Smart Concrete: Electronic Sensors Innovation description

What the innovation is

The innovation is the invention of smart concrete, which is concrete that is itself a sensor of strain or stress. The sensing ability is not due to the embedment or attachment of sensors. Rather, the concrete has been modified through the use of admixtures so that it becomes a sensor. Without the admixtures, the sensing ability is poor. The sensing ability is associated with the reversible change of the electrical resistance of the concrete upon deformation in the elastic regime. The extent of the effect is described by the gage factor, which is defined as the fractional change in resistance per unit strain. The gage factor is up to 700, in contrast to the value of 2 for a typical commercial strain gage, which involves metals rather than concrete. Thus, the smart concrete is a highly sensitive strain gage. Since strain and stress are proportional to one another in the elastic regime, strain sensing also means stress sensing. Since stress is force per unit area, stress relates to force. Hence, the smart concrete can serve as a scale for weighing.

Why it is innovative

The concept of concrete itself functioning as a sensor has not been put forth prior to this innovation. Prior concept involves the embedding or attaching of conventional sensors (such as conventional strain gages). The change of electrical resistivity with strain is a phenomenon known as piezoresistivity (not piezoelectricity). Piezoresistivity has not been observed in cement-based materials prior to this innovation. In fact, such strong piezoresistivity (as indicated by the abovementioned exceptionally high value of the gage factor) has not been reported in any material (including materials based on polymers, metals, carbons, ceramics, etc.) prior to this innovation. The origin of the strong piezoresistivity of smart concrete stems from a new mechanism of piezoresistivity - a mechanism that has not been put forth for any piezoresistive material prior to this invention. This mechanism involves the discontinuous carbon fiber used as an admixture in the smart concrete bridging microcracks and getting slightly and reversibly pulled out upon tension, thereby increasing reversibly the electrical resistivity of the concrete. The reverse occurs upon compression.

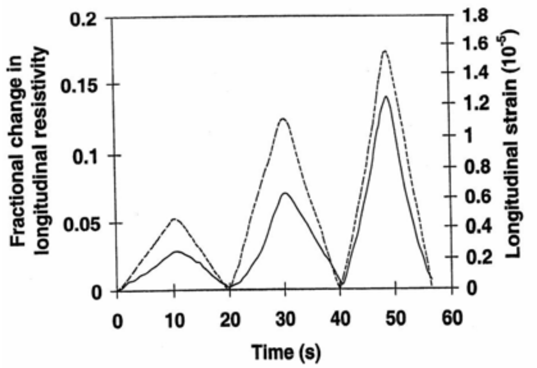
What it changed or replaced

Smart concrete replaces the need for embedded or attached sensors, which suffer from high cost, low durability, limited sensing volume and, in case of embedded sensors, degradation of the structural performance of the concrete.

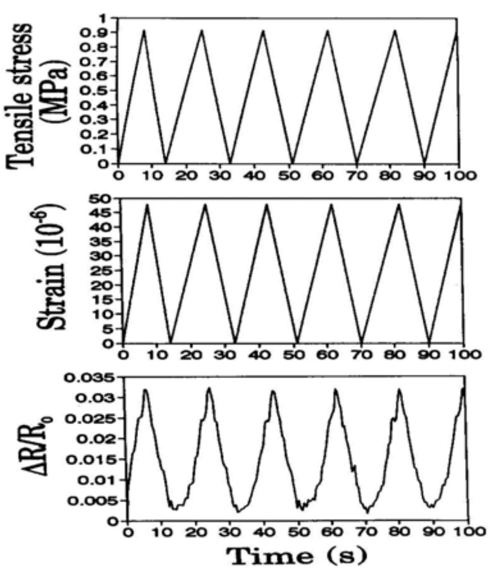
Where and when it originated, has been used, and is expected to be used in the future

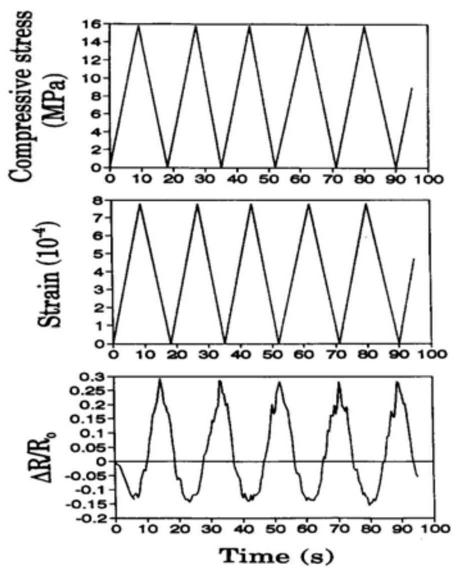
The innovation originated in the laboratory of Professor Deborah Chung in University at Buffalo, State University of New York. The first report of this innovation was made by Chung and her graduate student in a refereed research paper published in the professional journal *Smart Materials and Structures* in 1993. After this, numerous other research papers by Chung and her graduate students have been published in various professional journals (including *Cement and Concrete Research*, *ACI Materials Journal*, *ASCE Journal of Materials in Civil Engineering*, etc.) in relation to the strain sensing performance, the effects of various admixtures on this performance, and the physical origin of the piezoresistivity. A U.S. patent on this invention has been issued. This innovation is expected to be used in traffic monitoring, border monitoring, weighing in motion and building security. In addition, it is expected to be used for building facility management, i.e., the use of smart concrete to weigh each room of a building, thereby monitoring the room occupancy in real time, thereby allowing the lighting, heating, cooling and ventilation to be controlled in accordance with the room occupancy for the purpose of saving energy.

Smart Concrete: Electronic Sensors Innovation Illustration

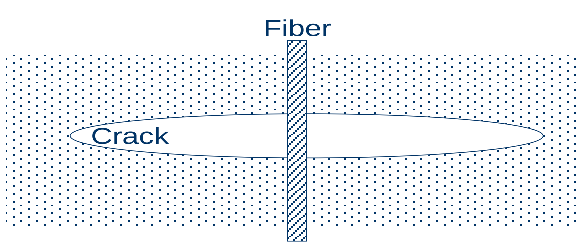


Graph to the left shows that the electrical resistivity fractional change correlates with the strain (measured with a conventional strain gage) in the same direction (longitudinal) for three loading cycles at progressively increasing strain amplitudes. Both the resistivity change and strain are reversible upon unloading.
Full curve: Fractional change in resistivity
Dashed curve: Strain





Fractional change in resistance ($\Delta R/R_0$) is shown above during cyclic tension (left panel) and cyclic compression (right panel). The strain is measured with a conventional strain gage to shown the correlation between strain and resistance. The resistance increases reversibly upon tensile loading and decreases reversibly upon compressive loading.



A single discontinuous conductive fiber is shown to the left. It bridges a microcrack, the opening of which is exaggerated for clarity. This is to illustrate the mechanism of the piezoresistivity in smart concrete.