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Editorial: Mechanical Property Characterization and Radiation Resistant Design of Nuclear Structural Materials Under Ion Irradiation

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Editorial on the Research Topic

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The development of advanced structural materials which can withstand the harsh and complex environments, such as high energy particle irradiation, high temperatures and cyclic stresses, encountered in nuclear power systems, either fission or fusion reactors, requires the understanding of the neutron radiation effects on the mechanical properties of the materials. The neutrons produced by either fission or fusion reactions create lattice damage and transmutation products. The irradiation induced defects cause or accelerate the degradation of the mechanical properties threatening the safe operation of the reactors. Moreover, the transmutation products, such as hydrogen (H) or helium (He), act synergistically with the lattice damage and degrade further the performance of the materials. The lattice damage is not produced by the neutron per se, but by the primary knock-on atoms. As a result single- or multi-ion irradiation, i.e., heavy ion + He + H, is used to emulate the effects of neutron irradiation, offering many advantages such as low cost, short irradiation duration, absence of radioactivity, well defined and easily controlled conditions in terms of ion energy and irradiation dose. On the other hand, small-scale mechanical testing can be used as a tool for material screening. However, the analysis of the mechanical test data at nano- or micro-scale, especially of the ion irradiated materials, is challenging and sometimes debatable. The current Research Topic is focused on the small-scale mechanical characterization of ion and neutron irradiated metallic structural materials.

The review article of Mei et al. focuses on the research progress on the application of small-scale mechanical property tests for investigating the mechanical properties of ion-irradiated materials, i.e., radiation-induced strengthening/hardening, embrittlement, as well as the creep and fatigue. The advantages and shortcomings of the currently used techniques and data analysis models are discussed as well as the consistency and reliability of them are overviewed. Das et al. focus their research on the effect of the ion energy on the hardening of pure Fe, ferritic Fe-9Cr, martensitic Fe-9Cr and ferritic-martensitic reduced-activation steel Eurofer 97 using depth sensing nano-indentation. Through empirical models they describe the hardness increase versus contact depth taken into consideration the profiles of the displacement damage and the implanted ions in combination with indentation size effects. An approach is suggested to separate the displacement damage contribution in hardening in order to make it comparable to

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that arising from neutron irradiation. Further, it is shown that the indentation depth in combination with the ion energy can be selected in such a way as to render the hardening contribution from the implanted ions negligible. Mao et al. use cantilever bending experiments coupled with Finite Element Analysis to investigate the deformation mechanisms as a function of plastic strain and grain orientation in neutron irradiated laser welds of 304L austenitic stainless steel. They show that the thermal annealing induced by laser welding limits crack tip extension at low He concentrations and provides a pathway to mitigating helium-induced cracking during weld repairs of irradiated materials. Huang et al. review experimental studies on the He-H synergistic effects in blanket structural materials of fusion reactors, and analyze their effect on cavity evolution and swelling under multi-ion beam irradiation. The role of gas-dose ratio, irradiation temperature and damage rate in He-He synergistic effects are discussed.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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