Optimization of microstructure and mechanical properties of Ni-Fe-based superalloy GH984

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1. Introduction

- Ni-Fe-based superalloy GH984, which has been used as superheater tube material in high pressure boilers for more than ten years, is now considered to be used as superheater, reheater, and header materials in 700℃ USC boilers in China.

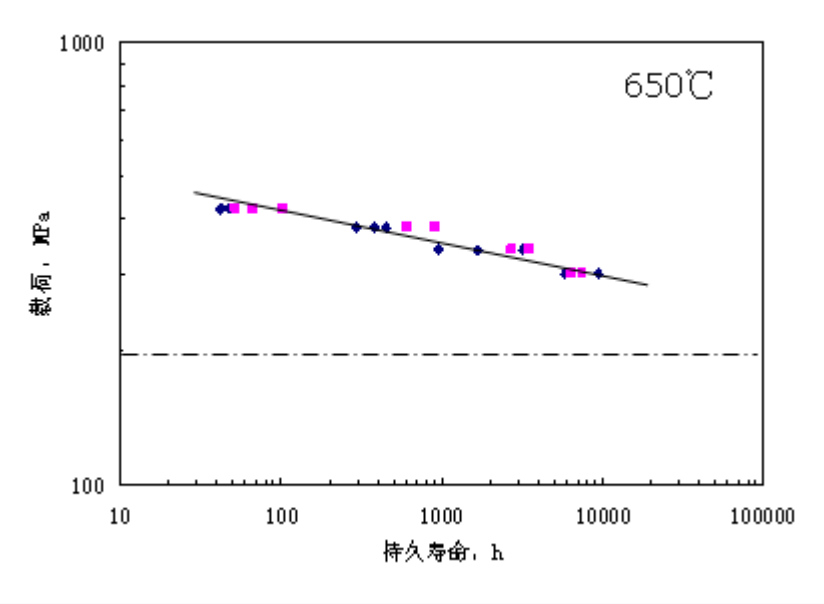
Nominal compositions for GH984 and other nickel alloys

alloys	C	Cr	Co	Mo	Nb	Ti	Al	Fe	Nl
GH984	0.06	19	—	2.2	1.2	1.3	0.4	33	43
IN 740	0.03	25	20	0.5	2.0	1.8	0.9	≤ 0.7	50
IN 617	0.07	22	12	8.7	—	0.4	1.2	≤3.0	56
N 263	0.06	20	20	5.8	—	2.2	≤0.6	≤0.7	50

Thermal conductivity for GH984 and other nickel alloys

	GH984	CCA617	IN740	N263
600℃	26.5	21	18.4	21.4
700℃	29.4	23	20.2	23.0
800℃	---	25	22.1	24.7

- GH984 has higher thermal conductivity over CCA617 and N263 by ～27%, over IN740 by ～45%;
- superheater materials with high thermal conductivity is beneficial to boiler efficiency.



Stress-rupture property of GH984 tubes
(Φ25×2.5, solution-annealed， grain size 5~7 grade)

Research objectives:

(1) reasons for the sharp drop of rupture life at 700℃;
(2) Method to improve thermal stability;
(3) B, P microalloying to improve creep strength.

