Experimental Study of Dislocation Density during Recovery of Eurofer and Copper

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INTRODUCTION

Eurofer97, a reduced-activation ferritic–martensitic (RAFM) steel, and copper are two key materials considered for use in future DEMO thermonuclear fusion reactors [1]. The intense heat fluxes and neutron irradiation generated by the fusion reaction between deuterium and tritium nuclei induce microstructural defects and thermal expansion, resulting in an increase in dislocation density. This increase may lead to hydrogen trapping and potential embrittlement of components exposed to the plasma [2]. Several modelling approaches attempt to describe hydrogen transport mechanisms by accounting for the evolution of microstructural defects and the competition between defect creation and annihilation through recovery processes [3]. However, these models remain limited by the scarcity of kinetic data describing the evolution of dislocation density as a function of temperature. A deeper experimental comprehension of this evolution is therefore essential to improve the accuracy and reliability of hydrogen transport models. Before investigating the hydrogen trapping capabilities of these defects and the influence of hydrogen on recovery kinetics, it is first necessary to focus on the recovery behaviour of the materials during annealing treatment alone.

MECHANICAL PROPERTIES VERSUS DISLOCATION DENSITY

This study first investigates the influence of annealing on the dislocation density of Eurofer97 and copper, followed by the effects of mechanical loading. The materials were examined in

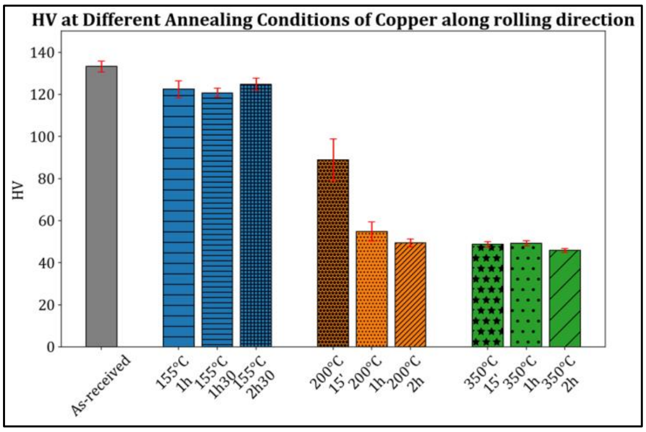

Figure 1: Vickers Hardness Measurement of Coppers

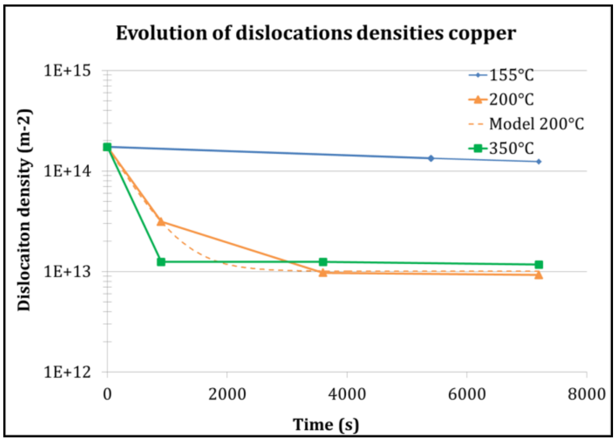

Figure 2: Evolution of dislocation densities in log scale of coppers from experimental results and first order model for 200°C set. Estimation of error is under evaluation.

their as-received state, after annealing, and following tensile deformation up to 35% total strain applied to Eurofer97, while copper was initially investigated in two cold-rolled states with rolling reductions of approximately 71% and 96%. Mechanical properties were characterized using micro-hardness measurements (Figure 1), dislocation densities were determined by X-ray diffraction with Williamson-Hall analysis for copper (Figure 2) and Williamson-Smallman analysis for Eurofer97, while microstructural information were observed by scanning electron microscopy and EBSD imaging. These methods provide detailed insights into the recovery kinetics, highlighting the characteristic temperatures and heating durations associated with defect annihilation - from 155°C to 350°C and annealing times ranging from 7 minutes to 2.5 hours for copper while the temperature range and the durations of Eurofer97 are under current works.

PROPOSITION OF DISLOCATION DENSITY MODELS

From experimental XRD results, different models of dislocation density evolution are proposed using an empirical phenomenological recovery kinetic model based on solving a differential equation with variable order exponents. The first order model is depicted on Figure 2 for the 200°C annealing set. Additionally, two more orders were also done for a comparison purpose.

The main results include temporal evolution models of dislocation density for copper at the two different rolling reductions, and for Eurofer97, with a comparison of the recovery kinetic exponent orders for each material alongside the observed evolution of microstructural features such as average grain sizes, disorientation angles and recovery fraction. The results present a novel experimental dataset and modelling approach that complements existing studies, providing more precise inputs for predicting hydrogen transport and material performance in fusion reactor environments.

REFERENCES

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