·Home
·Table of Contents
·Civil Engineering

Internal Strain Measurements in Concrete Specimens in Compression

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Abstract

Various applications of fibre optic strain sensors on cementitious materials are reported in literature. A new application is reported in this paper.
It has been designed in order to satisfy a specific need which arose in an experimental research. Our aim was to evaluate the strain in the core of concrete cylinders, avoiding any disturb to the stress state. To this purpose, we chose these innovative sensors and we inserted them into the concrete specimen, without any protective jacket. The performance of fibre optic sensors was very good, and allowed to validate the theoretical model supposed. The results obtained showed that the concrete in the core of the specimen has a behaviour independent from the shape and dimensions of the specimen.

Keywords : Concrete, Embedded, Fibre Optic Sensor, Strain, Compression, Damage.

Introduction

The stress and strain distribution in concrete specimens tested in compression isn't uniform. This is caused by different factors, as the material's inhomogeneity, the friction between sample and plates of the testing machine and progressive damaging of the external layers. The traditional methods are able to measure the external local strain and the average longitudinal strain, but not the internal strain. This paper deals with a joined research, in which the internal strain distribution in compressed concrete cylindrical specimens had to be determined.
In order to satisfy this need, fibre optic sensors (FOS) have been selected.
The authors tested this kind of sensors in other applications, such as monitoring of both steel internal reinforcements and fibre reinforced polymer (FRP) external strengthenings of r.c. beams (Bonfiglioli et al.,1998), (Pascale et al.,1999), (Arduini et al.,1999).

Background

Some studies concerning the application of FOSs to concrete and mortar were carried out by other researchers. A useful review of the state-of-the-art in the applications of FOS to cementitious composites is reported in (Ansari,1997). In particular, Ansari and co-authors developed a fibre optic sensor for determination of the air content in freshly mixed concrete (Ansari et al.,1991). Other researchers studied the crack's growth inside in concrete caissons using FOSs (Rossi,1989). A fibre optic sensor to be embedded in cementitious composites in order to measure displacements associated with the opening of microcracks was developed by Lee and co-workers (Lee at al.,1997). Nanni et al.(1991) analyzed the interface bond characteristics of the fibre optic sensors with respect to the surrounding concrete matrix. Glišic et al.(2000) applied a 60 cm long fibre optic sensor in monitoring of a concrete slab at very early age. A novel optical fibre sensor for detecting cracks and monitoring their opening was developed by Leung et al. (2000).
Another research refers to sensors embedded in silicon rubber to which two thin metal strips were attached (Habel et al., 1997).

In the above-mentioned researches, it can't be found an application aimed to measure the internal strain in concrete by a sensor directly embedded.
The main scope to be achieved in our work is to acquire the internal strain distribution in a small size specimen without absolutely affecting the stress state.
For this reason we avoided to use the commercial embedding type sensors which are usually protected by a steel jacket and with flanges. Such a sensor type is described by Quirion and co-workers (Quirion et al.,1998), where the aim was to test the effectiveness of working principle of this sensor.

Experimental Programme

Cylindrical Specimens
Two concrete cylinders have been tested in compression, see testing arrangements reported in figures 1 and 2. Both cylinders were 155.5 mm in diameter. The first was 235 mm in height, the second 620 mm. The concrete specimens were cast in plastic not reusable moulds.


Fig 1: Testing arrangement of cylinder n°1


Fig 2: Testing arrangement of cylinder n°2

The concrete had characteristic compressive strength equal to 25 MPa and it consisted in:

Cement grade 42.5	350	kg/m^3
Water	162	kg/m^3
Sand 0-5 mm	822	kg/m^3
Gravel 5-15 mm	524	kg/m^3
Gravel 15-22 mm	527	kg/m^3

The mix was compacted by an immersion vibrator .

Fibre Optic Sensor
The fibre optic sensor employed is based on a Fabry-Pérot interferometer.
In this kind of sensor the sensible part consists in two parallel, semi-reflective mirrors perpendicular to the axis of the fibre, namely Fabry-Pérot cavity. The light is originated by a LED source and it travels through the fibre cable until the cable end. An interference pattern is created by the reflections of the two mirrors, then the light signal is modulated and reflected back to the readout unit. This device works as an optical cross correlator with a space varying cavity length.
Since the Fabry-Pérot cavity is bounded to the materials subjected to strain, its length varies with the strain field. In the readout unit each value of the Fabry-Pérot cavity length is associated to a strain value.

Testing set-up
Both specimens were instrumented by:

- three electrical 10 mm rosettes, bounded on the external surface and placed in the same generatrix, at different high;
- two displacements transducers, placed in symmetrical position with respect to the cylinder, in order to measure the mean relative displacement between the plates of the testing machine;
- a fibre optic strain sensor, placed on the longitudinal axis and in the middle section, along a diameter, in order to measure the transversal strain of the cylinder's core.

