Characterisation of powder and hot isostatically pressed Eurofer-97 and PM2000 steels.

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Introduction

The development of nuclear powder infrastructure, both fission and fusion, is essential for a sustainable future. In order for these reactors to peak efficiency, they need to operate in extreme conditions posing a serious need to evaluate to structural materials in use. One of these conditions is high temperatures (>550°C), for this reason **Oxide Dispersion Strengthened (ODS) steels** have been developed where nano-sized clusters of yttrium oxide are present within the microstructure impeding the movement of dislocations leading to **Orowan strengthening**. ODS steels are in development for fission and fusion reactors due to this increase in tensile and creep strength[1,2] , as well as increased resistance to irradiation induced degradation.

ODS steels are limited to powder manufacturing to ensure a fine and homogeneous distribution of nano-oxides. The production of ODS steels involves atomisation, mechanical alloying followed by consolidation. The atomisation techniques and mechanical alloying has significant effects on the subsequent powder characteristic such as morphology, size distribution, flowability and powder density. **Hot isostatic pressing** is a desirable consolidation method to produce fully dense ODS steels because it is a near-net shape process and produces isotropic properties. The effect of powder quality and HIP parameters on the resultant properties must be fully understood.

Aim

- Assess the effects of powder quality and hot isostatic pressing on the microstructure and structural integrity of steels utilised in the nuclear industry; PM2000 and Eurofer-97; in extreme environments such as high temperatures and exposure to proton irradiation.

Materials

Both powders were gas atomised, the PM2000 powder was subsequently mechanically alloyed to introduce nano-sized yttrium oxide resulting in an ODS steel.

Alloy	Fe	Cr	Al	Ti	Y_2O_3	Other
Eurofer-97	Bal.	9.2	<0.01	<0.01	0	W, Mn, V, Ni, Ta
PM2000	Bal.	20	5.5	0.5	0.5	

