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An experimental set-up for cyclic loading of concrete

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Abstract

Innovative cementitious composite materials are drawing considerable interest due to their substantially improved mechanical properties as compared to ordinary cement-based materials. Their enhanced ductility is promising and particularly suited to structural applications under severe dynamic loading conditions. Cyclic response is essential to understand the effects of loading and unloading on the material, as well as to understanding how it behaves in the transition from tension to compression. It is also fundamental to identify its properties in terms of energy dissipation and strain-rate sensitivity.
This paper presents the first part of an ongoing research project which aims to develop the constitutive relationship in innovative cementitious composites and its numerical implementation. Results from this research will facilitate the investigation of the ductility and durability of existing buildings.
In this paper, an experimental set-up for uniaxial cyclic loading is described. It was developed to study reversed cyclic compression/tension loadings of innovative cementitious composites. To set the cyclic loading process, cylindrical specimens of concrete were tested. All the tests were performed on a Zwick testing machine with 50 kN load cell. The machine was customised with accessories specifically designed to meet test requirements, avoiding instability and bending moments during the alternating phases of uniaxial compression and tension. Strain gauges were used to measure lateral deformations. The customized machine has shown good performance so far. In order to test specimens with a higher number of cycles and a higher loading rate, improvements to the machine are currently under development. These tests will allow greater insight into the ductility of innovative cementitious composite materials.

Keywords: innovative cementitious composites; cyclic testing; constitutive modelling.

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1. Introduction

Concrete is one of the oldest and the most used construction materials in the world, mainly due to its low cost, its availability and its long durability. Its principal components have always been water, cement and fine and coarse aggregates. It has adapted to ever new architectural and construction needs, becoming the material of choice for big buildings and infrastructure in the world designed to last centuries.

Today, pressing environmental issues require that new construction materials should have a better performance and an energy-efficient and sustainable manufacturing process. Green concrete can be designed through partial substitution of raw materials and partial replacement of clinker with alternative constituents e.g fly ash, blast-furnace slag or silica fume (Supplementary Cementitious Materials, SCMs). Alternative binders are being developed such as calcium sulfoaluminate cement, magnesium oxide based cement, geopolymers, CO2-cured cement (Alternative Cementitious Materials, ACMs), or Manufactured Cementitious Materials e.g. carbon nanotubes, nano-oxides of metal, graphene.

Nanotechnology can change the world of concrete. The most promising contemporary developments include the synthesis of new forms of carbon (Sobolev and Ferrada-Gutiérrez, 2005). In recent years, Politecnico di Torino started experimenting with small fractions of multiwall carbon nanotubes in cementitious materials, finding excellent mechanical properties but also problems related to functionalization and cost (Gillani et al., 2017). A solution was sought by incorporating biochar, which is the sub-product of biomass pyrolysis process, and is a fine, porous and light material, rich in carbon, with zero cost. Politecnico di Torino has investigated pyrolyzed nano/micro carbon particles obtained from hemp hurd, polyethylene beads and coconuts shells, waste bagasse fibers, hazelnut and peanut shells, and coffee powder. A standardized biochar has also been studied in view of a possible industrial production of biochar cement-based composites (Cosentino et al., 2019). Monotonic uniaxial compression and flexural tests have been carried out. Results obtained so far are promising and can be summed up as:

- improvement of the flexural strength of innovative cementitious composites
- improvement of fracture energy of innovative cementitious composites
- improvement of ductility of innovative cementitious composites

Figure 1 shows the Load-CMOD example curve obtained from the flexural test, that reflects how the post-peak load behaviour changes and how the area under the curve increases in the biochar-based composites, generating a bigger fracture energy. This behavior contrasts with the brittle nature of traditional cementitious materials.

Overall, these results are very promising and show that these innovative cementitious composites are particularly suited to structural applications under severe dynamic loading conditions (earthquakes, impacts, blasts) (Yoo and Banthia, 2016).

