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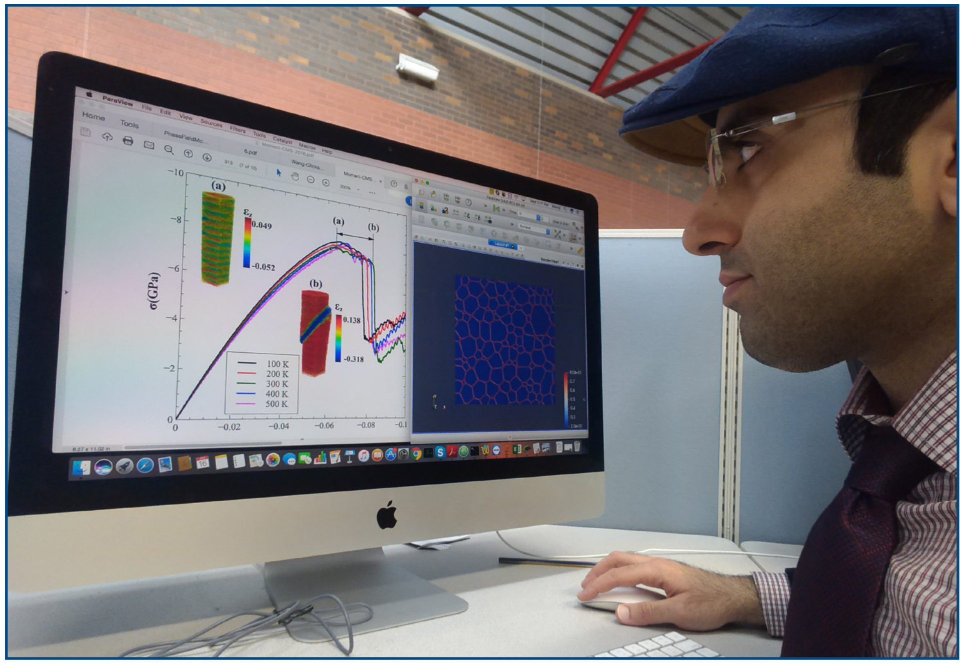
Perfect Materials: Hierarchical Material Design for Extremes Using Defects

Can something be better than perfect? Dr. Kasra Momeni thinks so! By introducing manmade defects in certain building materials, Dr. Momeni believes it is possible to create a material that can handle more weight than a corresponding "perfect" material. If successful, this new process could pave the way to stronger, cheaper, and safer materials, allowing for the production of safer aircrafts, better medical implants, and a wide range of other useful applications.

So, what is a "perfect" material? When a material is comprised of exclusively crystal structures, with no irregularities in the order of the atoms or molecules, it can be regarded as a "perfect" material. In engineering, there is often a need for a material that can support a large amount of weight. "Perfect" materials, with their crystal structures, are often used for this task. If multiple materials can be used to accomplish the same task, the "strength-to-weight" ratio will become the primary deciding factor. Simply put, this ratio is an indicator of how much weight the material can handle when compared to the weight of the material.

Dr. Momeni, along with his colleagues, is researching a method to strengthen materials without alloying them. Materials strengthened using this method would be capable of handling much more weight than usual, surpassing the capabilities of even their unstrengthened, "perfect" counterparts. How is this accomplished? It's simple: defects are manually introduced into the material.



Dr. Kasra Momeni views a computer simulation on the strength of 3-D printed metallic components. Momeni is a recent hire at Louisiana Tech University as part of the statewide NSF EPSCoR-funded Consortium for Innovation in Manufacturing and Materials (CIMM).

Now, you may be thinking "won't defects make the material weaker?" Normally, that would be correct. Defects in materials, known as stacking faults (SFs), can be the direct cause of the failure of a material. When a defect is present, in an otherwise even structure, an uneven amount of weight is transferred to the location of the defects, causing increased strain. The area of the material containing the defect cannot accommodate the increased load, so it causes a collapse, introducing even more defects. This "domino effect" of defects can result in the material completely failing. But in the proposed method, defects would be introduced in certain areas of the material, and in doing so, the crystalline structure is altered in a way that makes it capable of bearing increased strain.

