Chapter 2
Nanomechanical Characterization of Cement-Based Materials

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ABSTRACT

Nanoindentation technique is used to assess the mechanical properties of materials at nano-level. A very small tip (usually diamond) produces indents at the surface of the material to be tested. A load vs. deflection curve is generated and is used to study the elastic properties of materials. Generally, it is used for obtaining the hardness and Young's modulus of materials at nano-meter scale. Currently, the method to evaluate the mechanical properties by nanoindentation is restricted to homogeneous materials. Cement-based materials are heterogeneous in nature. Therefore, nanoindentation study of cement-based materials is critical and requires several important steps, which need to be performed accurately. This chapter provides a review of the theory of nanoindentation, instruments being used for nanoindentation, sample preparation techniques, indentation strategy, and determination of nanomechanical properties and data analysis for cement-based materials.

INTRODUCTION

Concrete is the most widely used construction material made commonly by mixing Portland cement, sand, crushed rock and water. The total world consumption of concrete is very high and man consumes no material except water in such tremendous quantities (Mehta and Monteiro, 2004). Present concrete consumption is much

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higher than what it was almost 40 years ago. In 2000, consumption of concrete in the world was of the order of 11 billion metric tons per year. The amount of world trade associated with concrete is estimated to be about 13 to 14 trillion dollars, providing jobs to 1% of the world's population. Over the past 100 years, concrete has made major progress in quality and performance through scientific and technological innovations. Nevertheless, little is known about the properties of concrete at the micro- and nanoscale, which governs its overall properties such as strength, ductility, durability etc. Concrete is the material of choice for new construction of high-rise buildings, roadway pavements, and bridges.

The construction industry is facing an escalating need for high-performance, durable and sustainable construction materials for buildings and roadway pavements. This need, in turn, is driving research to develop the next generation of materials. In Civil Engineering, the traditional method of designing a concrete mix is by trial and error where different additives are used to achieve a set of final properties. Recently, however the construction industry has recognized the need to investigate the science and fundamental properties of concrete and other construction materials.

HETEROGENEITY OF CEMENTITOUS COMPOSITES

Cementitious materials, like many other materials exhibit heterogeneous features over a wide range of length scales, from the nano-scale of the elementary chemical components to the macroscopic scale of the aggregate-mortar composite. This multi-scale heterogeneity ultimately determines the in vivo mechanical performance (stiffness, strength), and degradation (damage, fracture, failure) of cementitious materials. While most codes of practice in concrete engineering account for this heterogeneity through probability theory to achieve certain macroscopic material properties with some certainty, current trends in concrete science and engineering aim at a better representation of this heterogeneity at multiple length scales, to ultimately identify the scale where physical chemistry meets mechanics. The rationale behind this approach is that the different chemical components of cement-based materials are defined by specific chemical equilibrium states, for which the probability that some solid chemical compounds go into the solution is smaller than the probability that the same chemical species in the solution precipitates onto the solid. Such an equilibrium state is associated with a stable material state. Hence, if it were possible to break down the heterogeneities of cement-based materials to this scale, where the solid material manifests itself in a chemically stable state, and to assess, at this scale, the mechanical material properties, it would be possible to translate with high confidence chemical equilibrium states into macroscopic material properties.

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