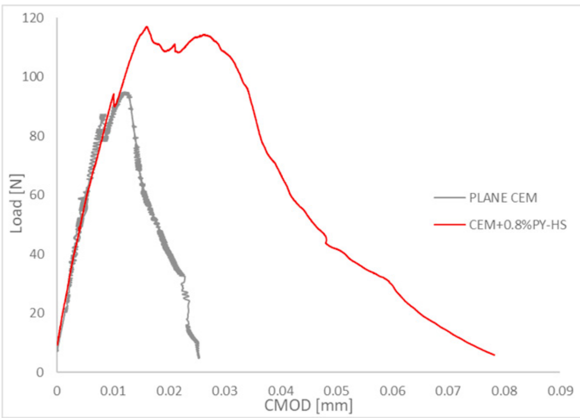

Fig. 1. Flexural test: Load-CMOD example curve.

To assess the effects of loading and unloading on the material it is essential to understand cyclic response. The behavior of the material can be examined through cyclic response in the transition from tension to compression. Cyclic response also allows the characterization of its properties in terms of energy dissipation and strain-rate sensitivity.

To date, very little literature is available. Jun et Mechtcherine (2010) investigated Strain-hardening Cement-based Composite (SHCC) under monotonic and cyclic tensile loading. The experimental results obtained served as a reliable basis for the development of constitutive relationships in SHCC. One relevant study is Kesner et al (2003) which evaluated the response of highly ductile fiber-reinforced cement-based composites (DFRCC) to uniaxial cyclic loading. Three different loading schemes were used: cyclic compression and two cyclic loading schemes that included reversals in load from tension to compression. All mechanical tests were performed under deformation-controlled loading regime. The DFRCC materials showed a distinctive loading and unloading response in both tension and compression. The inability of the fibers to retract into the matrix after pullout produced a low stiffness area in the cyclic stress-strain response. In compression, the behavior of the DFRCC materials was like traditional cementitious materials.

Present research describes an experimental set-up for uniaxial cyclic loading testing of cementitious materials. The objectives of research are:

- the investigation the specific behavior of innovative cementitious materials under cyclic loading
- the development of the constitutive relationship for cement-based composites under cyclic loading
- the evaluation of strength, deformability, and energy dissipation capacity of innovative cementitious composites, within the context of seismic assessment of existing buildings

2. Test Programme

To set the cyclic loading process, cylindrical specimens of concrete were used. The specimens were extracted using a core drill from a hardened concrete block. Then, they were carefully examined and prepared by levelling and subjected to compression testing using the normalized procedures. This concrete was characterized by a compression strength of about 40 MPa and a maximum diameter of aggregate equal to 14 mm. A series of homothetic specimens (height to diameter ratio fixed as 2) were tested, with a diameter of 44 mm to ensure a ratio 1:3 between the maximum size of the aggregate present in the concrete and the diameter of the specimen in order to not influence the resistance measured.

Cyclic alternate compression/tension tests were examined to investigate how the material behaves in the transition from compression to tension phases. All the tests were performed, under force-controlled regime, considering so far quasi static strain-rates defined in literature by Kesner et al. (2003). In order to be able to perform both compression and tension tests, the Zwick testing machine with 50 kN load cell (Figure 2) was customized with two circular steel plates carefully bonded to the specimen's end faces with epoxy resin. These plates have four holes to bolt them to the testing machine plates. A swivel was used above the specimen's end caps. The bottom end cap of the specimens was fixed. These accessories avoid instability and bending moments during the alternating phases of uniaxial compression and tension. Two HBM 120 Ohm strain gauges were used to measure lateral deformations. A dummy gauge was also used to compensate the electrical resistance. The data acquisition system HBM QuantumX was used to acquire signal and sensor information. Two different loading schemes were applied: cyclic compression and reversed cyclic tension/compression loadings (Table 1). Precautionary test parameters were used to not damage the testing machine and the instrumentation. A low number of cycles and loading rates equivalent with the elastic field of the material were used. A traction to compression ratio of 1/10 was adopted.

