Development and experimental investigations of extrinsic Fabry–Pérot interferometric sensor-bonding techniques for strain measurement in concrete and metallic structures

Subhash Chander Jain, Nahar Singh, J. K. Chhabra, Veto Varma, J. J. Charan, K. K. Vaze, A. K. Aggarwal, H. S. Kushwaha, S. C. Dhawan and R. P. Bajpai

Fibre-optic sensors are making revolutionary impact in various application areas such as industry, civil structures, novel materials, medicine, aerospace, power generation, transportation, military and scientific research. More recently, fibre-optic sensors have emerged as the key enabling technology for health monitoring of advanced civil and aerospace structures and materials and realization of futuristic smart and intelligent buildings. They provide a nervous system capable of sensing changes while being part of the structure itself, thus allowing measurement of critical parameters. This *in situ* monitoring capability of bonded/embedded fibre optic sensors offers the measurement tools required to optimize the design of advanced composite materials and concrete/metallic structures, monitor fabrication processes for improved quality control and detection of operational overloads to provide advance warning of catastrophic structural failures.

As the area of structurally bonded/embedded optical fibre sensors is evolving rapidly, it is important to reduce/eliminate the sensitivity of various leads. The Extrinsic Fabry–Pérot interferometric (EFPI) sensor offers the advantage of simple construction, single-ended operation, high resolution and accuracy, as well as low cost. Compared to conventional strain gauges, it offers the unique ability to be suspended within the matrix portion of the composite system and could provide a viable alternative for assessment of internal strain state of structures. Operation of an EFPI basically depends on an air cavity working as a low finesse two-beam Fabry–Pérot interferometer[1].

Optical fibres are fragile entities, and civil structures present a hostile and harsh environment for deployment of optical fibres. For a marriage of these two extremes, special bonding/embedding techniques need to be developed to take advantage of the potential benefits offered by optical fibre sensors for structural health monitoring. Experimental investigations were undertaken and techniques developed for bonding of EFPI sensors on concrete and metal structures, and performance compared with conventional strain gauge. To develop bonding techniques, it is important that the interfacial bonds so created are able to transfer the strain faithfully from the specimen to the sensor. In the present study, both commercially available and indigenously developed EFPI sensors were bonded to metal and concrete specimens and their performance compared with the conventional strain gauge. The basic procedure developed and implemented comprises of the following basic steps: surface prepa-

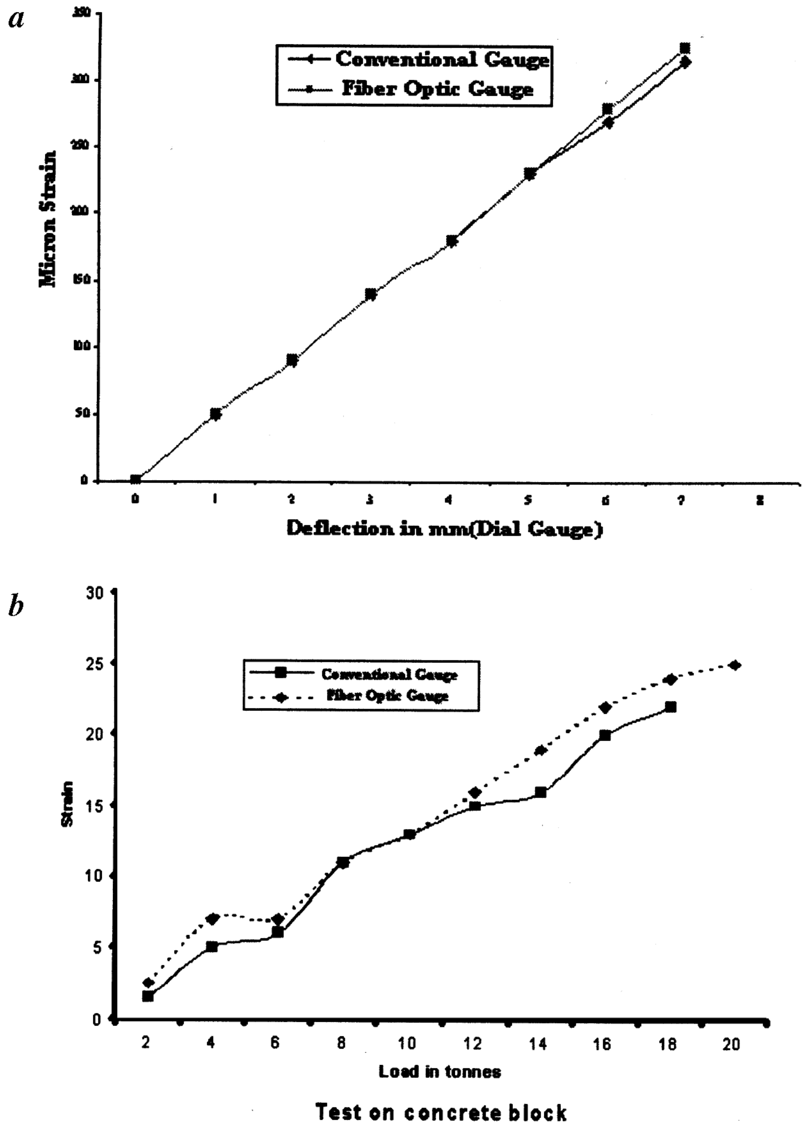

Figure 1. Strain response of EFPI sensor and conventional strain gauge bonded to (***a***) ASTM cantilever steel beam and (***b***) a concrete block loaded under UTM.

ration, bonding of EFPI and foil gauge, and application of protective coatings.