Dr. Kasra Momeni

Currently, a mathematical model is used to determine the exact location in the material that the defects need to be placed. "We show that introducing SFs with high-density increases the Young's modulus and the critical stress under compressive loading of the nanowires (NWs) above that perfect structure. The physics can be explained by the increase in intrinsic strain due to the presence of SFs and overlapping of corresponding strain fields," said Momeni.

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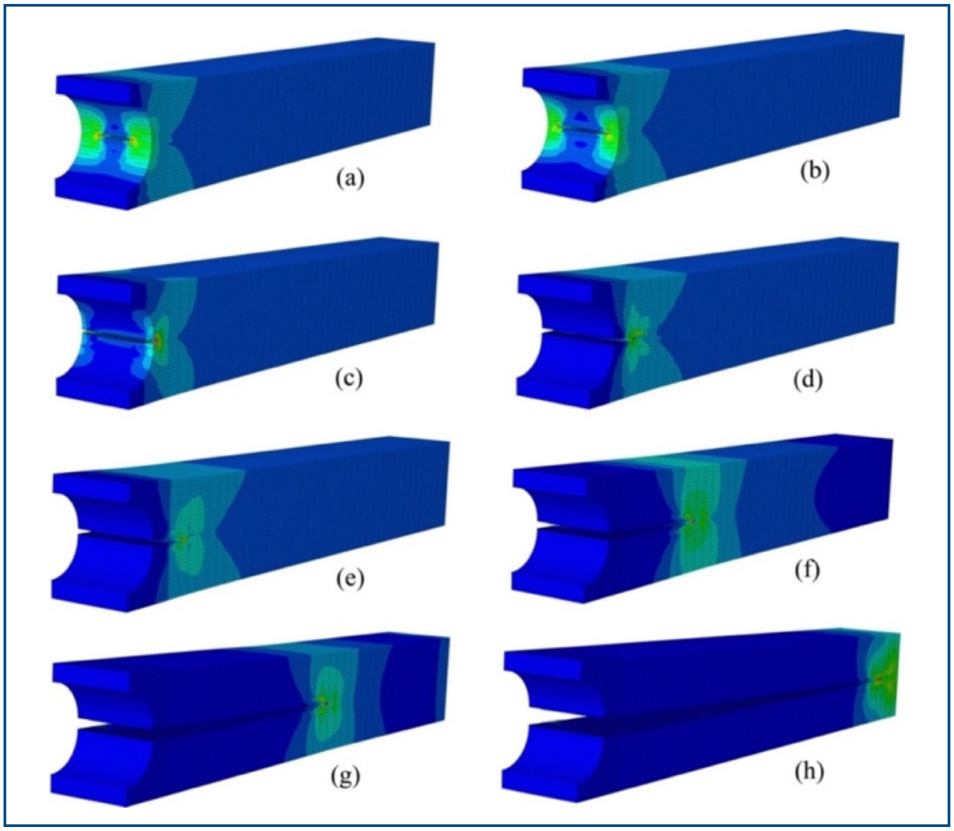

The illustration above shows eight crack propagation snapshots of an aluminum plate. The computer model predicts the placement and growth of the crack under loading of the aluminum plate and how the stress evolves as the crack propagates.

The chemical structure of materials created with this process would remain unchanged, meaning that only a single material would need to be manufactured, rather than two or more. By removing the need to manufacture several materials, and by removing the need to alloy those materials to achieve the same level of strength, this new strengthening process would drastically reduce the financial burden of manufacturing high-strength materials, such as titanium. This could allow people who need life-saving medical implants to afford them when they otherwise could not.

Multiscale Model for Materials Research

Modeling of fatigue crack initiation and growth requires understanding of the behavior of the crack at the microstructural level.

Although linear elastic fracture mechanics (LEFM) has been successfully used for long-crack growth modeling, its application for modeling of the crack initiation and short-crack growth is limited. Employing elastic–plastic fracture mechanics (EPFM) may remedy these limitations, but it still cannot justify the validity of using the homogeneous material solutions.

Accurate modeling of the crack initiation and short-crack growth can be achieved through more computationally demanding micro-mechanics-based simulation techniques. Louisiana researchers have developed a multiscale model that couples crystal plasticity, phase-field model of microstructure, and macroscale model of the crack growth using extended finite element method. The developed model captures the effect of microstructure such as grain boundaries on the final fatigue life of the components.

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