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Advanced characterization of high temperature structural materials for fusion reactor environments

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High temperature structural materials are of key importance for many traditional applications such as gas turbines for stationary power plants and jet engines, rocket engines, components for the chemical and oil & gas industry but also for fusion reactors under development and future applications. Materials used in fusion reactors are exposed to severe conditions, including intense thermal loads, high neutron flux, radiation damage and hydrogen implantation. These extreme environments highlight the urgent need for the development and improvement of advanced structural materials that can endure such harsh factors. To address this challenge, it is essential to characterize and understand both known and new materials in terms of their microstructure, defect structures, mechanical properties and damage correlations. This comprehensive approach allows researchers to identify the relationships between the material's microstructural features and its performance under extreme conditions. In this contribution, several examples will be presented to illustrate these correlations and highlight the significance of advancing material science in the context of fusion technologies. It will be shown how the changing chemical composition of intermetallics or irradiated W affects their fracture toughness, how hydrogen leads to an embrittlement of superalloys, how lattice misfits of two-phase materials can be precisely analysed by diffraction techniques, and how small-scale testing allows to measure mechanical properties locally and of small specimens. Therefore, various characterization techniques such as mechanical testing at different length scales, (high resolution transmission) electron microscopy, atom probe tomography, neutron and high energy X-ray diffraction and thermal desorption spectroscopy are employed. These examples should illustrate how studying the microstructure-mechanical properties-correlation enables us to get a deeper understanding of the used materials and how they can be further improved and new alloys can be developed to ensuring the integrity and longevity of fusion reactors and to avoid CO2 emissions for our future society.

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