A particular procedure was followed in order to realise a correct placement of the FOS.

Some features had to be guaranteed:

- only the end portion of the fibre must be perfectly embedded in concrete, in order to avoid damage due to strain and cracking of the cylinder's external layers;
- the fibre optic cable inside the concrete specimen must be protected without affecting the stress state;
- the sensor has to be correctly aligned;
- the fibre cable must pass through the mould;
- a particular attention has to be paid to the arrangement and cable handling.

The sensible portion of the FOS is about 1.4 mm long and it is located at 10 mm from the cable end. To minimise the disturb, the FOS was embedded without any protective jacket. A particular procedure was applied.

FOS embedding procedure

To allow to the fibre cable to exit from the external surface of the cylinder, a little hole was previously drilled in the plastic mould.

In order to protect the cable, a specific and very small steel pipe was used. This allowed to guarantee the perfect alignment of FOS in order to acquire the strain in the wanted direction. The pipe was fixed to the mould, in order to keep it horizontal and to protect the bare part of the cable.

The fresh concrete was cast with particular attention and subsequently it was compacted by an immersion vibrator. During these operating phases the FOS was continuously monitored in order to check its behaviour. Some strain variations were observed during the vibration, but any residual strain was recorded after casting and vibration.

The moulds had been designed in order to allow to be taken away without damaging the steel pipe. The specimens were cured in water and even in this phase the FOS was periodically read: no significant strain variation was observed.

Experimental results

The experimental results and following conclusions are presented in this section.

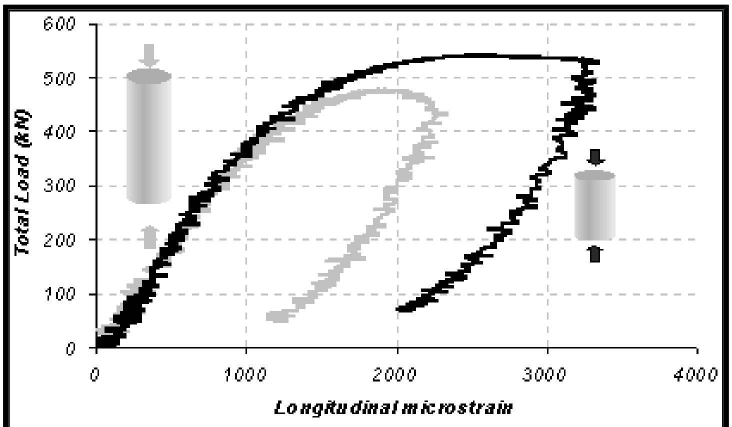

Fig 3: Longitudinal microstrain Vs. total load

In fig. 3 the total load-longitudinal strain is showed, for both specimens. We can observe that the initial slope is the same. The longer cylinder has lower compressive strength and lower ultimate strain.

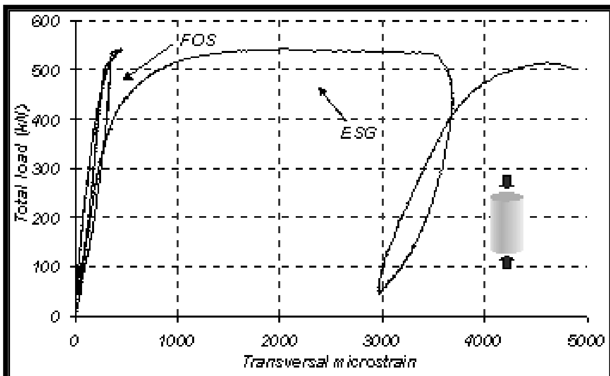

Fig 4: Transversal strain Vs total load for cylinder n°1

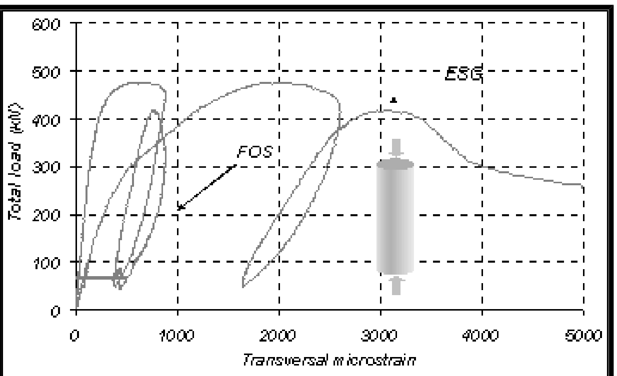

Fig 5: Transversal strain Vs total load for cylinder n°2

The total load-transversal strain curves of the cylinder n°1 and n°2 are represented in figures 4 and 5, respectively. For each specimen, the strain was measured by both electrical strain gauges (ESGs), externally glued, and fibre optic sensor (FOS), inserted in the concrete core.

The strain of the external layer is very higher than the core's one. This effect is more evident for the longer cylinder.

