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Monotonically increasing compressive and creep tests on concrete cylinders retrofitted by carbon cloth

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Abstract

One of the still open problems relating to the reinforcement and/or the repairing of reinforced or prestressed concrete structures is the durability (held in time) of the composites applied to the structural elements.
At the LCPC a four years long research operation has begun in January 2000 relating to the use of carbon fibre fabrics for strengthening and repairing structures. One of the objectives of this operation is to answer the preceding interrogation. With this intention, an exploratory experimental campaign was also launched with these following tasks, which will be successively presented:
- creep tests on concrete specimens,
- monotonically increasing compressive load (static) tests on retrofitted concrete cylinders with modelling their properties,
- same tests on retrofitted concrete cylinders cut up from the specimen after two years of long term creep and shrinkage tests.

We have creep results, which have to be compared with the reference and we compare the static tests carried out after two years of long term load with those who were carried out initially on virgin concrete.

1 Introduction

On the following pages we would like to give you a short glimpse of our results from the last few years on retrofitted concrete specimens (Verók and Clément [1]). These experiments were made within a framework of a project at the LCPC

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for examining the application possibilities of the carbon fibre fabrics (TFC) in the field of strengthening or repairing the structural elements. Within this project we made some:

- creep tests on Ø16x100 cm concrete specimens, some being retrofitted by TFC and others without TFC, used as reference,
- static compressive tests on retrofitted Ø16x32 cm concrete cylinders with modelling their properties,
- same tests on retrofitted Ø16x32 cm concrete cylinders cut out from the Ø16x100 cm specimen after two years of long term creep tests.

On the creep specimens we have many results on the effect of the retrofitting under various load conditions that means a load, which may equal to 30% and 60% of the average compressive strength of the concrete at 28 days. There are some columns, which are still under load for future examination. We did not find any significant difference between the specimen retrofitted or not.
All the Ø16x32 cm concrete specimens were tested using an MFL test machine with the measurements of various deformations. The objective is to compare these static tests executed on the specimens, which were cut out from the creep specimens after two year long term load under controlled humidity and thermal conditions (20°C and 50% of RH) with those that were carried out initially on virgin concrete specimens. The comparison of these experiments and the model of the retrofitting will be presented. With these results, the strengthening of RC columns is now available.

2 Creep tests

The LCPC has a great experience in the creep and shrinkage measurements for a long time. In the laboratory there are some special rooms with controlled humidity and thermal conditions equipped with special measure frames connected to a central computer to assure the best condition of the measurement.
So, we loaded three Ø16x100 cm columns under 30% and 60% load in the beginning of 1999, which are seen in Figure 1.

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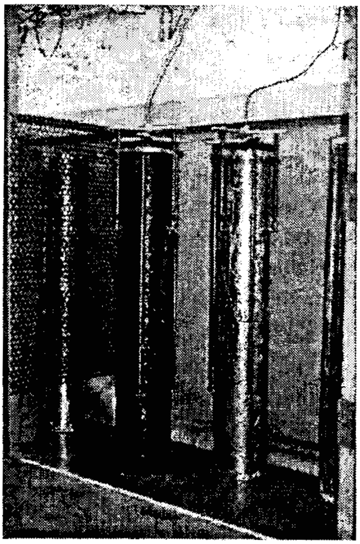

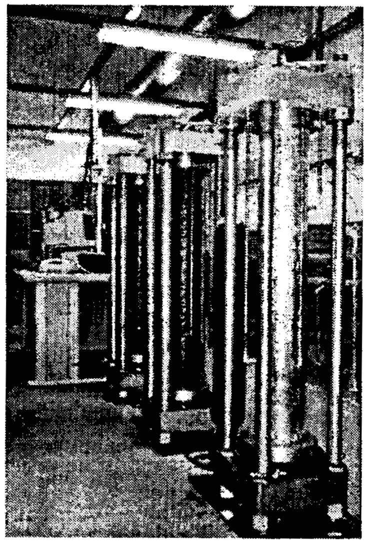

Figure 1: Creep specimens while measuring.

Since that time, the load and number of the specimens have been changed many times as it is shown in Table1. In this table you can find five names according to the five fabricated specimens. One after the other, TFC0 means a plain concrete specimen under 30% load, TFC1 means a retrofitted concrete specimen under 30%, TFC2 means a retrofitted concrete specimen under 60%, TFCret1 that is a plain concrete specimen without load and TFCret1 that is a retrofitted concrete specimen also without load.

Table 1. Load history of the creep specimens.

