Cement Composites for Civil Engineering Field

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Summary

A new cement composite, the CEMTEC$_{multiscale}$®, developed and patented by the Laboratoire Central des Ponts et Chaussées (Paris, France) is presented in this paper.

This cement composite has been tested under static bending and asymmetric fatigue bending. From this experimental study, the following comments can be made:

- The average modulus of rupture (MOR) is equal to 61.5 MPa;
- The average strain related to the average MOR is equal to 9.2 10^{-3}.
- The stationary damage fatigue evolution of a specimen is dependent of the initial static damage of this specimen.
- Below a loading ratio R = 0.65, failure during bending fatigue test never appears with a specimen of CEMTEC$_{multiscale}$®.
- A gain of 6.5 % is observed between the bending static behavior of the specimens being previously loaded in fatigue and those not being loaded in fatigue.

Keywords : cement composites ; steel fibres ; bending behaviors ; fatigue behavior

1. Introduction

A new generation of fibre reinforced cement composites has been developed at the Laboratoire Central des Ponts et Chaussées (LCPC, Paris, France) with the aim of obtaining a material sufficiently resistant and ductile to conceive structures or elements without other reinforcements that the fibers.

These materials are a direct application of the Multi-Scale Fiber Reinforcement Concept proposed by Rossi[1]. The idea is to mix short fibres with longer ones in order to act both at the scale of the material (increasing tensile strength) and the scale of the structure (increasing bearing capacity and ductility).

CEMTEC$_{multiscale}$®, which was the subject of a world patent filling by the LCPC in March 2001, has the following mix design characteristics related to the fibres: it contains 11% per volume of steel fibers and 3 different fiber geometries.

The LCPC launched, in 2000, a vast study over 4 years on CEMTEC$_{multiscale}$®, study which comprises mechanical tests to characterize the various mechanical behaviors of the composite (behavior in statics, in fatigue, at high stress rates...), tests of durability, tests on structural elements, and tests to optimize the manufacturing process (mixing and casting). In this article only the results related to static, high stress rates and fatigue tests are presented.

The composition of the CEMTEC$_{multiscale}$® is given in table 1.

Table 1: The composition of the CEMTEC$_{multiscale}$® (kg/m^3)

Cement	1050.1
Silica fume	268.1
Sand	514.3
Water	180.3
Superplasticizer	44
Steel fibers	858
Water/cement = 0.201	
Water/ binder = 0.16	
Air entrained = 20 litres	

2. Static tests

One of the industrial application aimed with this new composite material relates to the slabs and the floors strongly charged, such as the slabs of composite structures for example.

To dimension a structure or a structural element made up only of the material studied necessarily implies to do it by taking into account in a very controlled way of safety. It is consequently essential to reach characteristic mechanical behaviors which integrate the dispersion problems inherent in all materials. It is thus, that the tests evoked above were carried out on a sufficient number of specimens to determine these characteristic behaviors. The static tests presented in this study aim at determining the characteristic bending behavior of CEMTEC$_{multiscale}$® within the slab. In order to optimize the dimensions of the specimens with respect to the scale effects and of preferential orientation of fibers, and in addition to lead to a use which could be economically viable of CEMTEC$_{multiscale}$®, it was selected to retain following dimensions concerning the specimens representative of a slab:

- length: 600 mm,
- width: 200 mm ,
- thickness : 40 mm.

The 200 mm width allows an orthotropic orientation of the fibers, of which largest makes 25 mm length, representative of this existing in a slab

The specimens are cast flat and are vibrated during the casting on a mobile plate.

It is known that with the Ultra High Cement Composites, which is CEMTEC$_{multiscale}$®, the use of a heat treatment makes it possible to increase the mechanical performances of the matrix. Also, in the present study it was used a heat treatment which consists in placing the specimens in a drying oven at 90°c during 4 days, 48 hours after their release from the mould.

2.1 Four points bending tests - test set up

During these deflection tests the distance between the lower supports is 420 mm, and between the higher supports is 140 mm. The test is carried out at an imposed deflection rate equal to 0,3 mm/min. The deflection is measured using a special extensometer, placed on the specimens, designed to eliminate parasitic displacements on the level from the supports.

9 specimens were tested.

It is also necessary to announce that for all the specimens, a LVDT sensor was stuck on the face opposed to that on which the extensometer being used is fixed to measure the deflection. This sensor is positioned at the level of the bottom fiber of the specimens in the zone of constant moment.

2.2 Bending tests – Results

In figure 1 are presented the results in the shape of *bending tensile stress–strain* curves.

One can note that the average bending tensile strength, still called *average modulus of rupture (MOR)*, is very high. It reaches **61.5 MPa**;
The average strain related to the average MOR is equal to **9.2 10^{-3}**.

