Grain Boundary Precipitate Embrittlement in Alloy 617 due to Partial Solution Annealing

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Preamble

Thermal Efficiency > 50 %

Steam inlet temp. >700 °C

➢Advanced ultra super critical (AUSC) power plants- Improved efficiency due to high operating temperature

➢Alloy -617 suitable for boiler applications for AUSC power plants due to excellent high temperature properties:

- Creep resistance
- High temperature strength
- High temperature oxidation resistance

Alloy 617 -Ni, Cr, Co, Mo Alloy.
Strengthening mechanism- Solid solution strengthening, second phase formation (Carbide & γ')

Chemical Composition (wt %)

Ni	Cr	Fe	Mn	Mo	Co	Al	C	Cu	B	Si	S	Ti	N	V	Nb
Bal	21.69	0.14	0.01	9.28	12	1.19	0.059	0.01	0.004	0.02	0.002	0.045	0.004	0.01	0.01

Fabrication Flow sheet

Extruded blank → Solution annealing at 1190°C/120 min/ Water quenching → 1st pass pilgering → Solution annealing at 1190°C/60 min/Water quenching → 2nd pass pilgering

Tube cracked during 2nd pass pilgering

Failure Analysis

➢Hardness measured for tubes cracked during pilgering and successfully pilgered tube and as pilgered tube.

➢Study of fracture surface using SEM.

➢Microstructural characterisation and comparison with microstructure of successfully pilgered tube

➢Microstructure characterisation of samples from cracked tubes after re-annealing at 1190°C/60 min

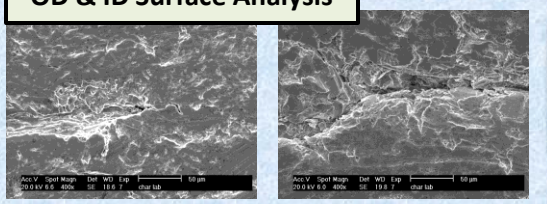
Scanning Electron Microscope (SEM)

Results

Hardness Comparison

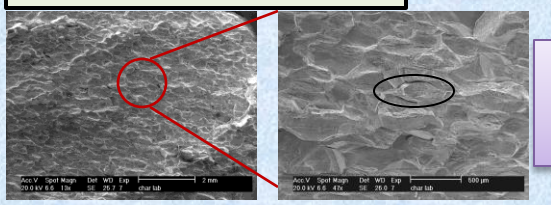
Condition	Hardness (HV 10, VHN)
As pilgered	380
Solution annealed -1190 C/60m – Successfully pilgered	178
Solution annealed -1190 C/60 min – Cracked during pilgering	181

OD & ID Surface Analysis



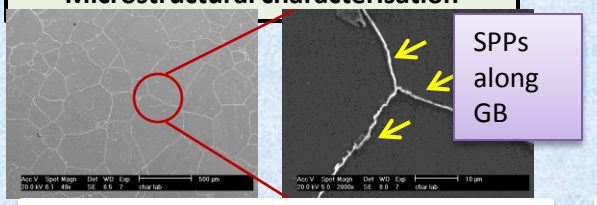
Fine crack like features observed on OD and ID surface

Fracture surface analysis

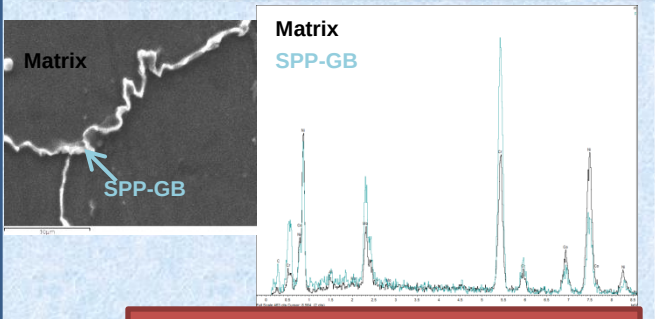


Crack propagation along Grain Boundary (GB)- Intergranular fracture

Microstructural characterisation

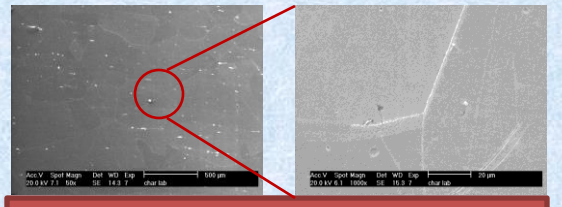


As received | Reannealed

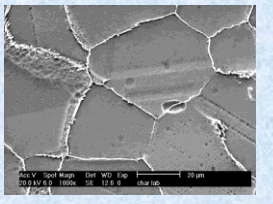


EDS Analysis of Second Phase particle(SPP)

% Composition		
	Matrix	SPP-GB
Ni	52.29	25.32
Cr	23.36	38.5
Co	11.74	5.8
Mo	11.79	15.5
Al	0.92	-
C	-	14.8



Microstructure of successfully pilgered tube : No GB enrichment



As extruded blank

Conclusions

➢No significant difference in Vickers Hardness values were observed in annealed mother tubes of cracked tube and tubes without cracks

➢ The Fracture surface showed intergranular fracture suggesting embrittlement along grain boundaries. Microstructural characterisation showed enrichment (Mo, Cr, C) along the grain boundaries.

➢No grain boundary enrichment was observed after re-annealing of mother tubes

➢It is confirmed that grain boundary enrichment resulted in embrittlement of grain boundary and subsequent cracking during cold working. Though proper solution annealing was imposed, slight delay in quenching resulted in formation of such precipitation and subsequent embrittlement.