

Fatigue Behaviour Study of a Cement Matrix Composite Reinforced by Sugar Cane Bagasse Short Fibers

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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

This work is devoted to the study of the fatigue behaviour of a cement matrix composite reinforced by sugar cane bagasse short fibers. The objective is analysis of the fatigue behaviour in order to assess its ability to withstand use on wall structures, in bracing, false ceiling of this material. Some series of tests carried out in compression and flexion characterized the material mechanical properties, the tests in monotonic and cyclic three-point bending showed the material behaviour in use. For the composite, another fairly conventionally used representation is to visualize the variations in material properties as a function of the number of cycles. The Wöhler curves is plotted from the strain stresses and the number of cycles for the end of test criteria. It shows the influence of increase in stress on the material service life face of breaking. The Fatigue limit corresponds to the line $\sigma = 26.40$ MPa, stress for which no breaking is observed after an infinite number of cycles, and the Endurance limit corresponds to the line of stress 26.79 MPa, the limit value towards which the stress amplitude tends when the number of cycles becomes very large.

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1. INTRODUCTION

Composite materials are used to answer more effectively for environmental, ecological, economic, social and energy criteria. These materials contribute to lighten the weight of structures. The objective of contributing to the reduction of the causes of climate warming by limiting the sources of production of greenhouse gases, is the choice of the waste of sugar cane bagasse and the rice husks, still poorly treated or destroyed by burning and harmful to the environment. Global sugar cane cultivation in 2018 reached one hundred and forty-nine million tons, a growth in relation to the one of 2017 [1]. An important quantity of waste called bagasse, which accounts for up to 30% of the sugar cane mass, abundant, renewable and inexpensive [2]. The analysis of the specific properties of cementitious matrix composites with short vegetable fibers through scientific reviews and the availability bagasses and of rice husks, shows an interesting solution thanks to the good ratio of specific properties/cost. The understanding of its fatigue behaviour is interesting for the dimensioning of parts using it for material. Sedan determined the 3-point and 4-point bending behaviour of a cementitious matrix composite of reinforcement, hemp fibers and demonstrated a quasi-linear behaviour before the first crack and of the peak, a co-controlled decrease of the load and concludes an aging of the material under the fatigue [3]. The design of the material must verify the resistance to mechanical stresses according to use, in terms of static loading and to validate a service life from the point of view of fatigue or, simply the expected service life. The verification of fatigue

behaviour is truly preponderant in most designs, because the fatigue failure occurs at stress levels for which the material's macroscopic yield strength is not reached. In this case, it is the fatigue phenomenon that becomes dimensioning and not the mechanical resistance to the maximum forces encountered. The characterisation of this material in fatigue will be determined, for the establishment of its curve (S-N), Wöhler curve [4]. In this dynamic, the behaviour of the cementitious matrix composite material reinforced with short fiber of sugar cane bagasse, subjected to monotone and cyclic bending is studied in order to predict its service life by using the Wöhler curve.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 The sand

The sand used, comes from the Dekoungbe sand quarry in Benin. The particle size analysis test is carried out according to the standard (NF EN 933-1) and its physical characteristics are recorded in Table 1.

2.1.2 The cement

A Portland cement of type BUFFLE CEMII/B-LL 42.5R Standard NF EN 197-1 produced in Benin. The physical characteristics of the cement are shown in Table 2.

The mechanical properties of cement are recapitulated in Table 3.