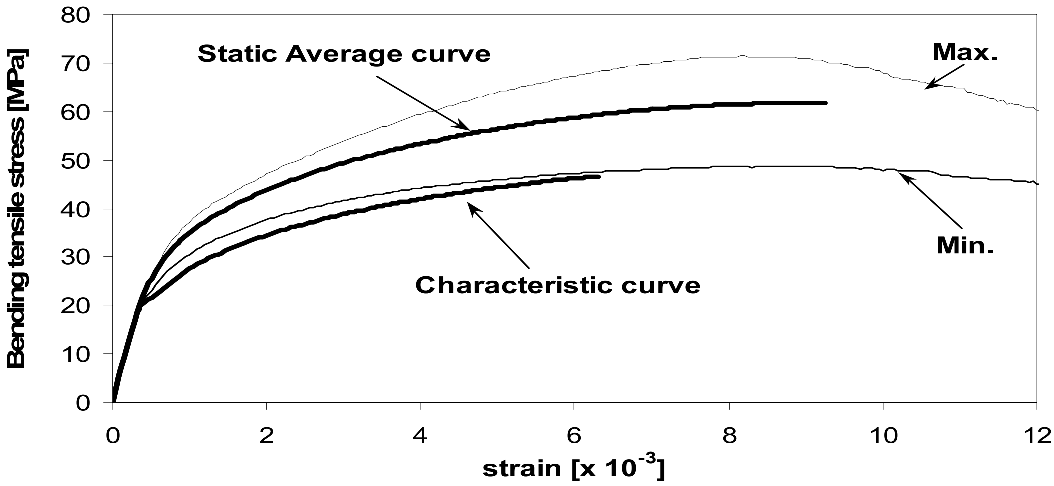

Fig. 1 Static Bending tensile stress-Strain curves

3. Fatigue tests

15 specimens were tested in bending fatigue, in an imposed loading rate (same test set-up than for static tests). A first slow loading rate is imposed to reach the chosen maximal fatigue load, then the load is decreased to reach the average fatigue load, and finally the asymmetric sinusoidal fatigue loading is taken between 10 and 100 % of the chosen maximal fatigue load. The imposed loading frequency was of 2.5 Hz. The test room is a 20 °C air-conditioned room. Tests were led until 2 millions cycles (10 days), except in the case of premature failure.

During the study, the loading ratio R (ratio between the applied stress and the characteristic static stress) varied between 0.77 and 1.03.

In the Fig. 2 are presented examples of *deflection-cycles number* curves respectively related to the case where the specimen is broken before 2 millions cycles and the case where the 2 millions cycles were reached. We find the usual shape of the fatigue curves with three different phases:

- a first phase, corresponding with a starting micro-cracking of the matrix. The deflection evolution is fast.
- a second phase marked with a slowing down of the deflection evolution.
- a third phase which marks the resumption of the damage and leads very fast to the ruin of the structure. This last one is of course absent for specimen weakly damaged.

On the Fig. 3 is represented the *fatigue cycles number-load rate (R)* diagram. From this figure one makes the following remarks:

- results are relatively scattered, that is usual for fatigue tests ;
- below a loading ratio **R = 0.8** specimens in $CEMTEC_{multiscale}$ ® do not fail by fatigue before 2 millions cycles.