Table 1. Test programme.

Type of loading	Specimen N°	Number of cycles	Loading rates [N/s]	σ_{max} [N/mm^2]	σ_{min} [N/mm^2]
Compression loading	1	10	38	-9.86	-0.07
Compression loading	2	3	380	-9.86	-0.07
Compression loading	3	100	3800	-9.86	-0.07
Compression loading	4	100	7600	-9.86	-0.07
Compression loading	5	300	7600	-29.59	-0.07
Compression/Tension loading	A	3	38	-3.29	0.33
Compression/Tension loading	B	10	380	-3.29	0.33
Compression/Tension loading	C	10	380	-9.86	0.99
Compression/Tension loading	E	17	380	-9.86	0.99
Compression/Tension loading	F	14	380	-9.86	0.99

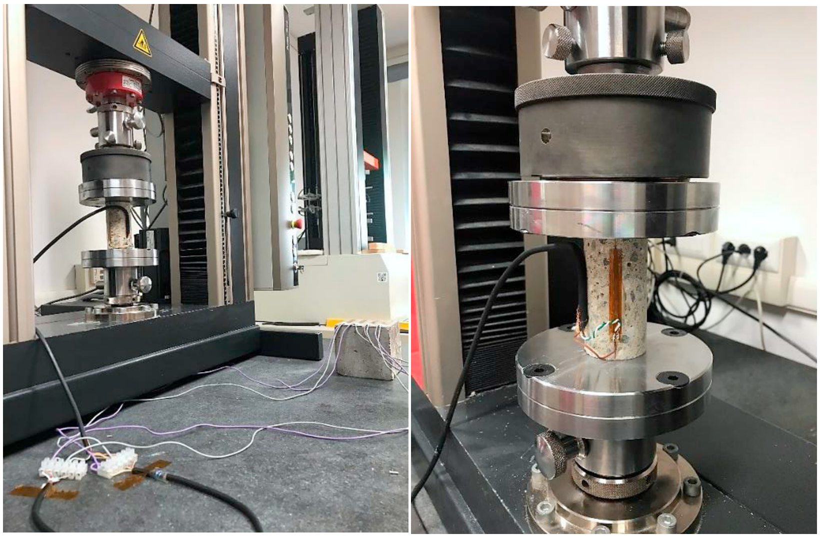

Fig. 2. An experimental set-up for cyclic loading of concrete.

3. Test Results

The customized testing machine has shown good performance so far. Improvements to the experimental set-up are currently under development. Some difficulties concerned the bonding of the steel plates to the specimen's end faces using epoxy resin. The achievement of the flatness of specimen's end faces was also delicate. All these factors could induce bending moments during the alternating phases of uniaxial compression and tension.

The mechanical tests allowed to set the cyclic loading process. To date, very few results are available. The Figures 3 and 4 show an example of results obtained by cyclic compression testing of concrete. The light blue and the dark blue signal are superimposed, corresponding respectively to 100 and 300 compression cycles (Figure 3). The specimen n°4 was subjected to a compression loading from -0.07 to -9.86 MPa. The specimen n° 5 was subjected to a compression loading from -0.07 to -29.59 MPa. In both cases, a loading rate of 7800 N/s was used. Deformations of the specimens are shown in the Figure 4. The Figures 5 and 6 show an example of the results of reversed cyclic tension/compression testing of concrete. The dark grey and the light grey signal are superimposed, corresponding both to 10 cycles (Figure 5). The loading was applied from 0.33 to -3.29 MPa on the specimen n° B and from 0.99 to -

9.86 MPa on the specimen n° C. In both cases, a loading rate of 380 N/s was used. Deformations of the specimens are shown in the Figure 6.

These tests will allow to test innovative cementitious composite materials under reversed compression/tension cyclic loading. They also will allow greater insight into the ductility of innovative cementitious composite materials.

