The effect of vanadium and copper on defect structure generation during neutron irradiation of zirconium-based materials – Callum Andrew

Zirconium alloys – materials that are primarily made up of the metallic element zirconium, with other elements added to it - are used in pressurised water reactor nuclear power plants to encapsulate the fuel and its radioactive products. This cladding keeps the fuel contained so that it does not escape into the surrounding environment and acts as the first barrier to radiation released during nuclear fission.

Zirconium is a suitable material for this application because it has high strength, corrosion and heat resistance properties, even when the material is exposed to high levels of radiation, which causes damage to the atomic structure of the metal. Most importantly, neutrons emitted in the nuclear reaction can pass through zirconium with little interaction, where they go on to maintain nuclear reactions, which is important for the efficiency of power generation (1–3).

The harsh environment of a reactor damages zirconium alloys. They experience corrosion, hydrogen reactions with the material, and irradiation damage (4–7). When zirconium alloys reach the end of their working lifespan, the reactor has to be shut down in order to replace them, which reduces energy production. It is the aim to increase the efficiency of nuclear power plants as much as possible in order to generate more cost-efficient energy, produce less nuclear waste and prolong the lifespan of nuclear power plants. Therefore, zirconium alloys are continuously improved to be more corrosion and heat resistant, and more resistant to the effects of radiation. Manufacturing more durable zirconium alloys enables them to be replaced less frequently, hence more energy can be produced and less nuclear waste is generated.

Westinghouse have developed a zirconium alloy for nuclear reactors that contain the elements vanadium and copper. During testing, this new alloy has shown improved resistance to hydrogen pickup and corrosion, as well as resistance to irradiation damage. However, it is unknown how these elements reduce the irradiation damage.

This PhD project focuses on two alloys manufactured by Westinghouse, one with vanadium additions and one with copper additions, which have been irradiated. Experimental studies will be performed to establish the role copper and vanadium play in zirconium alloys during irradiation and whether they are beneficial to alloy performance. The results will be compared to more conventional zirconium alloys irradiated during the same irradiation campaign.

References:

1. Northwood DO. The development and applications of zirconium alloys. Mater Des. 1985 Apr 1;6(2):58–70.
2. Krishnan R, Asundi MK. Zirconium alloys in nuclear technology. Proc Indian Acad Sci Sect C Eng Sci [Internet]. 1981 Apr [cited 2020 Nov 15];4(1):41–56. Available from: https://link-springer-com.manchester.idm.oclc.org/article/10.1007/BF02843474
3. Schemel JH. ASTM manual on zirconium and hafnium. Astm International; 1977.
4. Adamson R, Griffiths M. Irradiation Growth of Zirconium Alloys A Review. Adv Nucl Technol Int Eur AB, ANT Int [Internet]. 2017 [cited 2020 Nov 15];3–6. Available from: www.antinternational.com
5. Motta AT, Couet A, Comstock RJ. Corrosion of Zirconium Alloys Used for Nuclear Fuel Cladding. Annu Rev Mater Res [Internet]. 2015 Jul 1 [cited 2020 Nov 15];45(1):311–43. Available from: http://www.annualreviews.org/doi/10.1146/annurev-matsci-070214-020951
6. Fürth FG, Rudling GP. Performance Evaluation of New Advanced Zr Alloys for PWRs/VVERs Charles Patterson Disclaimer. Adv Nucl Technol Int [Internet]. 2011 [cited 2020 Nov 15]; Available from: www.antinternational.com
7. Griffiths M. A review of microstructure evolution in zirconium alloys during irradiation. J Nucl Mater. 1988 Oct 1;159(C):190–218.