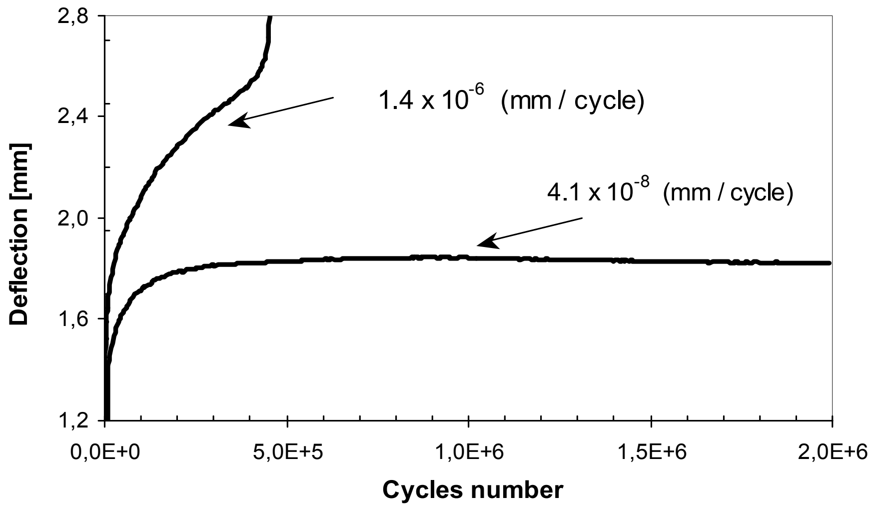

Fig. 2 Deflection evolution-Cycles number curves

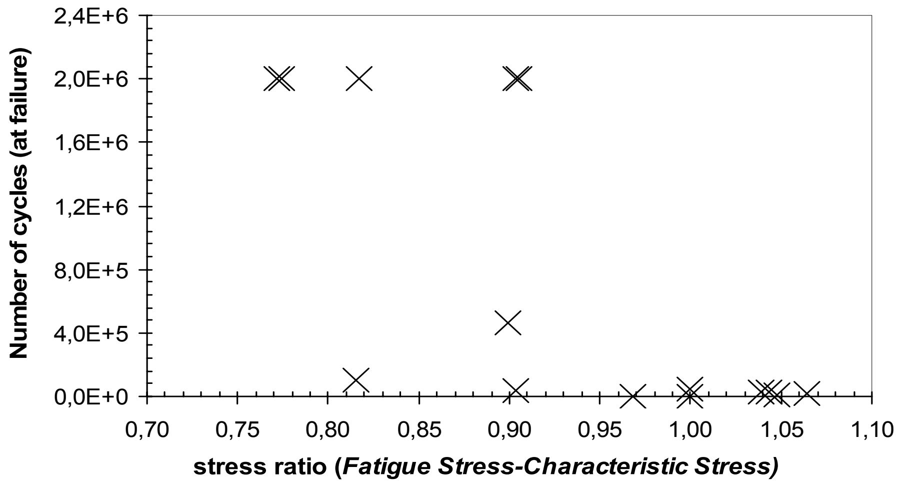

Fig. 3 Fatigue cycles number-Stress ratio diagram

The stress scattering observed on the Fig. 3 indicates that the applied load ratio is not good parameter to analyze the fatigue failure probability related to composite. The applied stress/MOR ratio related to each specimen is surely a best parameter to evaluate this fatigue failure probability of a specimen of CEMTEC$_{multiscale}$®. Not being able to determined this ratio, the specimen MOR not being known, the initial static damage (quantitatively represented by the initial static strain) generated during the first static load could be a good parameter to evaluate this fatigue failure probability.

To show this dependence, we consider in a first step S, the derivative of *Deflection evolution-cycles number* curve. The *S-initial strain* diagram is presented in Fig. 4. This figure shows a good correlation between the stationary fatigue damage phase and the initial static damage.

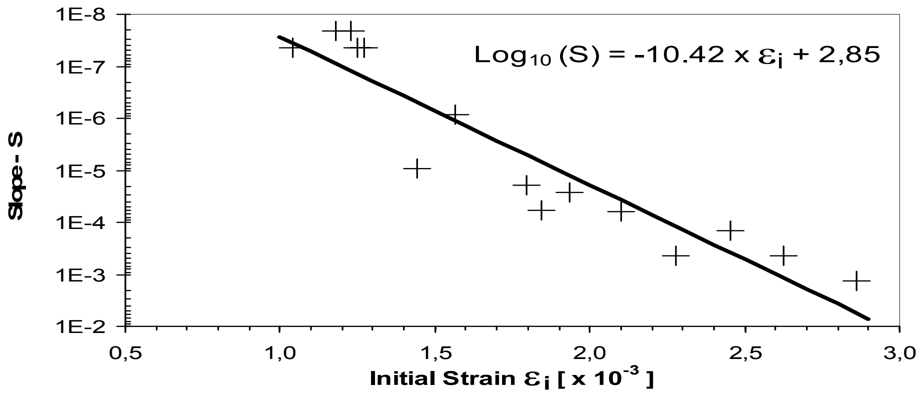

Fig. 4 Deflection evolution Slop-Initial strain diagram

Considering this positive result, the *fatigue failure cycles number-initial strain* diagram is, in a second step, drawn (Fig. 5). If we consider the Fig.5, we can make the following comments:

There is a critical initial strain threshold below which specimens do not break before 2 millions cycles, while below this threshold the rupture becomes inevitable. This threshold value is between 1.27×10^{-3} and 1.44×10^{-3}.

Beyond the threshold, there is a linear relation between the fatigue failure cycles number and the initial static strain.

Specimens having reached the 2 millions cycles were then reloaded in quasi-static test until rupture.

Average static curves, before and after 2 millions fatigue cycles are represented in the Fig. 6. For more legibility, we incorporate the min. and max. reloading static curves. We observe that the static bending behavior after 2 millions fatigue cycles is better than those related to the specimens not loaded in fatigue. The gain is about **6.5 %**. The deflection at the strength peak is approximately the same in the two curves.