Prior to bonding of EFPI strain gauge, a proper surface preparation is important as it is critical to good bonding. The procedure for bonding of EFPI gauge involves the following basic steps: (i) Grinding and smoothening of the concrete specimen surface using 220-grade emery paper and 340-grade emery paper, followed by cleaning it with a gauge piece. (ii) Cleaning the area with a conditioner liquid (isopropyl alcohol) followed by further cleaning with a neutralizer (ammonia liquid). (iii) Mounting an EFPI gauge and a conventional gauge side-by-side (gap ~ 10 mm). (iv) Covering the EFPI gauge with a suitable epoxy and allowing it to cure.

Gloves were used during the installation procedure to prevent contamination of the strain gauge and installation surfaces. Following the above steps, an EFPI sensor was bonded to an American Strain Testing and Measurement (ASTM) Standard. Its performance under varied beam deflections was studied and a satisfactory correlation (Figure 1) was observed. In another study, an EFPI sensor was bonded to a concrete block (6″ × 6″ × 6″) which was subjected to compressive loading under a Universal Tensile Machine (UTM). The applied load was first measured with a load cell, and strain data from both the strain gauges were recorded by varying the load in steps of 2 tons up to a maximum of 20 tons (limit of the load cell). As shown in Figure 1 *b*, a satisfactory correlation was observed between the strain values indicated by both the gauges. Further, the load cell was removed and the applied load was read directly from the pressure gauge of the UTM. This loading experiment was repeated in steps of 5 tons, and the conventional gauge indicated sudden jump in strain values from –30 to 220 microstrains, signifying a stage of fracture load. The fracture line appeared to be crossing the conventional gauge but not the EFPI gauge.

An indigenously developed EFPI sensor was also bonded to an aluminum cantilever beam along with a conventional strain gauge. Important design parameters of this sensor are: size of single mode fibre, 7/125 μm; ID/OD of silica capillary, 150/250 μm; width of Fabry–Pérot air cavity, 46 μm and gauge length, 12 mm. The performance of this sensor was found comparable with that of the conventional gauge[2,3].

---

1. Eric, U., *Fibre Optic Smart Structures*, John Wiley, NY, 1995.
2. Jain, S. C., Singh, N., Aggarwal, A. K. and Bajpai, R. P., In Proc. PHOTONICS 2002, TIFR, Mumbai.
3. Singh, N., Jain, S. C., Aggarwal, A. K. and Bajpai, R. P., *Curr. Sci.*, 2004, **86**, 309–314.

ACKNOWLEDGEMENT. Financial assistance provided by the Board of Research in Nuclear Sciences, Department of Atomic Energy, is acknowledged.

Received 17 March 2004; revised accepted 13 May 2005

Subhash Chander Jain, Nahar Singh, J. K. Chhabra, A. K. Aggarwal and R. P. Bajpai are in the Coherent Optics Division, Central Scientific Instruments Organization, Sector 30, Chandigarh 160 030, India; Veto Varma, J. J. Charan, K. K. Vaze and H. S. Kushwaha are in the Reactor Safety Division, Bhabha Atomic Research Centre, Mumbai 400 085, India; S. C. Dhawan is in the Department of Information Technology, Chandigarh Administration, Chandigarh 160 009, India*
**For correspondence.*
e-mail: scj_42@rediffmail.com

MEETINGS/SYMPOSIA/SEMINARS

8th National Symposium on Soil Biology and Ecology

Date: 5–7 October 2005
Place: Thanjavur

The scientific programme involves: soil bacteria, soil fungi, soil algae and other microflora, soil mesofauna, soil arthropods, earthworms, nematodes and soil biota in human welfare.

Contact: Dr. C. Lakshminarasimhan
Ponnaiyah Ramajayam College
Thanjavur 614 904
Phone: 4362-236707
E-mail: prcprinci@prcolleges.com

Post-graduate Skill Development Course in Animal Cell Culture and its Applications

Date: 10–14 October 2005
Place: Madurai

Topics include: Basics of cell culture; Primary (mouse and chick embryo) culture; Cancer cell culture; Monitoring of cell transformation; Biologicals from cultured cells.

Contact: Dr. G. Shanmugam
Director, Oncophyta Labs
3/118c, Palkalai Nagar East
Madurai 625 021
Phone: 0452 245 8228
Fax: 0452 245 9586