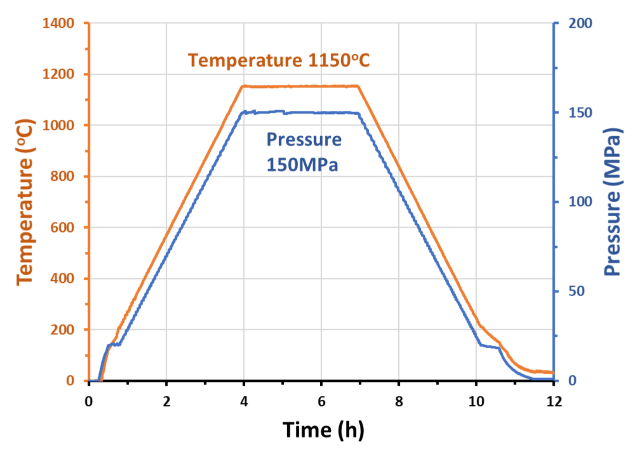
Methods

Powder Characterisation

Microstrac SYNC particle analyser

Hall Flowmeter

Hot Isostatic Pressing



HIP parameters: 1150°C, 150MPa, 3 hour dwell

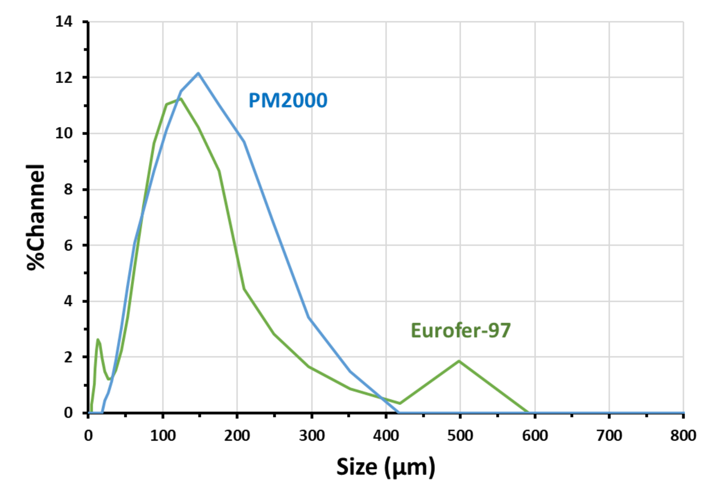
Microstructural Characterisation

Jeol 7000F scanning electron microscope with EBSD detector

Powder Characterisation

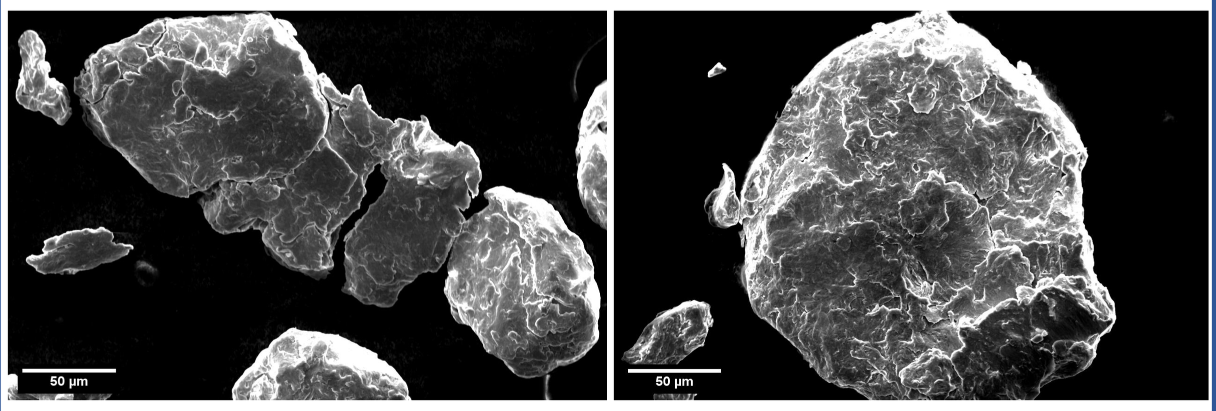
Property	PM2000	Eurofer-97
Flowability (s/50g)	29.7	34.0
Apparent density (g/cm^3)	3.1	5.3
Tap density (g/cm^3)	3.8	5.8

