Characterisation of Nuclear Fusion Materials

Lucy Fitzgerald[a], Slava Kuksenko[b], Duc Nguyen[b], Yiqiang Wang[b], Biao Cai[a]
a. School of Metallurgy and Materials, University of Birmingham, B15 2TT, UK
b. United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, OX14 3DB, UK

Introduction

- Iron-Chromium based steels are a top candidate for use as structural materials within nuclear fusion reactors due to their desirable properties of low activation potential, high temperature resistance, and reduced sensitivity to neutron irradiation [1].
- Studying the effects of irradiation on these material's microstructure is essential to understanding their behaviour and mechanical performance within the harsh environment of a nuclear fusion reactors.
- An important mechanical change experienced by steels under irradiation is the ductile-brittle transition temperature (DBTT).

Lab Characterisation

Eurofer97, an Fe-9Cr steel, has been extensively characterised in its microstructure and mechanical properties before irradiation.

Microstructure

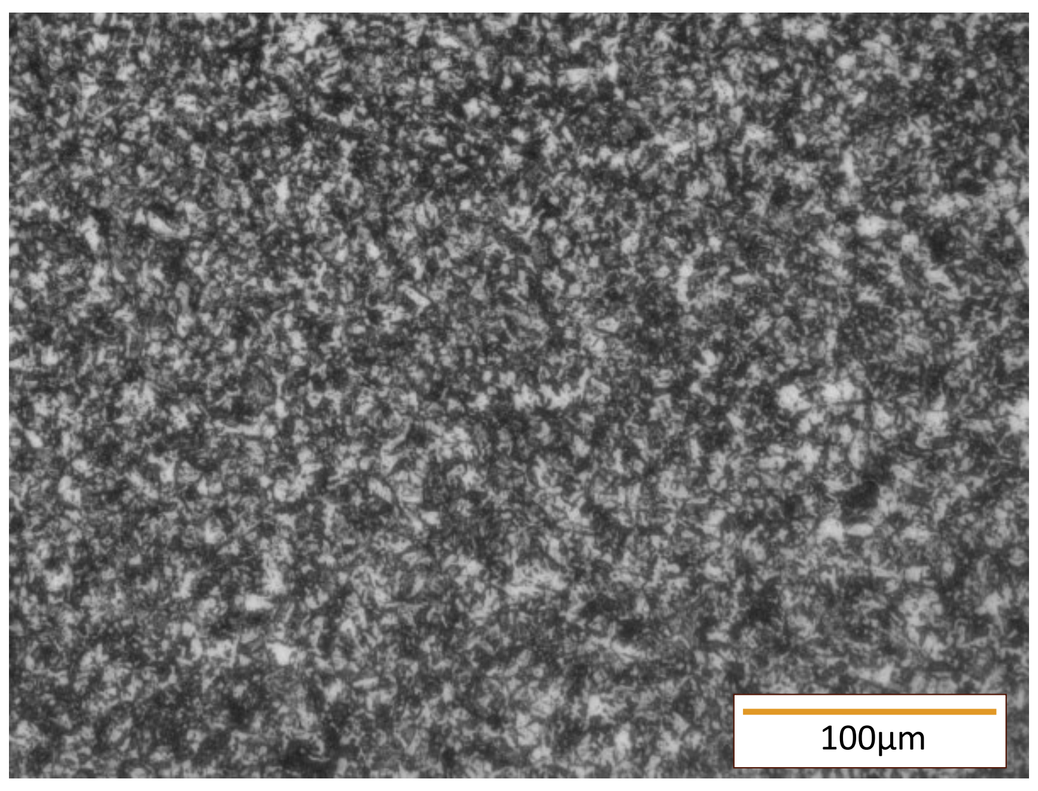

Figure 1. Optical microscope image of Eurofer97's microstructure.

- Vilella's Reagent was utilised to etch the surface of the steel for viewing via optical Microscope.
- It is seen that Eurofer97 has equiaxed shaped grains.
- The average grain size is 2.5 µm.

