Multiscale modeling speedily predicts fatigue failure in hip implants

After a traumatic accident that includes bone damage, patients can recover some of their initial capabilities due to porous titanium-based orthopedic implants. These artificial materials are built like mini-Eiffel towers, with metallic struts 100–400 μm in diameter forming repeating cubic diamond unit cells (see Figure a). After implantation in the body, the porous structure undergoes cyclic mechanical loadings from daily activities. Modeling and predicting the number of cycles after which it might fail would help improve the design, durability, and the patient's recovery. However, due to the complex porous structure and large sizes of these structures, the computing time required for modeling the mechanics in an entire implant during cyclic loading is enormous.

To address this issue, researchers from Amirkabir University of Technology in Tehran, Iran, and from Delft University of Technology, The Netherlands, teamed up and developed a multiscale modeling method that could resolve the modeling of fatigue loading in a real-size implant in a week-time. "For complete crack propagation modeling in a bone, the computational time would be around one week for the same computational power," says Reza Hedayati, the first author of the study published in a recent issue of the *International Journal of Fatigue* (doi: 10.1016/j.ijfatigue.2018.05.006).

The multiscale modeling uses microscale beam elements to model the area at the crack tip and macroscale volumetric elements to model areas further away (see Figure b,c). Factors were added that take into account possible local stress concentrations from irregularities in the struts, surface roughness, and change in materials properties during damage. With this strategy, the computation time is dramatically reduced as compared to microscale modeling.

To confirm their modeling capacity and verify their results, the researchers performed tension–tension cyclic loading on rectangular three-dimensionally printed metallic specimens with dimensions of 80 × 78 × 15 mm^3 and found that these withstood 9000 ± 3000 cycles (see Figure d). The model predicted 8000 cycles.

In real applications, the porous implants are filled with a soft phase that changes the stress distribution and increases the static and dynamic fatigue strength by a factor of two to seven as demonstrated in an earlier article published in the *Journal of Mechanical Behavior of Biomedical Materials* (doi:10.1016/j.jmbbm.2016.10.003). Follow-up work will thus apply the new modeling on such samples. "Since our multiscale model has been validated against experimental results from samples [with a single notch and placed under tension], the multiscale modeling can now be applied to [the] prediction of crack propagation in load-bearing implants," Hedayati says.

Jakob Faber, a researcher from ETH Zürich and specialist in modeling of bioinspired structures, is interested in seeing an application of multiscale modeling to a concrete and useful case. "The fatigue life of biomedical implants with a similar material selection and internal structure can surely be assessed with a similar workflow as demonstrated." He now expects the treatment in a follow-up study of similar structure but under a different loading profile, for example using the loads from an accident of the patient like falling.

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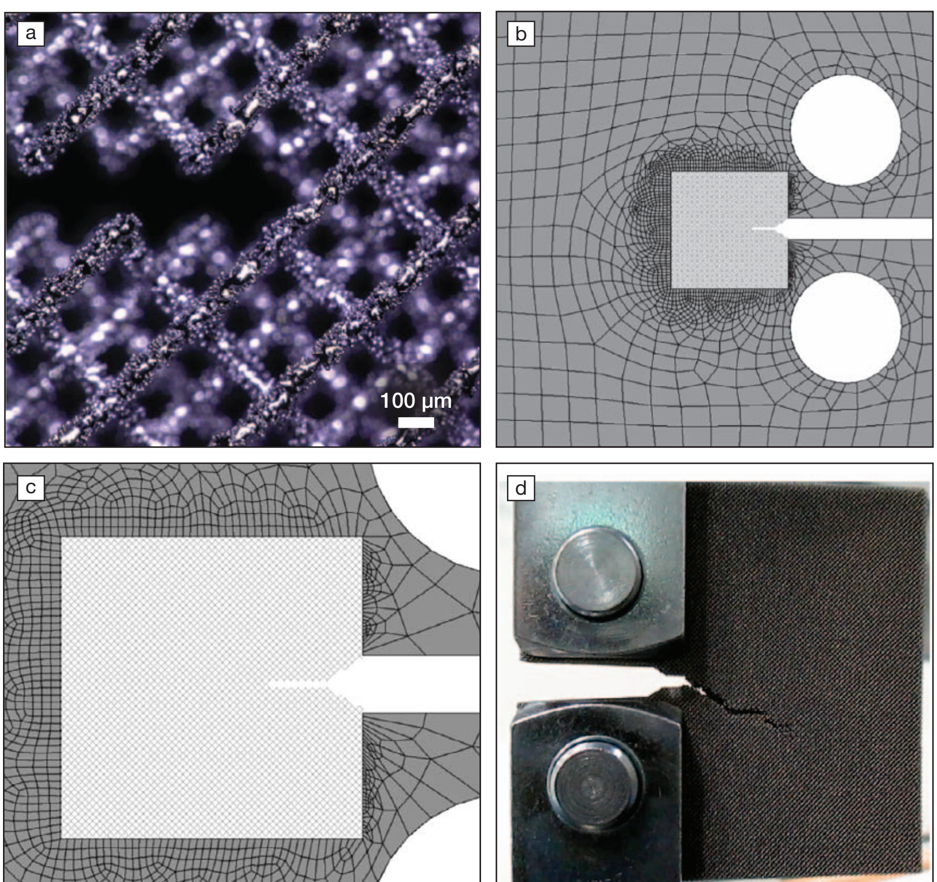

(a) Microscopic view of the notch tip in the experimental sample; (b) the whole multiscale model; (c) the crack-tip area in the multiscale model; and (d) damage in the sample under the isostatic loading condition. Credit: *International Journal of Fatigue*.

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