2. Materials and experiments

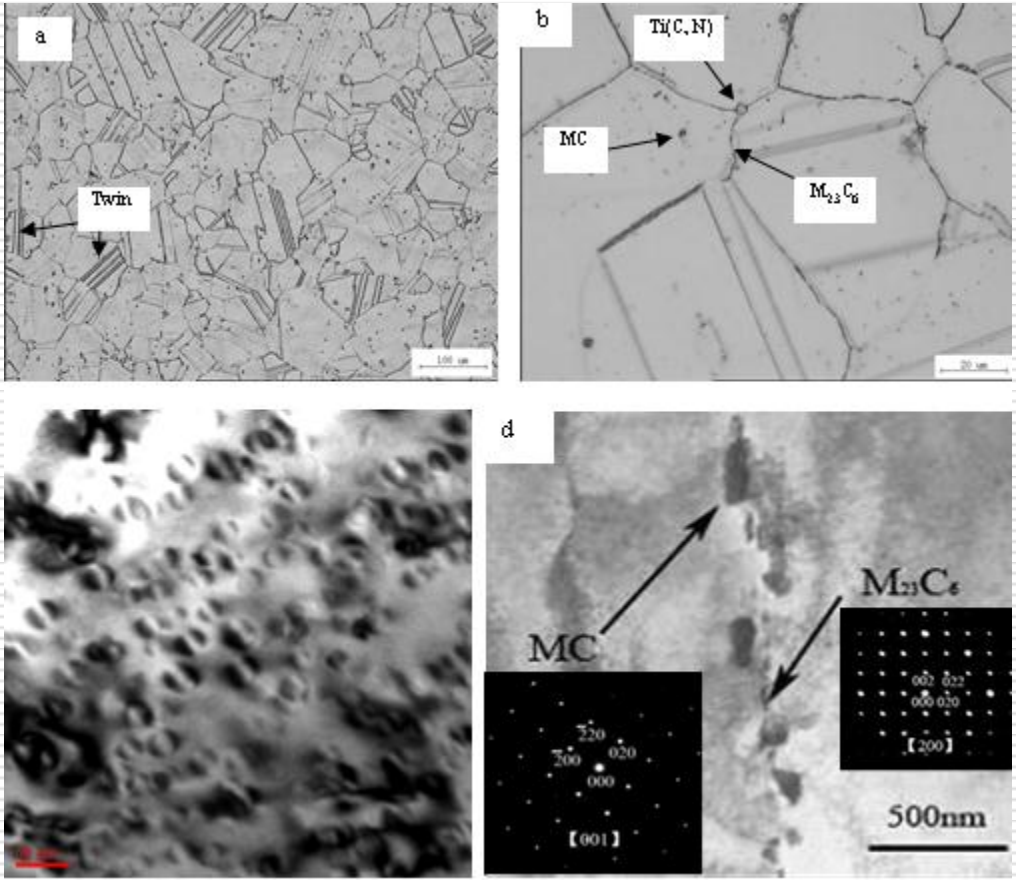
Chemical composition of GH984 master alloy

C	Cr	Mo	Nb	Al	Ti	Fe	Ni
0.05	19.1	2.15	1.08	0.39	1.20	34.0	Bal.

- vacuum remelted into 16kg ingots and then hot worked to bars of 16 mm in diameter
- heat treatment: 1100℃/1 h/AC+ 750℃/8 h/ AC
- Long-term aging at the temperature ranges of 650~800℃ up to 5000h, and still continue.