PSD Percentile	PM2000	Eurofer-97
D10	49	14
D50	115	92
D90	217	188

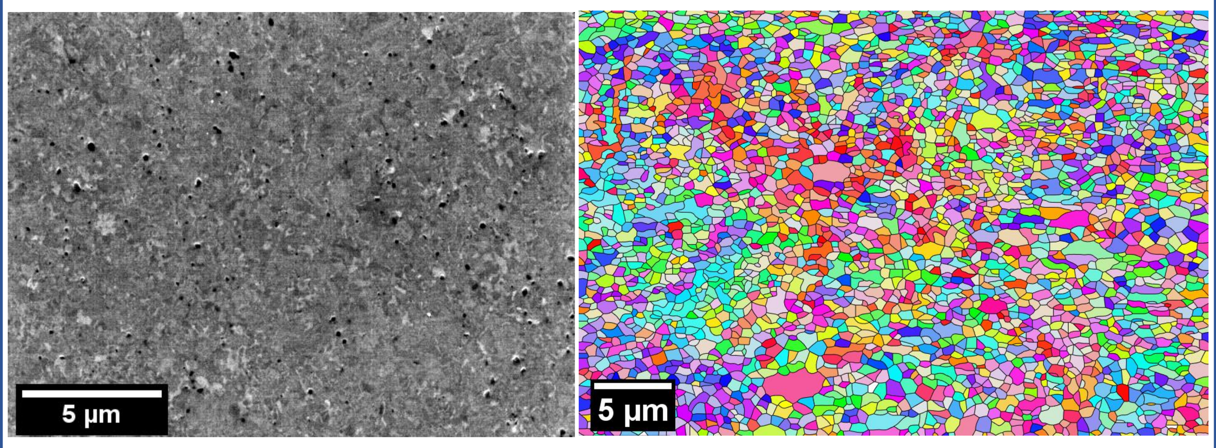


Particle size distribution of PM2000 and Eurofer-97

PM2000

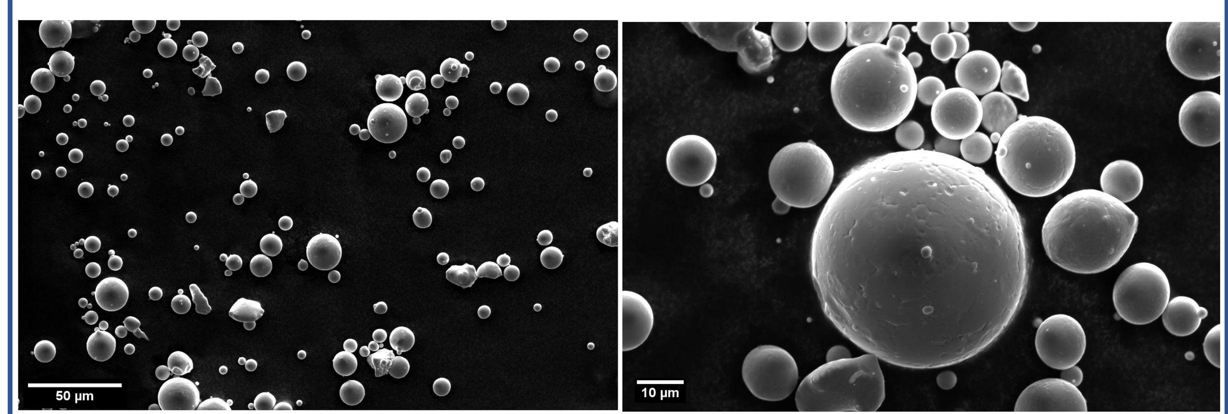


SEM micrographs of the morphology of PM2000 powder

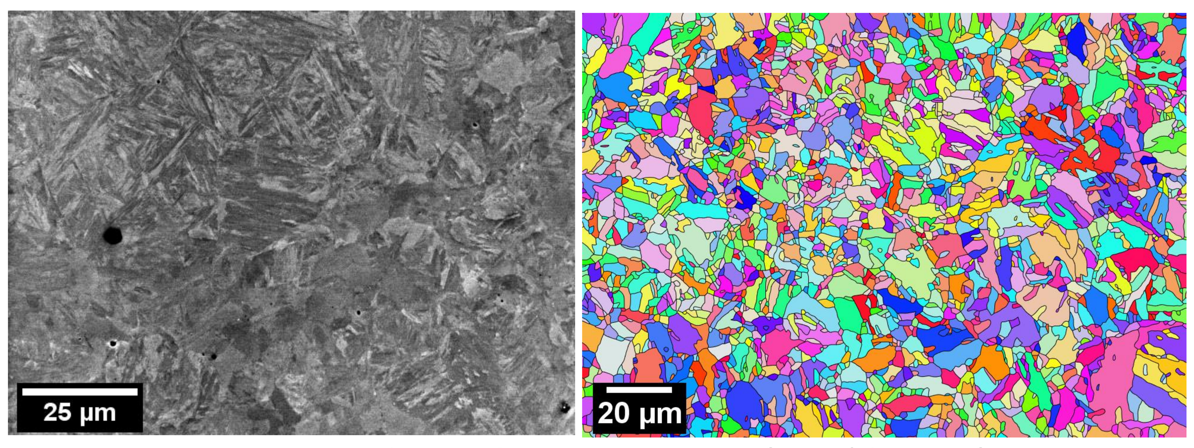


SEM micrographs and EBSD image of HIP'd PM2000.
The average grain size was found to be 1.62µm.