Date	Day	TFC0	TFC1	TFC2	TFCret1	TFCret2
		%	%	%	%	%
11.03.1999	0	0	0	0	0	0
01.06.1999	82	30	30	60	0	0
27.01.2000	322	0	0	60	0	0
23.03.2000	378	60	60	60	60	60
26.01.2001	687	0	0	0	60	60

At the beginning, the two last specimens were applied as retreat specimens that are references, which were used for measuring the net creep. The first date in the table is the date of the concreting of the specimens and the second is the start of the loading. After 240 days of loading, the load configuration was changed. Using a 56 days long exoneration period of time, all the specimens were loaded up to 60%. Another 309 days later, because the results showed that there were no significant difference between the creep of the retrofitted and the plain concrete

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columns, the load on the three first loaded columns was stopped and these specimens were cut into pieces for the static tests described later.
The load history of the specimens is shown in Figure 2. In this figure, all the curves are presented in a special scale on the abscissa for assuring the comparability of the creep on different load levels.
In the first load period until 322 days, there was 5.71% difference between the retrofitted (TFC1) and the not retrofitted (TFC0) specimens under 30% load. This is not significant if we consider that there is only one measurement on one specimen, the accuracy of measurement is about ± 14%, according to the previous experiments at the LCPC (Clément and Le Maou [2], [3]).

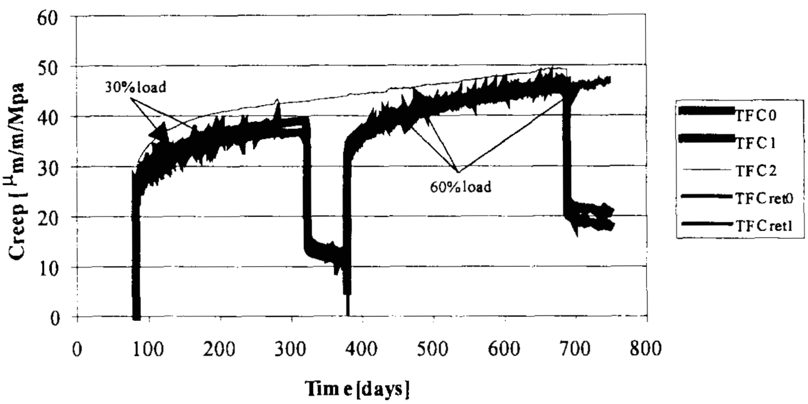

Figure 2: Creep curves measured until 26.01.2001.

After this first part, all the specimens were loaded up to 60% load, but the comportment of the columns was not changed, the curves stayed together. The one, who was loaded with 60% load at the beginning, had a little bigger creep, but the tendency of his evaluation was the same.
To explain this phenomenon, we built two hypotheses. According to the first, in the service limit state, the transversal deformations have little effect and the epoxy does not creep effects, or according to the second, the epoxy gives creep effects even so, and because of that, the TFC is not able to block the creep deformations.
In the reality, the structures to retrofit certainly have creep effects already. So, in this point of view, we decided to partially stop this experiment to examine the load carrying capacity of the two year old retrofitting, but we have not stopped all the creep test yet. There are two columns, the TFCret0 and TFCret1, which are under 60% load as it can be found in Table 1, too.
The main objective of this part of study is to be able to observe - or not – an influence of our tests conditions (two years at 50% RH) on the mechanical behaviour of the carbon cloth (with resin)

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3 Static tests

In this chapter the results of the static load tests will be presented. Firstly a short summary of the tests comes from '99 with the presentation of the developed model specimens (Verók and Clément [1]), and it follows the introduction of the recent one.

3.1 The "young" concrete mechanical behaviour

At the same time with the creep specimens, 6 pieces of Ø16x32 cm concrete cylinders were concreted with the same concrete property as it can be found in Figure 3.

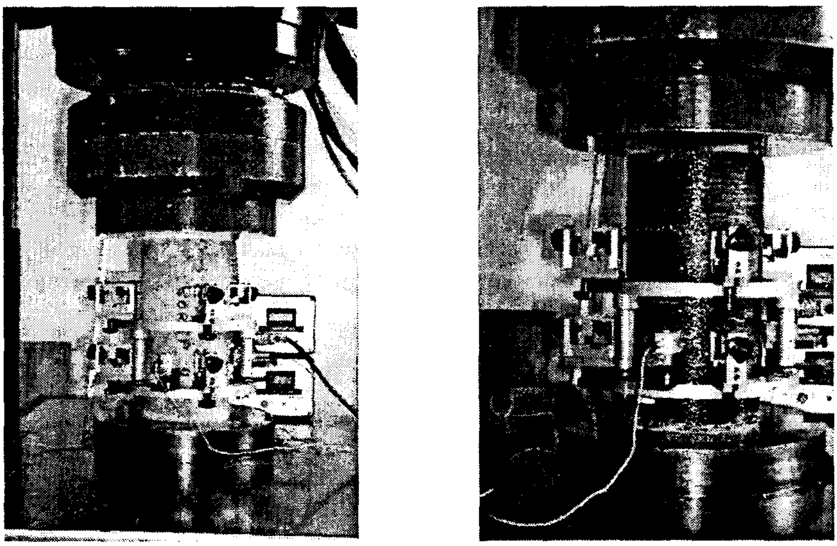

Figure 3: Static specimens while measuring.