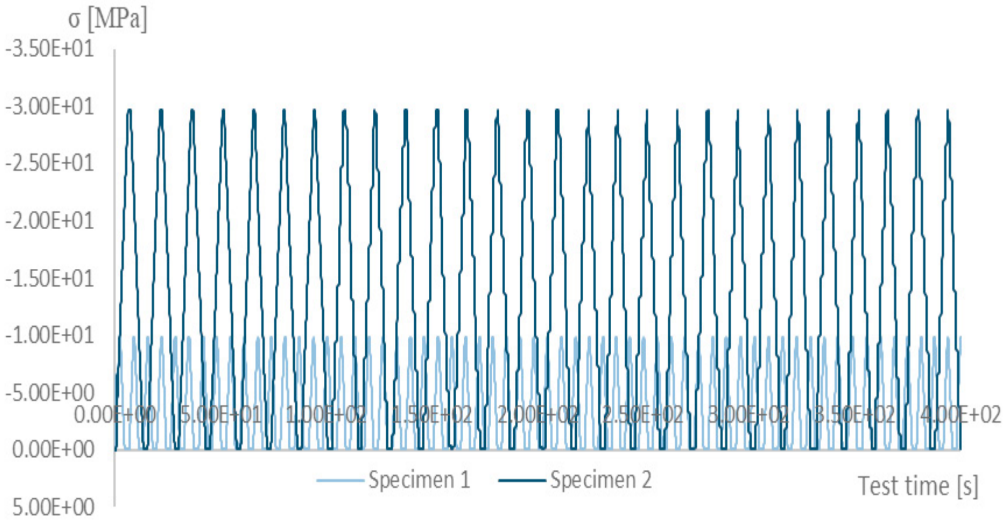

Fig. 3. Compression loading: σ-t diagram.

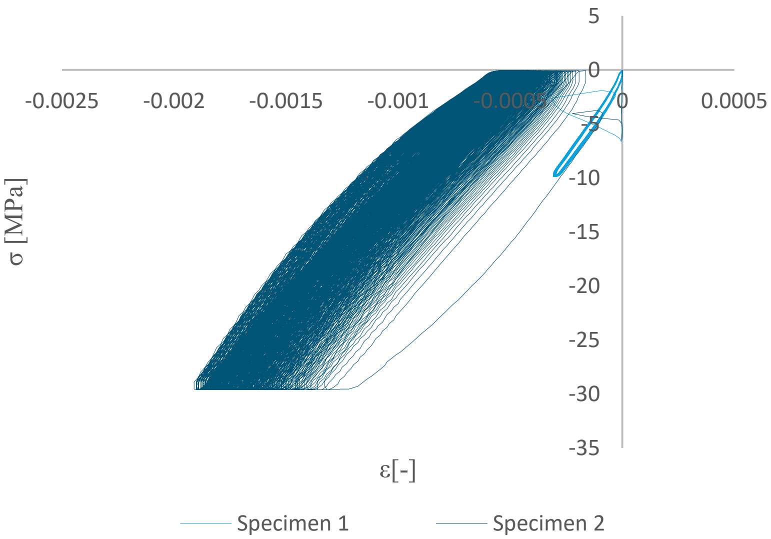

Fig. 4. Compression loading: σ-ε diagram.