Finally, if we consider the characteristic stress related to a strain equal to 1.27×10^{-3}, which is the lower value of the critical initial strain evocated above, we obtain a characteristic stress equal to 30 MPa, that corresponds to a loading ratio R of **0.65**.

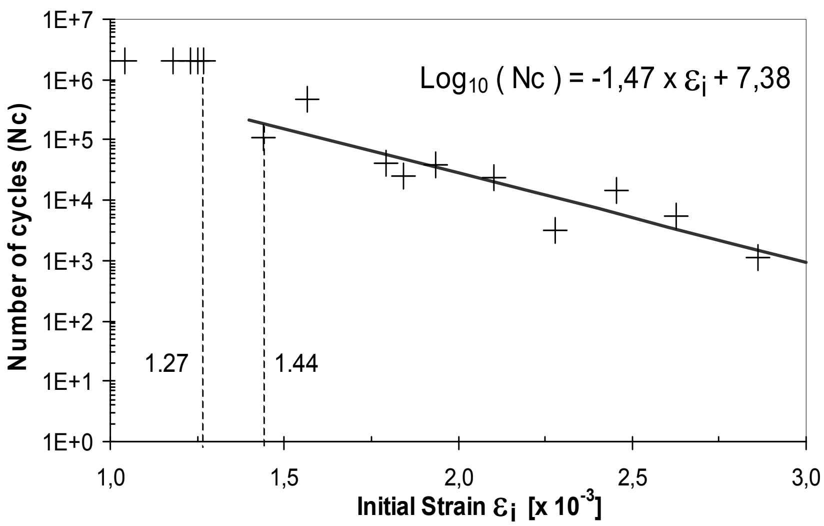

Fig. 5 Initial strain-number of cycles (at rupture) diagram

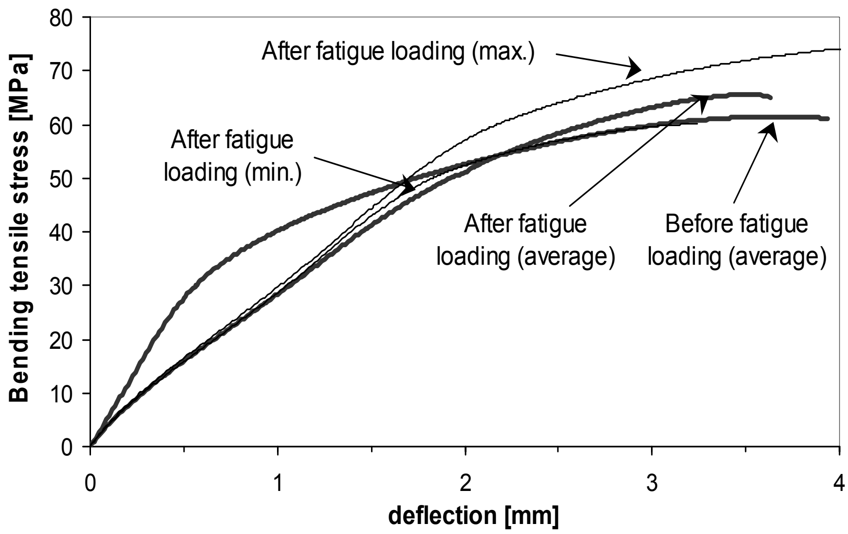

Fig. 6 Static behaviors before and after fatigue loading

4. Conclusion

A new ultra-high performance cement composite, the CEMTEC$_{multiscale}$®, was tested under static bending, stactic compression and under asymmetric fatigue bending. From this experimental study, the following comments can be made :

1. The average modulus of rupture (MOR) is equal to 61.5 MPa;
2. The average strain related to the average MOR is equal to 9.2 10^{-3}.
3. The stationary damage fatigue evolution of a specimen is dependent of the initial static damage of this specimen.
4. A critical initial static strain threshold exists. Before this threshold a specimen in CEMTEC$_{multiscale}$® does not fail during a bending fatigue loading and beyond this threshold the failure fatigue cycles number linearly depends of the initial static strain. The strain threshold determined in this study is between 1.24 x 10^{-3} and 1.44 x 10^{-3}.
5. Below a loading ratio R = 0.65, failure during bending fatigue test never appears with a specimen of CEMTEC$_{multiscale}$®.
6. A gain of 6.5 % is observed between the bending static behavior of the specimens being previously loaded in fatigue and those not being loaded in fatigue.

5. References

[1] ROSSI, P., ACKER, P., and MALIER, Y., "Effect of Steel Fibers at Two Stages : The Material and the Structure," *Materials and Structures*.1987, Vol. 20, pp. 436-439.