Deformation Mechanisms in Advanced Disc Ni-base Superalloys

E. Knoche¹, B.M.B. Grant¹, M. Daymond², J. Quinta da Fonseca¹, M. Preuss¹

¹University of Manchester, School of Materials, UK
²Dept. of Mechanical and Materials Engineering, Kingston, Ontario, Canada

Acknowledgements: EPSRC/DSTL for providing funding (EP/E020933/1), beam line scientists at ISIS, Rolls-Royce plc. for providing material
Material studied RR1000

- Polycrystalline nickel based superalloy for turbine disk application
- Good creep and fatigue properties even at elevated temperatures
- Main strengthening by ordered $\gamma'$ precipitates (close to 50 vol.%) → multimodal size distribution

$\gamma'$ in Ni$_3$Al ($L1_2$)
Objectives

- Microstructure - deformation mechanism relationship poorly understood
- classical precipitation strengthening mechanisms fail to provide a full mechanistic understanding

Methodology

- Deformation mechanisms in polycrystalline nickel-base Superalloys (RR1000) with high vol.% of $\gamma'$ studied using simplified model microstructures with unimodal $\gamma'$ size distribution.
Generating the model microstructures

- Coarse γ’ (230 nm)
- Medium γ’ (130 nm)
- Fine γ’ (90 nm)

Temperature

- 1050°C
- 925°C
- 1160°C
- 800°C
- 20°C

Time

- 1h

Cooling rates:
- -1°C/min
- -0.1°C/min quench
Tensile tests

Yield strength decreases with increasing particle size at all three test temperatures.
In situ loading

- we measure the elastic strain response of grain families

- (100) and (110) superlattice peaks required (position and width) to fit γ+γ’ (200) and (220) reflections
Elastic lattice strain response of the matrix and precipitate phase almost identical even in the regime of plastic deformation

$\Rightarrow$ Deformation of $\gamma$ is not possible without deformation of $\gamma'$

Fine $\gamma'$ tested at 20°C
In-situ neutron diffraction

20°C tests

- Elastic lattice strain response identical at first for $\gamma$ and $\gamma'$
- After certain level of plastic strain: load transfer from $\gamma$ to $\gamma'$
- $\gamma$ takes up more plastic strain than $\gamma'$
Load transfer

Tendency for load transfer increases with increasing particle size and test temperature.

- 20°C
- 500°C
- 750°C

Typical error

Fine γ'

Medium γ'

Coarse γ'
Post-mortem SEM (20° C test)

- Shearing dominates all three deformed microstructures
Localised deformation

- Very fine shear lines in coarse $\gamma'$ microstructure, but not in fine or medium $\gamma'$.
TEM results for 500° C tests

Fine γ' RR1000
500° C
Strongly coupled dislocations

Shear lines

→ Results suggest shearing by strongly coupled dislocations as main deformation mechanism → good agreement with neutron/modelling results suggesting joint deformation of γ and γ'.
Medium $\gamma'$ RR1000 500°C

Increased dislocation density around precipitates

Bowing of dislocations

Neutron/modelling results: $\rightarrow \gamma - \gamma'$ load transfer after initial joint deformation

TEM/SEM: $\rightarrow$ shearing
$\rightarrow$ dislocation pile up on precipitate boundaries
$\rightarrow$ bowing of dislocations
Coarse $\gamma'$ tested at 500°C

- Features comparable to medium RR1000, but more pronounced
750°C tests

Stacking faults in all three microstructures
Extending through both phases in fine $\gamma'$
Mainly restricted to $\gamma'$ in medium and coarse

→ Also increasing pile up of dislocations on precipitate boundary with increasing particle size
Conclusions

• Load transfer changes with temperature, level of plastic strain and $\gamma'$ particle size $\rightarrow$ change in micromechanisms of deformation

• For fine $\gamma'$: $\gamma$ cannot deform without $\gamma'$ $\rightarrow$ post-mortem microstructures testify uniform deformation of matrix and precipitates

• For coarser $\gamma'$: deformation of $\gamma'$ becomes harder to deform after initial level of plastic strain $\rightarrow$ load transfer and less localised deformation

$\rightarrow \gamma$ can deform without $\gamma'$ to some extent $\rightarrow$ visible in TEM images as pile up of dislocations around $\gamma'$
Thank you