Understanding metal cracking in nuclear reactors

Professor Sergio Lozano-Perez's research on Stress Corrosion Cracking, one of the most important issues affecting nuclear power plants, is making a major contribution to the safety of pressurised water reactors.

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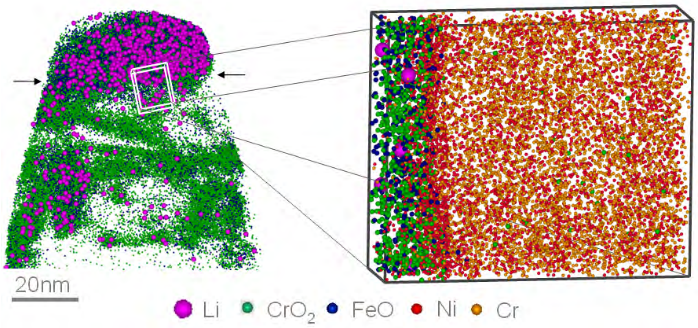
Nuclear power is likely to remain a key component of electricity generation in the developed world, especially as governments try to adopt low-carbon alternatives. The UK government, for example, has just given the go-ahead for the UK's first new nuclear station in a generation at Hinkley Point C. It is vital that the most robust materials available are used in construction, since materials failure is not only dangerous but expensive.

In this context, the work of Professor Sergio Lozano-Perez is critically important. For the past ten years his group has studied Stress Corrosion Cracking (SCC) in the stainless steel and nickel alloys used in the construction of pressurised water reactors (PWRs). Under normal conditions these materials are extremely durable and corrosion-resistant. However, when subjected to the stressed conditions of a PWR, the alloys start to oxidise. Microscopic cracks develop in the metal along the grain boundaries (the planes where two crystals of metal meet), leading to the risk of unexpected and devastating failure. The cracks can take years to develop and are so difficult to detect, monitor and predict that for a long time the specific mechanisms that led to cracking remained a matter of speculation.

Now Professor Lozano-Perez's research has led to a vastly improved understanding of SCC, through carefully-designed experiments that analyse the cracking mechanisms one factor at a time. Under simulated PWR conditions, Lozano-Perez and his collaborators create samples of alloy with the right SCC features; this in itself can take months. They then isolate and examine a minute part of the crack tip (an area just a few nanometres wide). Central to the experiments is the use of novel analytical techniques that enable a 3D-study of the materials at the atomic level. New discoveries include the following:

- Lithium is present in the oxide layers. Lithium and boron are added to PWR cooling water in tiny quantities to absorb excess neutrons from the fission reaction and control the pH. The discovery that Lithium (but not Boron) migrates from the water into the oxide layers shows that it may play a part in the oxidation process. Prior to these experiments the possible role of Lithium and Boron in SCC was purely a matter of speculation.



Oxidation of stainless steel in contact with reactor coolant

- Isolated 'islands' of oxide occur within supposedly intact metal, suggesting that atoms of oxygen pass through the metal and oxidise within it. 'Internal oxidation' was previously thought to be unlikely.

- Micro-cantilever tests have established exactly how the oxide in the cracks breaks, and how much stress it can take before it fractures. Previously the mechanics of oxide fracturing were unknown.

This pioneering and detailed approach has led to a vastly improved understanding of SCC in which a number of mechanisms can be seen to be acting together to cause cracking. As well as analysing the flaws in existing alloys and thus improving the ability to predict SCC, Lozano-Perez is also able to create new alloys that are more resistant to SCC, and this may have a major impact on future construction of nuclear power stations.

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