Table 1. Physical characteristics of sand

Percentage of loss (P)	19%	0.19 <2	Particle size analysis curve respected the standard.	(NF EN 933-1)
Coefficient of fineness (Mf)	2.25	2,2 < Mf < 2,8	suitable sand for a good workability and a good resistance	(NF EN 933-1)
Uniformity Coefficient(Cu)	4,02	2 < Cu < 5	sand of tight particle size	(NF EN 933-1)
Sand Equivalent (ES)	81,38%	0,71	Clean sand	(NF EN 933-1)
True density	2,64 Kg/m3			(NF EN 1097-6)

Table 2. Physical characteristics of cement

Bulk specific gravity	1,073
Density	3,01
Start time of binding of cement	3 h 05 mn
End time of binding of cement	4 h 9 mn
Spécifique surface (Blaine)	3155
Expansion	1,50
Refusal on sieve 0,08	10,92
Refusal on sieve 0,16	0,80

Table 3. Mechanical characteristics of cement

Number of days	Compressive strength (Mpa)
2 days	13,20
7 days	24,20
28 days	33,00

2.1.3 Sugar cane bagasse

Sugar cane bagasse is a residue generated largely by the agro-industry. It is a fibrous residue from sugar cane stems obtained after the extraction of sugar cane juice [5]. Leaving the sugar mill, it consists of 50-60% dry base of useful fibers [6]. Often used as fuel for boilers, this waste is obtained from the Complant Sugar Factory of Benin (SUCOBE). They underwent a preliminary treatment consisting of separating on the one hand from this waste other materials such as sand and certain organic materials and on the other hand separating the marrow from bagasse fiber; and this after immersion in water. The bagasse fibers obtained are then dried in the

open air for seven (7) days. They were also made anhydrous at a temperature of 105°C in an oven before any use. The size distribution of crushed sugar cane bagasse fibers is shown in Fig. 1.

The shape of this curve is similar to that obtained by M. A. El-Sayed and his collaborators [7].

The particle size analysis test is done according to the standard (NF EN 933-1).

2.1.4 Pozzolana

Artificial pozzolans are minerals from factories, thermal power stations and even from the calcination of agricultural by-products containing a significant amount of reactive silica and alumina [8]. The pozzolana is the ash of rice husks burnt at 650°C. The constituents are obtained by the X-ray Fluorexance analysis. These constituents are contained in Table 4.

Table 4. Mineralogical composition of rice husks ash

Constituents	Rate in %
SiO ₂	98,78
Al ₂ O ₃	0,10
Fe ₂ O ₃	0,24
CaO	0,41
MgO	2,64
SO ₃	0,05
K ₂ O	1,93
Na ₂ O	0,00

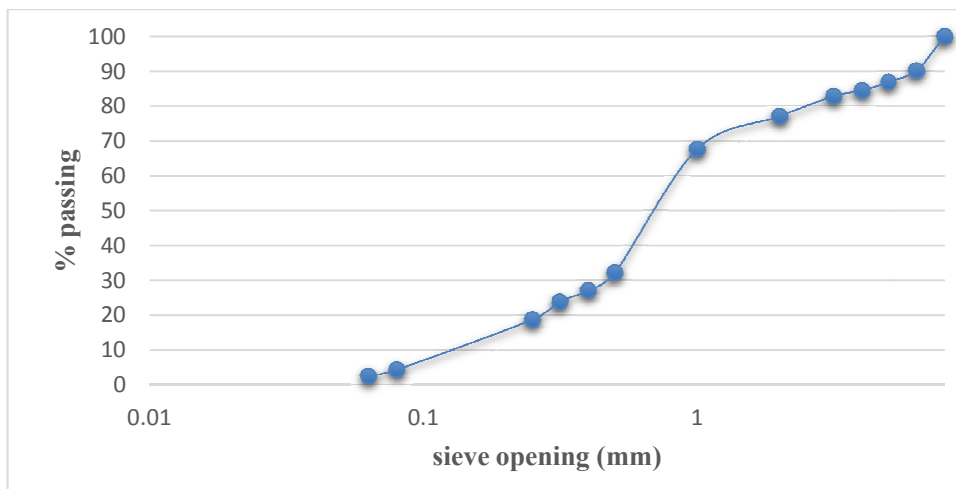


Fig. 1. Particle distribution of sugarcane bagasse fibers

2.2 Methods

2.2.1 Composite formulation

For made-up composites, we are interested in the granular class [2,5]. In order to obtain a reactive pozzolan, the rice husks are calcined at different temperatures (400°C to 850°C) to determine the optimal calcination temperature. The oven heating speed is adjusted to 5°C / min to be able to obtain a well-calcined ash. Once the desired temperature has been reached, the ash is kept at this temperature for two (2) hours. The calcination temperature is that from which the loss on ignition becomes constant. The formulation of the cement matrix composite, reinforced with sugar cane bagasse fibers under study, consisted of:

- To set the E/C ratio at 0.7 because it has good handling;
- To evaluate the volume of the granular skeleton (SG), in the saturated state of the fibers, in accordance with the principle of formulation by volume substitution in the saturated state by the expression by [9,10]:

$$V_{SG} = \frac{1m^3 - V_C - E_{eff}}{1 + W_{FBCS}} \quad (1)$$

W_{FBCS} is the water absorption coefficient, V_C the amount of cement and E_{eff} the effective amount of water. Effective water is defined by standard NF EN 206-1 [11] by:

$$E_{eff} = E_{gr} + E_{adj} + E_{cent} - E_{abs} \quad (2)$$

The formulation selected is that having good mechanical performance. It is a formulation approach allowing the quantity of the binder to be kept constant in the volume of the bio-fiber composite.

2.2.2 Molding of test pieces

The control samples are obtained by following the following cement / sand mass fraction: 1/3) and a constant water / cement ratio (E / C) of 0.7 according to Standard EN 196-1 [12]. To identify the rate of substitution of sand with reinforcements of sugar cane bagasse to be used for the preparation of the composite, several substitutions were made (2.5%, 5%, 7.5% and 10%). These rates being applied to the quantity of sand used in the control specimen. Regarding the rate of cement removal from rice husk ash, a rate of 10% has been set. In fact, in order to set up this rate of substitution, we made up several test tubes with the rates of 2%,6%,10%,14% until 25%. Then we note an increase of performances until 10% and above we observe their decrease. Elsewhere that is what [13] meant in 2012. In this study, specimens of dimensions 4cm x 4cm x 16cm are made up and kept in the laboratory until maturity. These composites called "CFBC" (Bagasse fiber composite of sugar cane) are air dried. The various composites made underwent several mechanical tests including the axial compression and three-point bending test. This in order to determine the mechanical characteristics of the composite.



Fig. 2. Molding of test tubes



Fig. 3. Drying of test pieces

3. RESULTS AND DISCUSSION

3.1 Flexural Test

The three-point bending test on the mortars made it possible to draw the different curves recorded.

The flexural strength of the different composites at 28 days of maturity calculated by the relationship:

$$Rf = \frac{1,5 \times F_f \times l}{b^3} [10] \quad (3)$$

The values of the tensile strengths of the composites are highlighted in the Fig. 5.

It can be seen that the flexural behavior of the cement mortar is fragile, the rupture is sudden

with a relatively weak displacement. This means that pozzolana (silica SiO_2 and alumina Al_2O_3) transforms portlandite CH into silicates [14]. However, this is not enough to make the material ductile. For composites where part of the granular skeleton has been taken over by sugarcane bagasse fibers, the area of rupture is widened as appropriate. For the various composites that are the subject of this study, we note that the fiber substitution up to a rate of 5% improves the bending behavior of the fibrous composite. On the other hand, beyond this threshold, the stress at break in bending of the composite decreases up to 7.71 MPa at a substitution rate of 10% of fibers. This sudden decrease in resistance after 5% could be linked to the fact that the increase in fibers leads to an insufficient cement paste for total coating of reinforcements; therefore, poor adhesion. This aspect of the curves of the fiber-reinforced and cementitious matrix composites was already highlighted by Sedan [3].