3. Results

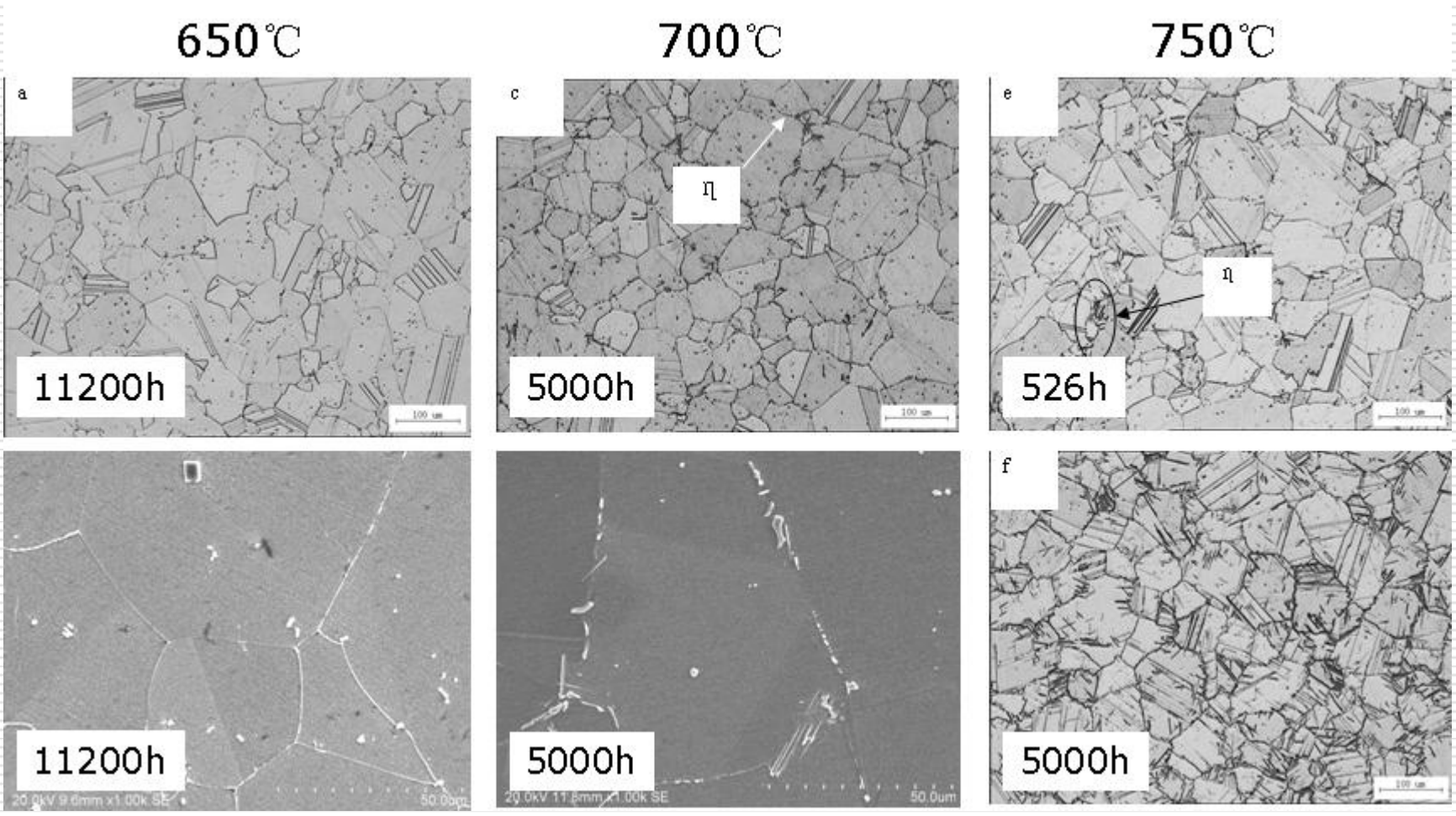
3.1 Thermal stability



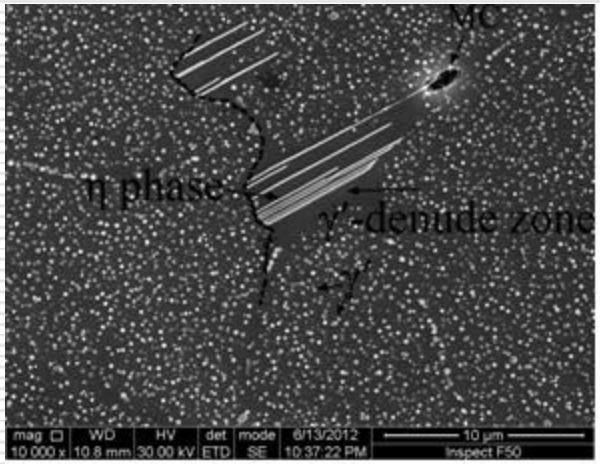
γ′ size: ~20nm
γ′ volume: ~6%,

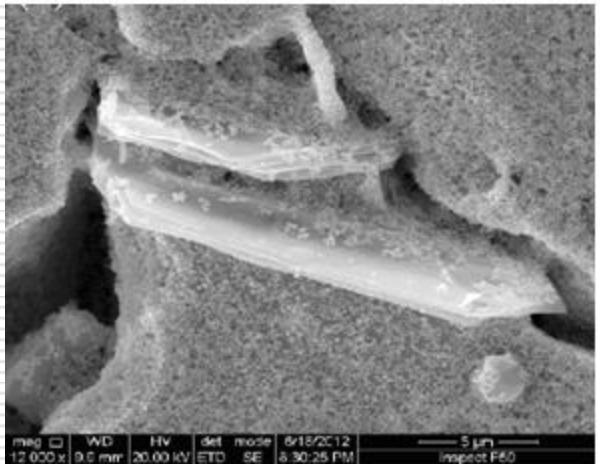
MC（NbC、Ti(N,C)）
MC size: 1~10μm
MC volume: ~0.5%

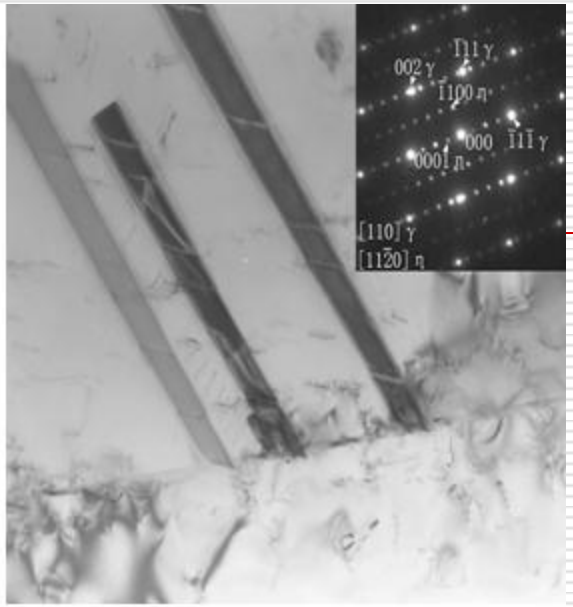