Hardness

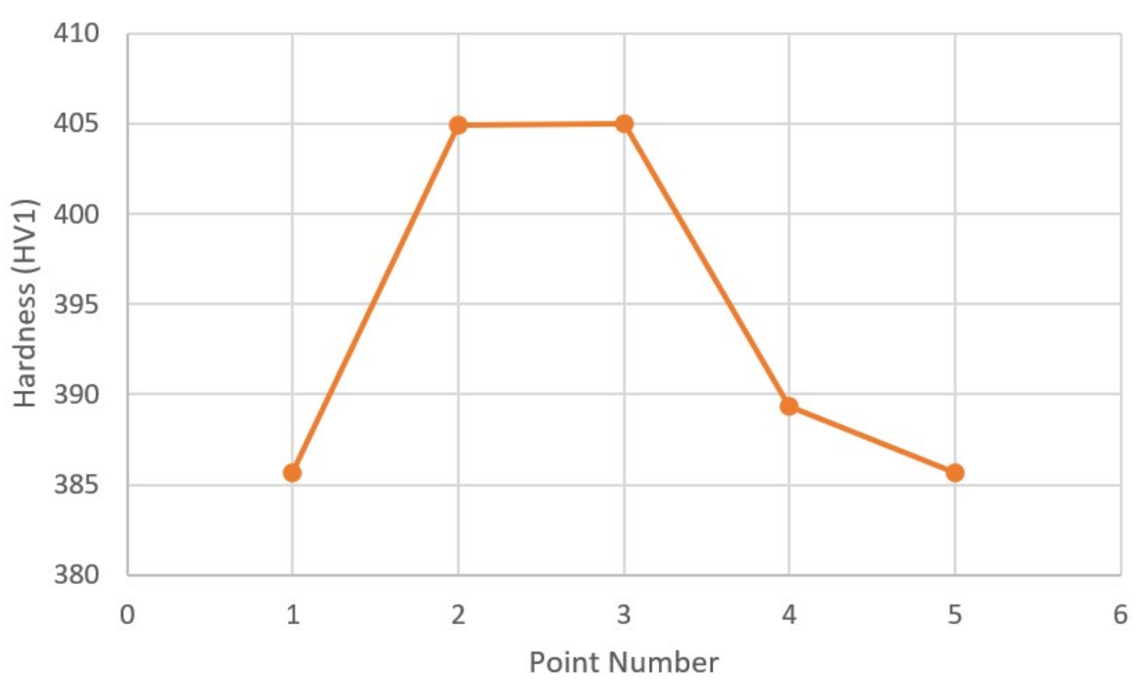

Figure 2. Graph of hardness testing results for Eurofer 97.

- Hardness testing was carried out using a Struers Duramin-40.
- The average hardness for the material was HV1 394.
- The large difference in measurements show that they were taken on different grains, each with differing hardness values.

In Situ X-Ray Ductile-Brittle Temperature Tensile Synchrotron Experiment

Eurofer97 has previously shown good resistance to a change in DBTT, with an increase of only 50°C after neutron irradiation [2]. Before irradiation, the DBTT has been found to be between -147-109°C depending on the annealing temperature during manufacture [3].

Method

- In situ tensile tests were carried out at RT, -50°C, -100°C, and 140°C during synchrotron two-dimensional X-ray diffraction.
- Diffraction patterns were collected every 2 seconds.