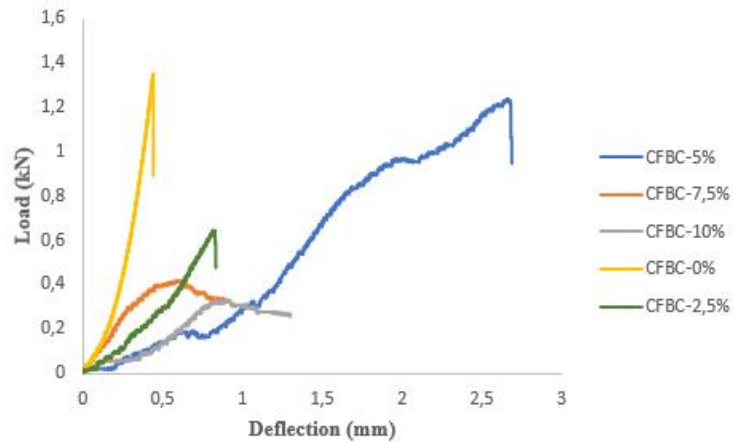


Fig. 4. Load Deflection Curves for composites [14]

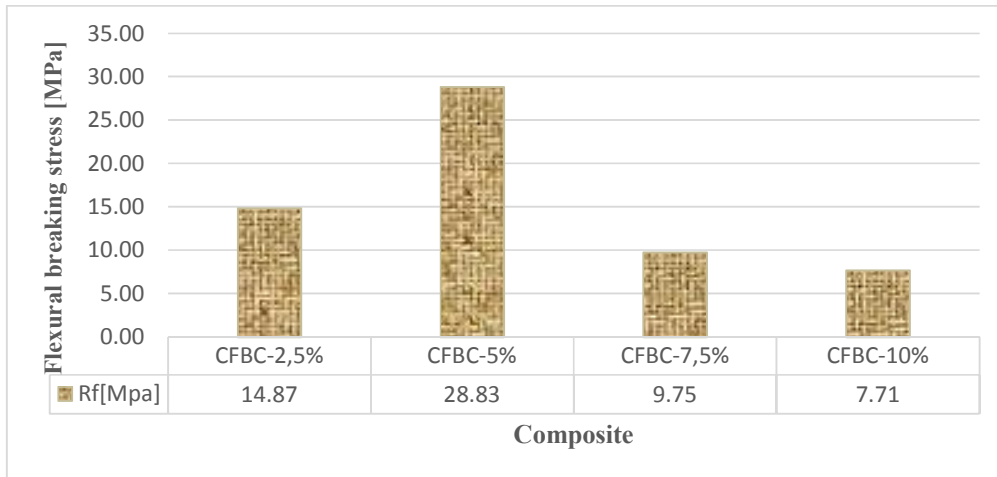


Fig. 5. Stress at break in bending of composites at 28 days of age

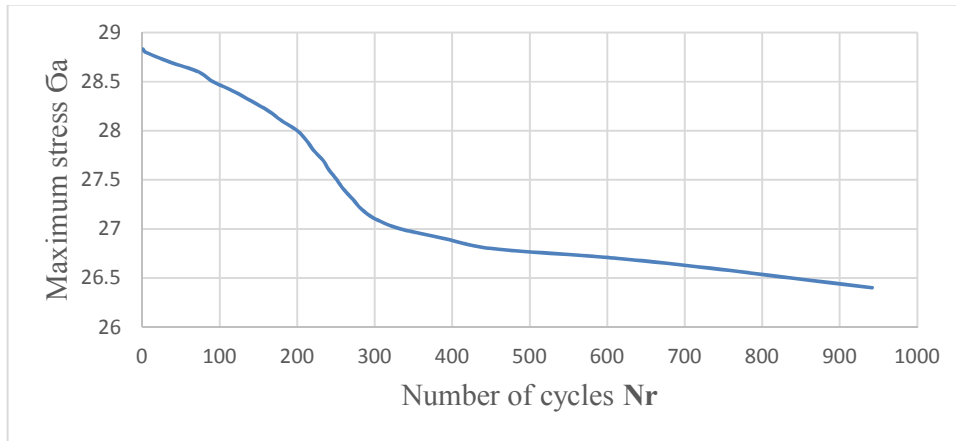


Fig. 6. Wohler curve Stress – number of cycles

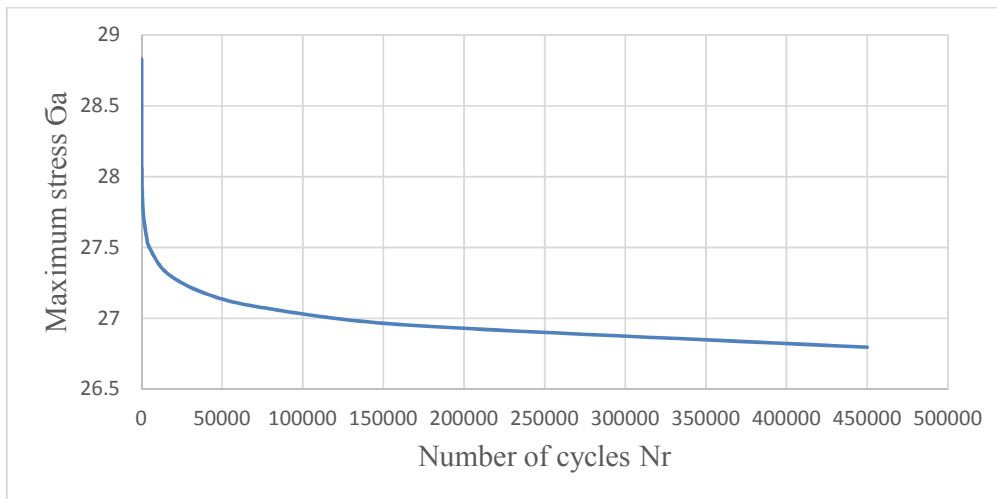


Fig. 7. Endurance curve Stress – number of cycles

3.2 Behaviour under Cyclic Stress

The curve Fig. 6, and Fig. 7, let to visualize the behaviour of the material in the field of fatigue, defined from a relationship between the applied stress and the number of breaking cycles N. The test, to subject test pieces to periodic cycles of stress, the constant loading amplitude below the stress value obtained at the breaking of 28,83 MPa, and to record the number of break cycles N.

Fatigue limit corresponds to the line $\sigma = 26.40$ MPa, stress for which no breaking is observed after an infinite number of cycles.

Endurance limit corresponds to the line of stress 26.79 MPa, the limit value towards which the stress amplitude tends when the number of cycles becomes very large.

The curve represents the boundary between a field considered exploitable and in which the material is considered to be unbroken below the curve, and an unusable field, in which this one is considered to be broken and for which the piece can no longer perform its functions. For this composite material, $\sigma_{max} = 28.83 - B \cdot \text{Log}(N_R)$, is the linear portion of the curve that separates the broken zone from the unbroken area $B = 0,36$, $\sigma_{max} = 28.83 - 0.36 \text{Log}(N_R)$, the curve represents the limit between an area considered to be exploitable and in which the produced material is considered as not broken, the zone located below the curve and an unusable domain, the zone above the curve, in which the latter is considered broken and for which the part can no longer fulfill its functions. For a given load, the user will be able to limit the lifespan of the material.

4. CONCLUSION

By the monotone and cyclic bending tests, the behaviour of this material is studied. The Wohler curve is drawn, which gives the fatigue behaviour of the material. The breaking stress is 28,83 MPa. The Fatigue limit $\sigma = 26.40$ MPa, corresponds to the stress for which no breaking is observed after an infinite number of cycles and the endurance limit $\sigma = 26,79$ MPa, corresponds to the limit value towards which the stress amplitude tends when the number of cycles becomes very large. This information allows us to control the quality of the material by building a tolerance interval below which the pieces are deemed non-compliant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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