In fig. 6 the curves reported are cut at the end of the ascending branch and they give us a very useful and important information. We can note that the transversal strain measured in the cylinder core is the same in both specimens. Comparing the plots of figures 3 and 6, we can observe that the curves diverge at about the same load for both specimens. This means that up to this load, the concrete core isn't macroscopically damaged; in fact the stress state depends on the actual cross section.

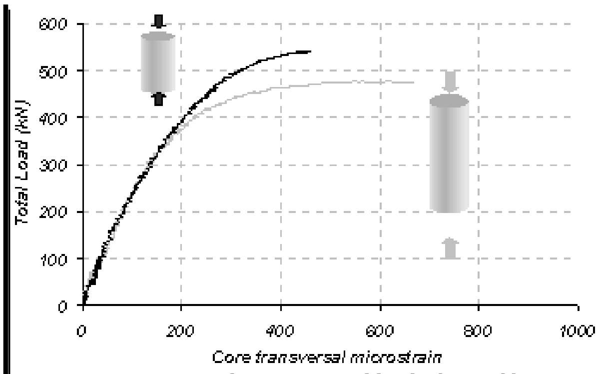

Fig 6: Core transversal strain Vs total load, obtained by FOS

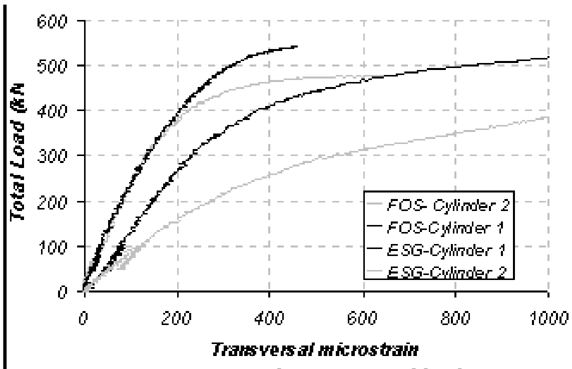

Fig 7: Transversal strain Vs total load

In fig. 7 the data obtained by ESG externally glued are added to the previous data. The external strain highly differs from the internal one. This result was expected because the external layer is damaged more quickly than the core (Ferretti and al., 1999). This behaviour is more notable for the longer cylinder, for which the resisting area degrades faster. The damage of the external layer affects the transversal strain much more than the longitudinal strain, as it is clear by comparing the plots of figures 3 and 7.
For the same reasons we can observe a great difference between the values of the Poisson's ratio, represented in figures 8 and 9.

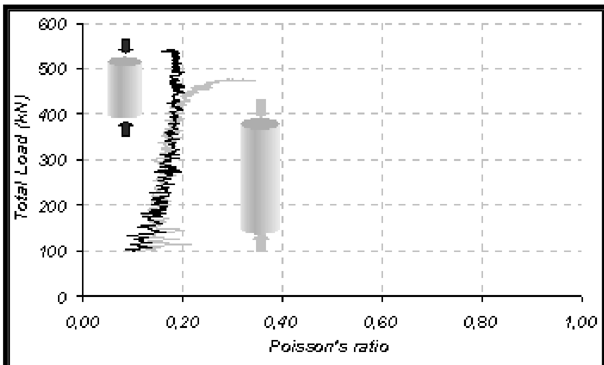

Fig 8:Poisson's ratio Vs total load, obtained by FOS

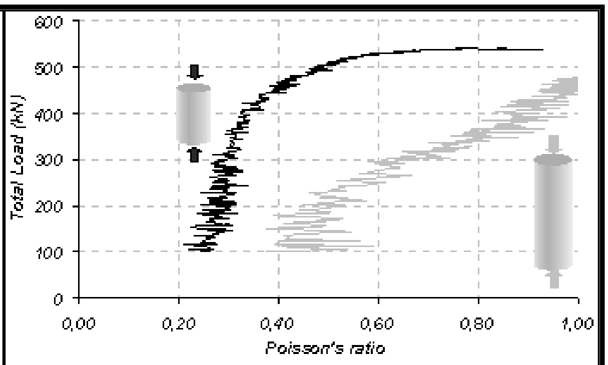

Fig 9: Poisson's ratio Vs total load, obtained by ESG

The true values of the Poisson's ratio for concrete are the ones of fig. 8, obtained by FOS and referred to the cylinder's core.

Conclusions

The research gave some useful results.
Fibre optic strain sensors make it possible to measure the internal strain state without any disturb to the stress state of the specimen, independently on their dimensions.
They can survive and work well into the concrete also without any protective jacket.
The effectiveness of the data obtained by FOS is confirmed by the values of some parameters, like the transversal strain measured and Poisson's ratio calculated.
The data acquired only by ESG could not allow these conclusions.
We can conclude that these kind of strain sensor is very useful in experimental testing of concrete specimens.
The success of this experimental research encourages the application of this technology, which could also be able to realize a monitoring of the internal strain state of structures.

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 |Home| |Top|