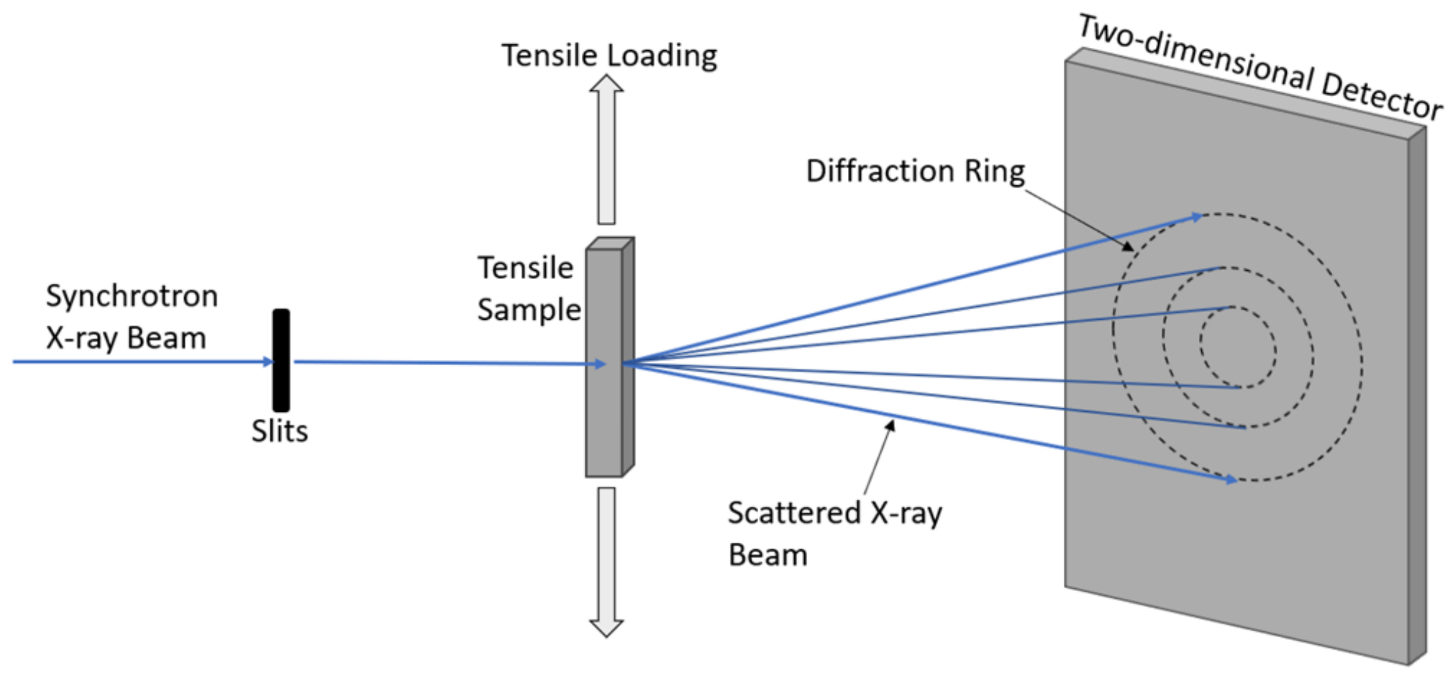

Figure 3. Schematic diagram of experiment set-up of in situ x-ray diffraction.

Tensile Results

- As the temperature was lowered, the material hardened, causing a higher stress.
- As there was no sudden breakage of the material, it would appear that the DBTT was not reached.
- Temperature calibration for the gauge of the dog-bone tensile sample, was done as it may not have been the same as the area where the temperature-controlled grippers hold the sample.