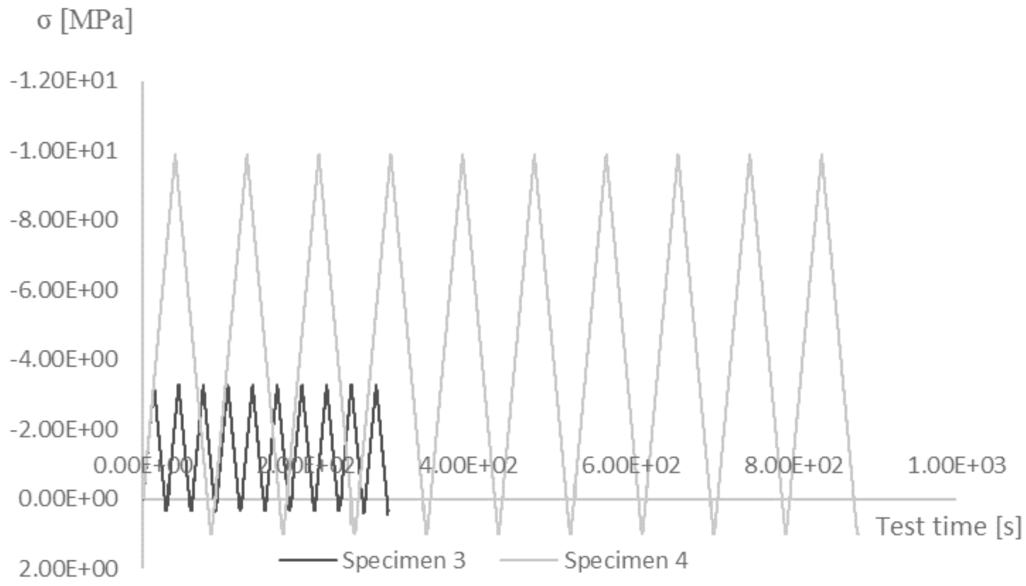

Fig. 5. Compression/tension loading: σ-t diagram.

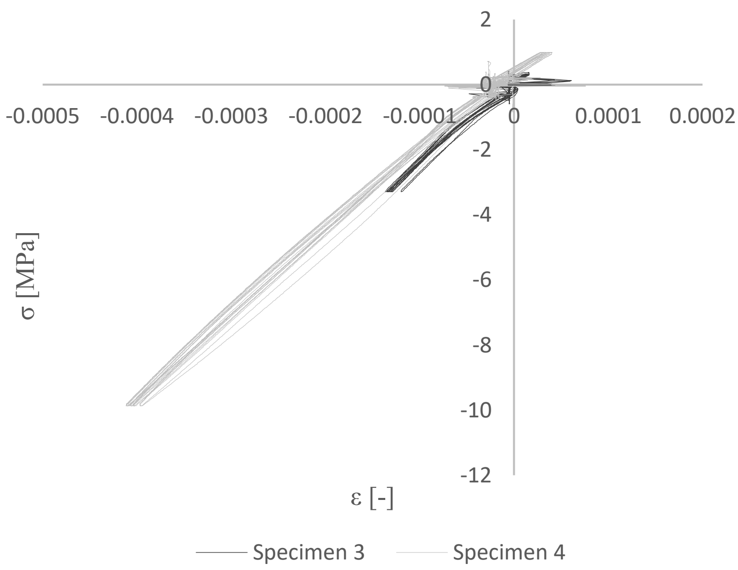

Fig. 6. Compression/tension loading: σ-ε diagram.

4. Conclusions and future developments

Innovative cementitious composites showed improved mechanical properties compared to conventional cementitious materials: among the others, higher tensile strength, tensile strain hardening, flexural strength, fracture toughness and resistance to fatigue.

This paper presents a first part of an ongoing research project which aims to investigate the response of innovative cementitious composites to cyclic uniaxial loading. An experimental set-up was developed to study reversed cyclic compression/tension loadings of innovative cementitious composites. This set-up will allow greater insight into the ductility of innovative cementitious composites. Results from this research will facilitate the investigation of the durability of existing buildings.

One next step of research will be the evaluation of the influence of scale effects, testing specimens with different dimensions. Ferro and Carpinteri (2008) analyzed the size effects in compression on drilled cylindrical concrete specimens. Experimental results showed scale effects on dissipated energy density rather than on the compressive strength.

The variability and reproducibility of the testing results will be considered by employing a minimum number of three specimens per loading condition. Moreover, the comparison between cored specimens and specimens cast in moulds will be investigated in order to evaluate the disturbing effects of the coring on the resistance measured.

In both cases, results will represent a reliable basis for the development of constitutive models suited to numerical simulation in innovative cementitious composites.

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