CARBON FIBER REINFORCED CONCRETE AS AN INTRINSICALLY SMART CONCRETE FOR DAMAGE ASSESSMENT DURING DYNAMIC LOADING

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INTRODUCTION

Smart structures capable of damage assessment in real time are important due to the need to maintain the functions of critical civil infrastructure systems. The sensing provides an electrical, optical or acoustic response to damage in real time during dynamic loading. Requirements of the sensor include (1) low cost for both materials and implementation, (2) durability and reliability, (3) measurement repeatability and stability, (4) ability to provide quantitative signals with high sensitivity and resolution, (5) ability to provide spatial resolution, (6) fast response, (7) sensitivity to a wide dynamic range of strain, covering both the elastic and inelastic regimes of deformation, (8) not weakening the structure, (9) not requiring expensive peripheral equipment, and (10) applicability to both old and new structures.

In a new sensor technology [1], concrete itself is the sensor, which satisfies all of the requirements listed above. Moreover, the intrinsically smart concrete exhibits high flexural strength and toughness, and low drying shrinkage [2]. In this paper, the sensing ability and its origin are described in relation to the sensing of elastic deformation, inelastic deformation and fracture. In contrast to techniques such as acoustic emission, which cannot sense elastic deformation, this new sensor technology allows the sensing of elastic deformation, in addition to inelastic deformation and fracture. The signal provided is the change in the electrical resistance. Reversible strain is associated with reversible resistance change; irreversible strain is associated with irreversible resistance change; fracture is associated with irreversible and particularly large resistance change. The origin of the signal associated with fracture is crack propagation, which increases the resistance due to the high resistivity of the cracks. The origin of the signal associated with irreversible strain is conducting fiber breakage; the origin of the signal associated with reversible strain is conducting fiber pull-out. The detection of fracture does not require fibers in the concrete, whereas the detection of irreversible and reversible strains require the presence of short and electrically conducting fibers in the concrete.

EXPERIMENTAL

The fibers were unsized carbon fibers based on isotropic pitch and of diameter 10 μm, nominal length 5 mm and electrical resistivity 3×10^{-3} Ω.cm. Their amount was 0.5% by weight of cement. The aggregate was natural sand.

Simultaneous to mechanical testing, resistance measurements were made at a DC current from 0.1 to 4 A. The displacement rate was 1.27 mm/min. During compressive or tensile loading up to fracture, the strain was measured by the cross-head displacement in compressive testing or by a strain gage in tensile testing, while the fractional change in electrical resistance along the stress axis was measured using the four-probe method. The electrical contacts were made by silver paint. Testing was performed either in one cycle up to the breaking stress or in multiple cycles upon loading up to a fraction (1/3 under compression and ~ 1/2 under tension) of the breaking stress.

CONCLUSION

Carbon fiber reinforced concrete was found to be an intrinsically smart concrete that can sense elastic and inelastic deformation and fracture. The signal provided is the change in electrical resistance, which is reversible for elastic deformation and irreversible for inelastic deformation and fracture. The presence of electrically conducting short fibers is necessary for the concrete to sense elastic or inelastic deformation, though the sensing of fracture does not require fibers. The fibers bridge the cracks and provide a conduction path. They do not need to touch one another. The electrical resistance increase is due to conducting fiber pull-out in the elastic regime, conducting fiber breakage in the inelastic regime, and crack propagation at fracture. The fractional change in resistance at fracture is higher under compression than tension, due to the higher ductility under compression.

REFERENCES

1. Pu-Woei Chen and D.D.L. Chung, Smart Mater. Struct. 2, 22-30 (1993).
2. Pu-Woei Chen and D.D.L. Chung, Composites 24, 33-52 (1993).