help to control the cracks observed as they are created. The more fibers there are in the mortar, the better this resistance will be.



Our analysis and interpretation of the results show that :

Due to the presence of BCS and GM fibers, the compressive strength of composites is generally lower than that of MT. These significantly increase the volume of voids in the mortar, and are at the root of the mortar's reduced performance. The fibers do not have the strength to improve the mortar's compressive strength.

Density



The above histogram shows a variation in the density of composite materials as age progresses. This variation tends to decrease, and can be seen on every curve in the diagram. We can deduce that the slight drop in density is mainly due to the shrinkage of water in each material.

Considering the low density of the fibers and the gradual shrinkage of water in the composites, it is logical to obtain a lower density for each material at 28 days than at their young ages. These results are confirmed by those obtained by Abdullah and colleagues (Alida et al., 2011) who observed the evolution of some physical characteristics of coir fiber-reinforced mortar as a function of the amount of fiber present in the mix. The results show that the fibers contribute to a decrease in the density of the final material. This is due to the fact that the density of fibers is lower than that of other aggregates. The same applies to water absorption by the material: the more fibers there are, the higher the water capacity.

Conclusion:-

The aim of this study is to valorize waste from agricultural production, in particular plant biomass, through the production of lightweight composite materials capable of meeting the technical and structural requirements of the construction sector.

Our first task was to formulate the materials to be used in the study, using the experimental design method. We specifically chose mix designs, which offer us a wide experimental field and a large number of formulations based on the factors we have selected for the present case. These factors include different quantities of cement, water, millet pods and sugarcane bagasse. This led to the choice of four formulations, including the control "MT" and the others "MC-E2-CEGB1", "MC-E11-CEGB2" and "MC-E12-CEGB3".

Next, we had to master the behavior of the various composite and MT formulations. To this end, physical and mechanical characterization tests were carried out. The results obtained enabled us to determine which of the formulations offered optimum performance in both bending and compression, and to deduce the optimum fiber content to incorporate for best strength. Characterization of mechanical behavior in compression shows that the formulations present strength proportional to the presence of BCS and GM fibers. The three-point bending tensile test indicates that the composite formulations are more resistant than the control, to such an extent that their strengths are higher than those of the control. As for the physical tests, the results show that the density decreases as the fiber content incorporated and the age of the composite increases. The water shrinkage observed on composites at different ages and the presence of fibers increase the volume of voids and consequently reduce the compactness of the resulting material.

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