Four of them were wrapped with TFC varying the winding: spiral and parallel ribbons. The results can be found in Figure 4.

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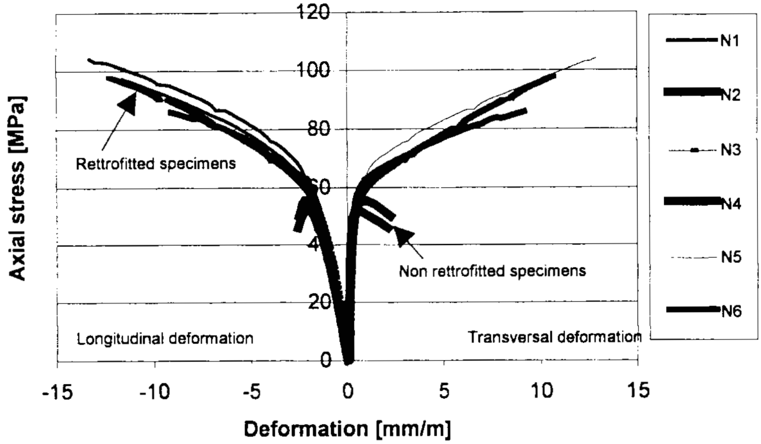

Figure 4: Compressive tests on the concrete at 28 days.

At lower load values, the reinforcement has no effect on the comportment of the specimens until the stress starts to approach the compressive strength of the plain concrete strength. At this point, the TFC displays his force and the specimens can carry more axial load. According to the experimental results, one can consider the reinforcement working efficiently and the augmentation of rupture stress is significant as it is in Table 2.

Table 2. The measurements on the "young" specimens.

Sing	**Ultimate Strength** [MPa]	**Young's Module** [MPa]	**Sign**	**Ultimate Strength** [MPa]	**Young's Module** [MPa]
Without TFC			*With TFC*		
N°2	55.4	40829	N°1	98.9	43591
			N°3	104.1	43482
N°4	52.2	40364	N°5	97.6	43252
			N°6	*85.9**	43914
verage	**53.8**	**40597**	**Average**	**100.2 (+86.25%)**	**43560**

In Table 1., the (*) means that this specimen was not involved into the calculation of the average stress value, for due to the debond a rupture effect appeared.
With these experimental results a model was developed for the epoxy glued carbon fibre tissue on the base of the studies of Mirmiran and Shahawy [4]. This model has good correlation with the experimental measurements on the young concrete specimens as it can be found in Figure 5.

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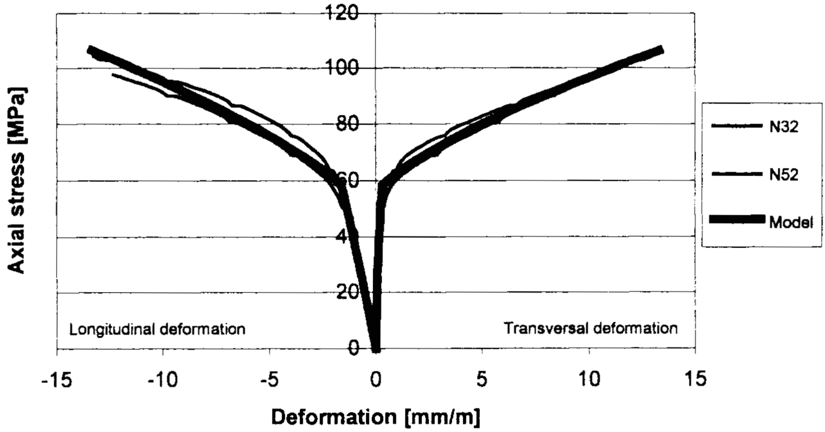

Figure 5: The model and the measurement.

3.2 The "aged" concrete mechanical behaviour

It was mentioned in Chapter 2. that these specimens were cut out from the creep specimens. In the followings we will show the reorganisation of the different specimens and after that we will instantiate the experimental results.

3.2.1 Fabrication of the new specimens

Accomplishing the large part of the creep tests, we had four two years old 1 meter high specimens from the same concreting that we used for the static experiments in '99. According to the cutting plan that is found in Figure 6., we got nine specimens to break.