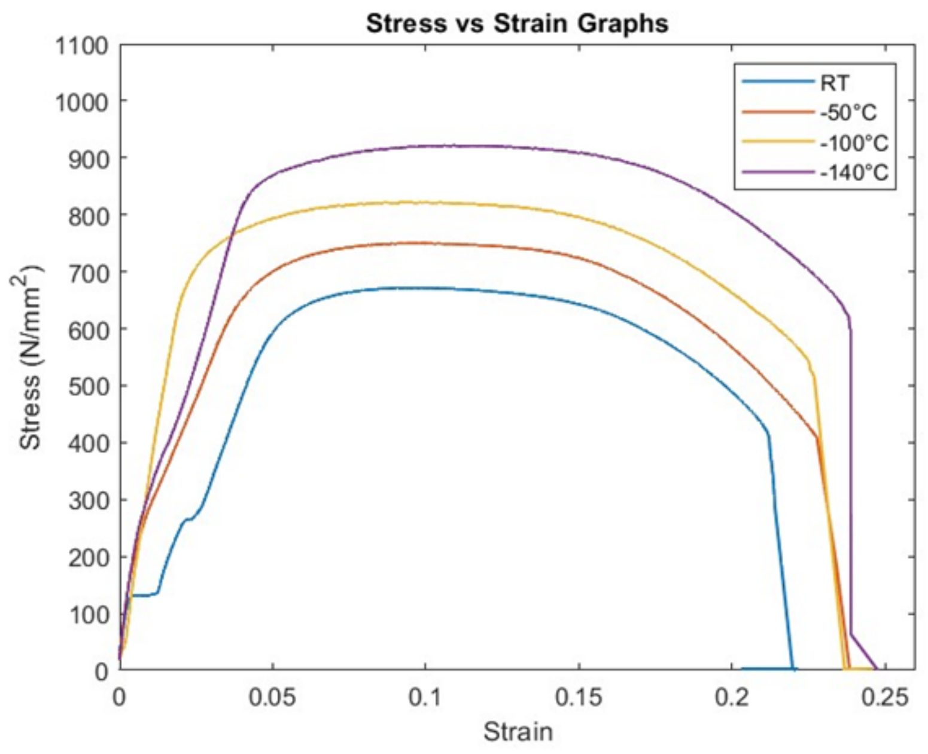

Figure 4. Stress-strain curves produced during

Jaw Temperature (°C)	Sample Temperature (°C)
-50	-49
-100	-94
-140	-130

Table 1. Calibrated temperatures for the sample at each temperature tested.

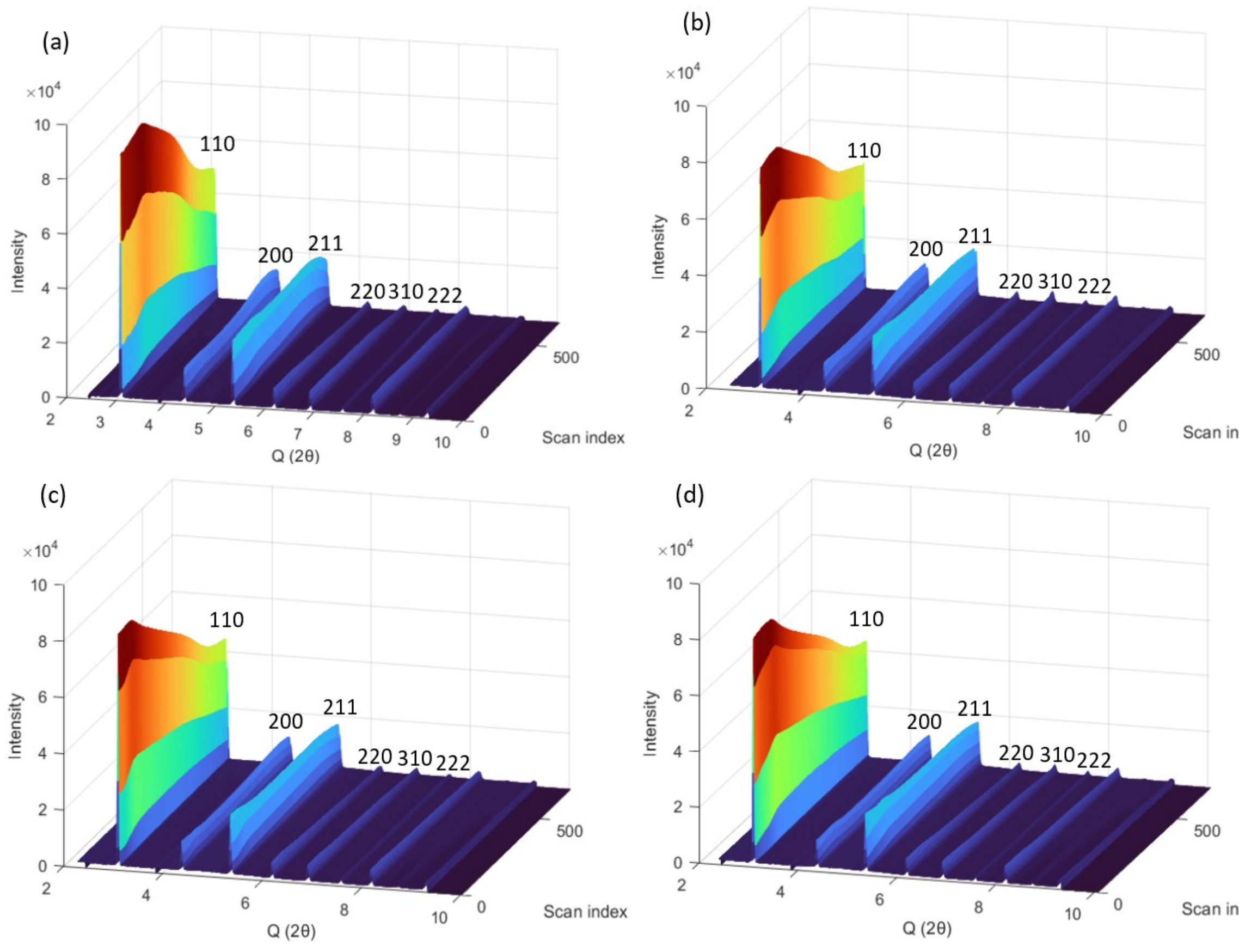

Figure 5. In-situ synchrotron XRD results for tensile tests at (a) room temperature, (b) -50°C, (c) -100°C, and (d) -140°C.