Eurofer-97



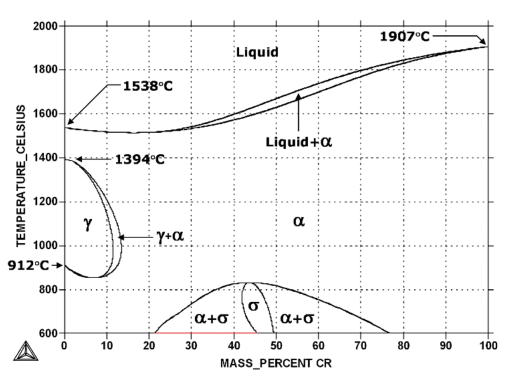
SEM micrographs of the morphology of Eurofer-97



SEM micrographs and EBSD image of HIP'd Eurofer-97.
The average grain size was found to be 11.65µm.

Future Work

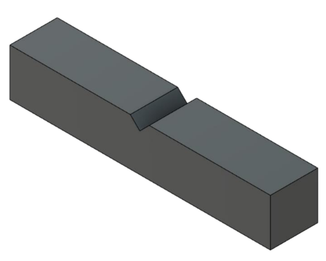
Planetary ball mill for the production of ODS Eurofer-97



Fe-C phase diagram

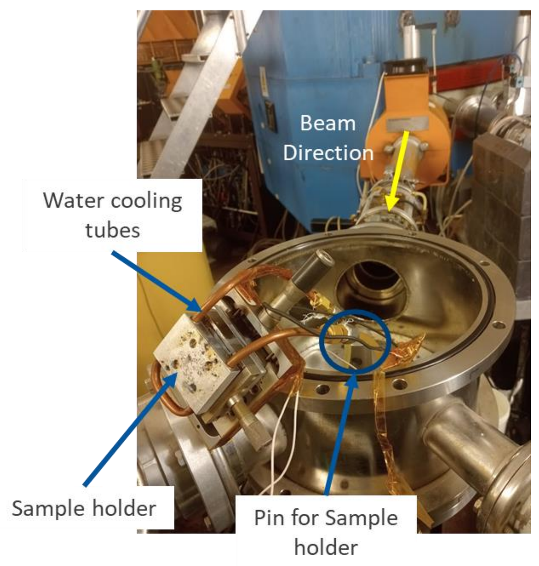
Heat treatment for Eurofer-97: 950°C+WQ (austenising), 750°C/AC (tempering)

Tensile and Creep test specimens



Charpy Impact test specimen

Zwick screw-driven test machine for creep tests



University of Birmingham's cyclotron for proton irradiation and materials testing vacuum chamber.

Irradiation parameters: 2.9MeV proton beam for 15 hours to reach a peak of 1dpa in both PM2000 and Eurofer-97 at approximately 30µm. The sample will be held at 300°C. .

Production of ODS Eurofer-97 → Mechanical Testing → Irradiation Testing

Foundation

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1. Ukai, S., et al., *ALLOYING DESIGN OF OXIDE DISPERSION-STRENGTHENED FERRITIC STEEL FOR LONG-LIFE FBRS CORE MATERIALS.* Journal of Nuclear Materials, 1993. **204**: p. 65-73.
2. Kim, G. E., T. K. Kim, and S. Noh. 2020. 'DIFFERENCE OF MICROSTRUCTURES AND MECHANICAL PROPERTIES BETWEEN 9Cr-1W FERRITIC/MARTENSITIC STEEL AND ODS STEEL', *Archives of Metallurgy and Materials*, 65: 337-41.

This publication was made possible by the support of TWI and Lloyd's Register Foundation. This work was enabled through, and undertaken at, the National Structural Integrity Research Centre (NSIRC), a postgraduate engineering facility for industry-led research into structural integrity established and managed by TWI through a network of both national and international Universities. This research is funded by TWI's Core Research Programma, a market-driven promgramme of research and development activities that underpin the creation and optimisation of joining, materials and engineering technologies. www.twi-global.com/crp