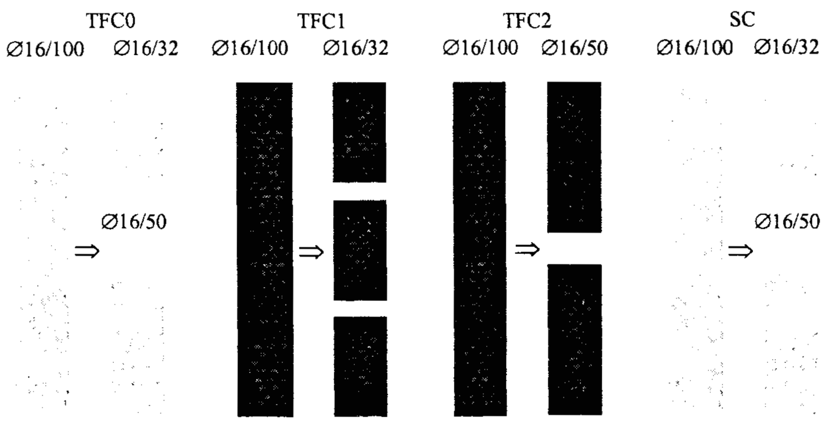

Figure 6: The cutting plan of the creep specimens.

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The names of the creep specimens have already been described except the "SC", which means a special column that was never ever loaded before. We decided to cut some 50 cm high specimens, too, to examine the size effects.

3.2.2 The test results

So, the same test series were made on the short columns cut out from the creep specimens, which were loaded for two years than in the case of the young specimens described in Chapter 3.1. The objective was to see whether there is any effect of the years under load on the comportment of the specimens.

The different comportment of the columns is in Figure 7., where there is one measurement for each kind of specimens, like a plain concrete specimen and a wrapped specimen from 1999 and from 2001.

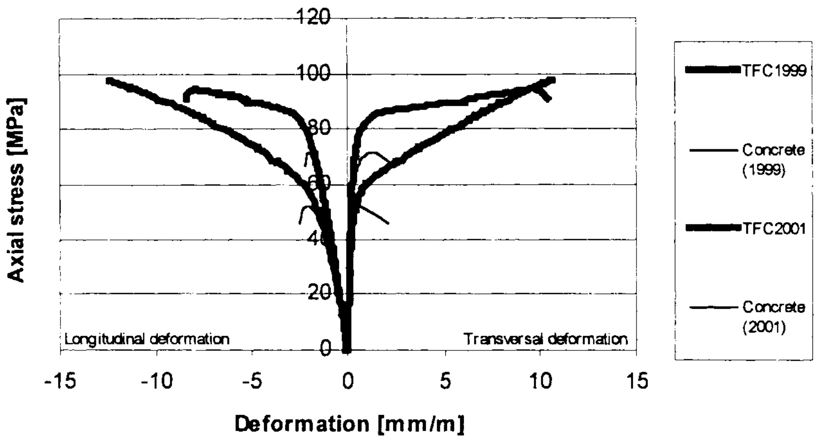

Figure 7: Comparing the experiments of the "young" and the "old" concrete.

The concrete strength grew up, certainly, with the progress of time (see the Concrete in 1999 and in 2001), but the rupture force was the same in all cases (see the TFC 1999 and 2001). It looks like that the transversal deformation is the rupture criteria of the composite structure : the FRP strain value at failure is the same in both cases. It means that the TFC keeps its tensional properties during the time.

We can say that the application possibility of TFC reinforcement on the structure that is under creeping or being crept is relatively weak. In spite of all, the ultimate capacity of the retrofitted specimens remained the same as it was in the young case, and the deformations capacity of these structures could grow up to 10 times bigger than by the plain specimens.

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Conclusion

According to the experiments we had done or we have been doing actually, we can state that:

- the composite fabrics that are glued on the concrete specimens have little effects in service state, they have no influence on the different deformations of concrete according to our two hypotheses:
    - in the service limit state, the transversal deformations have of little effect and the epoxy does not give creep effects, or
    - the epoxy gives creep effects even so, and because of that, the TFC is not able to block the creep deformations.
- the age of the reinforced structure is important, because the effectiveness of the retrofitting changes with time,
- the effect of wrapping the specimens starts after reaching the compressive strength of the concrete and it does not matter how old the concrete is,
- the wrapping kind have no influence on the comportment of the reinforcing,
- the TFC keeps its mechanical properties with time according to a two year long test series (20°C, 50% RH),
- additional examination is needed to develop a physical model to tackle the changing of the comportment of the retrofitting with time.

Acknowledgements

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The used carbon cloth was the TFC® of Freyssinet International.

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