Available online at www.sciencedirect.com
ScienceDirect
Cement & Concrete Composites 29 (2007) iii–iv
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Editorial

Functionally Graded Materials (FGMs) are composite materials in which the composition and/or structure of the constituent phases are spatially varied to produce corresponding, desired changes in the properties of the composite system. Variations can be continuous or stepwise, where the latter case corresponds to a layered composite. Porosity can be viewed as an individual phase, the amount and distribution of which affects composite strength and stiffness. In addition to interfaces between phases, composites materials also contain defects such as cracks.

FGMs abound in Nature. Common examples include animal bone and bamboo, both of which are load bearing systems formed from biological materials with graded composition and structure. Many of these systems are notable for their high specific strengths, which complement the various other important functions they perform. This optimization of form and function is due, in part, to evolutionary pressure on such natural systems.

The first synthetic FGMs were developed over two decades ago for aerospace applications, because certain performance requirements could not be practically met with spatially uniform material compositions. One major development has been the design and production of refractory ceramic–metal composites, in which increasing the volume fraction of the ceramic phase (as the outer surface is approached) provides better resistance to heat, wear, and oxidation. Towards the opposite surface, increasing the volume fraction of the metallic phase provides the necessary strength, ductility, and machineability. The phase volume fraction, and several other factors, determine whether or not an individual phase is disperse or interconnected within the material domain. Multiple phases can be interconnected at intermediate volume fractions. In general, the degree of connectivity greatly affects the transport properties of the composite material, especially when the transport properties of the individual phases are dissimilar.

The interest in functionally graded cement composites is growing, as evidenced by recent conference sessions on the subject. In simple terms, concrete mix design involves the determination of the mix ingredients and their semi-optimal proportions, in accordance with the methods of processing and the various performance requirements of the target applications. The size distribution of aggregate inclusions is graded to improve economy, workability, volume stability and several material properties. In an average sense, however, the aggregate contents are assumed to be uniformly distributed throughout the domain. Likewise, short fiber additions are generally assumed to be statistically uniform with respect to their spatial and orientation distributions. Deviations from uniformity, or segregation, are generally undesirable and occur due to various inadequacies in the mix design and processing methods, along with wall effects near the domain boundaries.

One potential application of the FGM concept in concrete technology is suggested by the differing roles of cover and core concrete within a structural concrete member. The cover concrete protects the reinforcement and core concrete from the environment during service conditions. Environmental conditions include exposure to chloride ions or other potentially harmful chemicals, for which the transport properties of the cover concrete are important. For high temperatures, as would occur during fire loading, the cover concrete protects the steel reinforcement and therefore its resistance to spalling is critical. In the strength limit state, however, it is generally the confined core concrete that provides load resistance and enables stable mechanisms for energy dissipation. With respect to new construction, few efforts have been made to address these different functional requirements through spatial variations in the material composition and structure. Much more attention has been given to the use of cement composite overlays for repair or upgrade of existing structural concrete.

When considering the different functional requirements of cover and core concrete in structural concrete members, it is tempting to draw analogies to biological systems (e.g. the cover concrete functions like a protective skin). A key difference is that bone, for example, is a living material that models and remodels itself according to external stimuli. Some bone cells exhibit piezoelectric properties that promote bone growth in regions of straining (i.e. mechanical straining of the bone cells is converted to an electrical potential that stimulates the osteoclasts and osteoblasts

0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2006.10.004

associated with bone degradation and formation, respectively). The local structure of trabecular bone arranges itself according to the predominant directions of principle stress. Similar cell-based mechanosensing enables adaptive modeling in other biological materials, as well. With appropriate additions of short carbon fibers, the electrical resistivity of cement composites changes with strain, which can be viewed as a form of self-sensing of load. However, this form of sensing is passive in that the material does not react to such stimuli in an intelligent, adaptive manner.

The optimization of concrete mixtures for multiple design objectives is a challenging and important area of research. Spatial gradation of the material composition and/or structure adds a new set of design parameters that must be accommodated within such optimization frameworks. An understanding of the interdependencies between mix design and effective processing methods becomes even more critical. The prospect of developing smart cement-based materials that self-organize (undoubtedly in the form of a graded microstructure) in response to external stimuli is intriguing.

J. Bolander
University of California, Davis,
Department of Civil and Environmental Engineering,
One Shields Avenue, Davis,
CA 95616, United States
Tel.: +1 530 752 8226; fax: +1 530 752 7872
E-mail address: jebolander@ucdavis.edu