Analyzing Materials Under Extreme Conditions

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Engineering and science rely on the ability to make accurate predictions of material behavior in order to create innovative and transforming technological advances. Most properties of materials—such as electric, magnetic, thermal, and optical properties—are sufficiently well understood so that scientists can make meaningful predictions from fundamental principles of physics. Important exceptions to that rule are the mechanical properties of a material. Certain mechanical properties such as stiffness and thermal expansion can be calculated with great accuracy. However, others such as strength, plastic hardening, fatigue limit, ductile-to-brittle transition temperature, and fracture toughness cannot yet be calculated from fundamental principles. Therefore, engineers must rely predominantly on experiments to determine properties when designing new materials for life-critical applications such as those for the aerospace and automotive industries.

The defects of a material determine its interesting mechanical properties. Different types of defects can be idealized as being points, lines, areas, or volumes within a material, and the defect sizes can range from the atomic-length scale to the millimeter-length scale. Further, initial defects in a material create new defects, all of which subsequently move about within the solid and interact with each other in complex and different ways. The conceptual and computational challenges that must be overcome in order to predict the resulting mechanical behavior are daunting. One of the researchers at the forefront of this work to make meaningful predictions of mechanical behavior is Jeffrey W. Kysar.

Kysar's current research is focused on the mechanics and mechanical behavior of materials at multiple scales and under extreme conditions. A second focus is to create new materials that have mechanical properties which interact with other properties, such as optical or electrical, that can be used to make microscale sensors, actuators, and power generation devices.

Kysar was part of the Columbia Engineering team that completed the first strength tests on graphene in 2008, proving it to be the strongest material ever measured. The specimens used in those experiments were sufficiently small so that no defects were present in the material, which is the reason why graphene is so strong. According to Kysar, "The mechanical properties of graphene will enable its use in many new applications that require materials with excellent strength." More practical applications of graphene include use as a transistor that can take the strains of faster microprocessing in computers or as a durable, mechanically operated electrical switch for communications devices, including cell phones and advanced radar.

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