Diffraction Data Results

- The XRD patterns show that at low temperatures the intensity of the 110 peak decreases.
- There is no loss of existing peaks or appearance of new ones, showing that there mustn't have been any phase transformations due to temperature change or deformation.

Ultimate Tensile Strength vs Temperature

- The ultimate tensile strength increases with decreasing temperature.
- The hardening of the material due to low temperatures have affected the ultimate tensile strength of the material by increasing the stress that it can withstand.

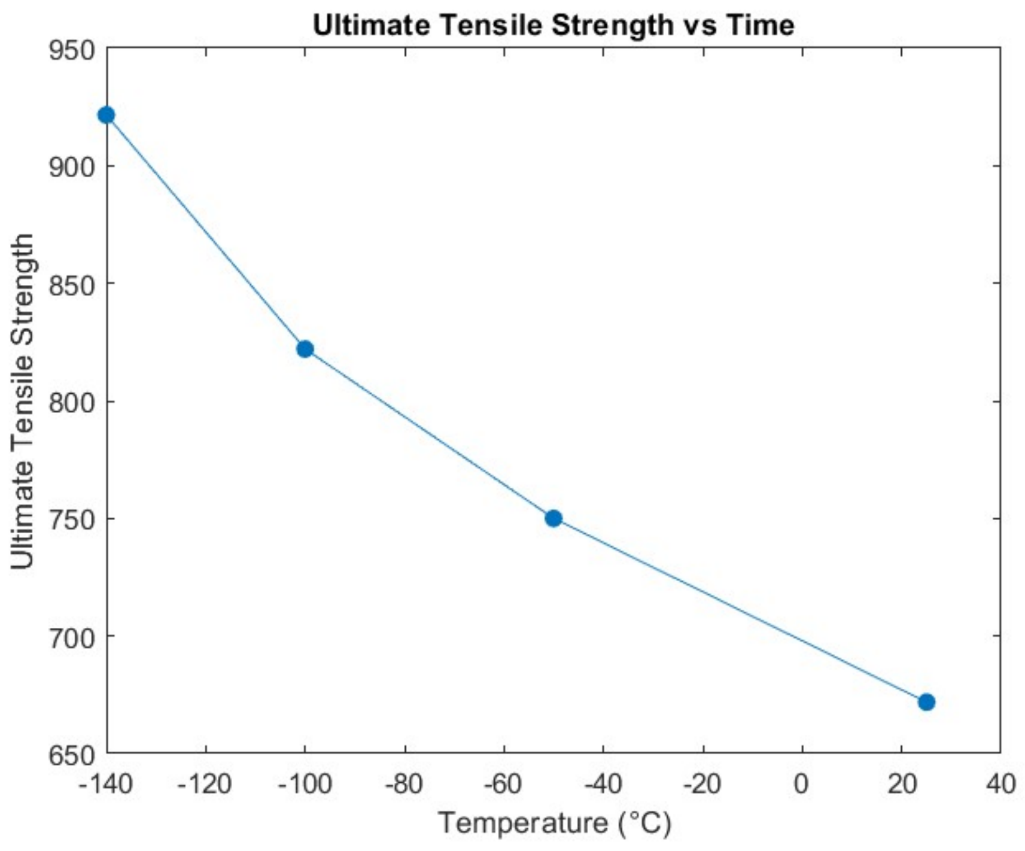

Figure 6. Graph showing the ultimate tensile strength at each temperature.

Conclusions and Future Work

- The DBTT of Eurofer97 must be lower than the temperature reached in the synchrotron experiment.
- No phase transformations occur due to low temperature in Eurofer97.
- Post-irradiation analysis is to be carried out using more synchrotron techniques.

Acknowledgements

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References

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[2] D. Kumar *et al.*, *Journal of Nuclear Materials*, vol. 554, p. 153084, 2021, doi: 10.1016/j.jnucmat.2021.153084.
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