- microstructures of GH984 under standard heat treatment



- Microstructures of GH984 alloy after long-term exposure at the temperature range of 650~750℃

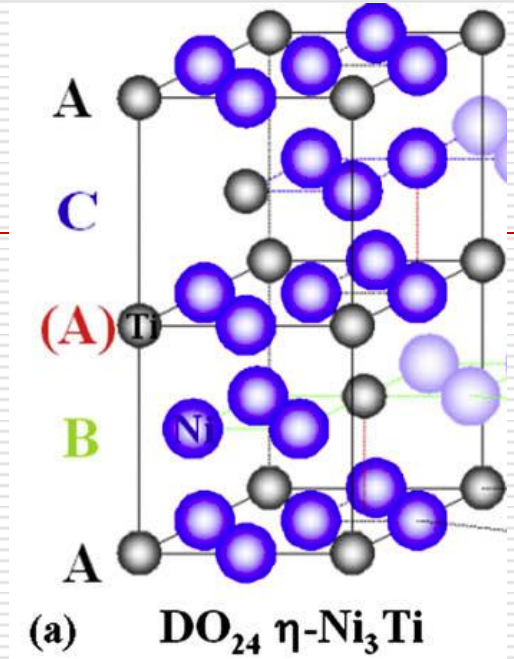


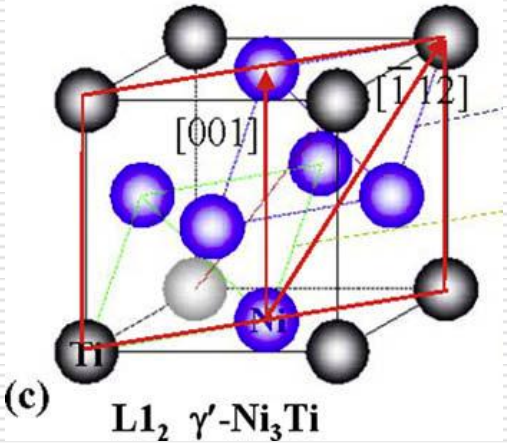




$\{111\}\gamma // \{1000\}\ \eta$

$[110]\ \gamma // [1120]\ \eta$

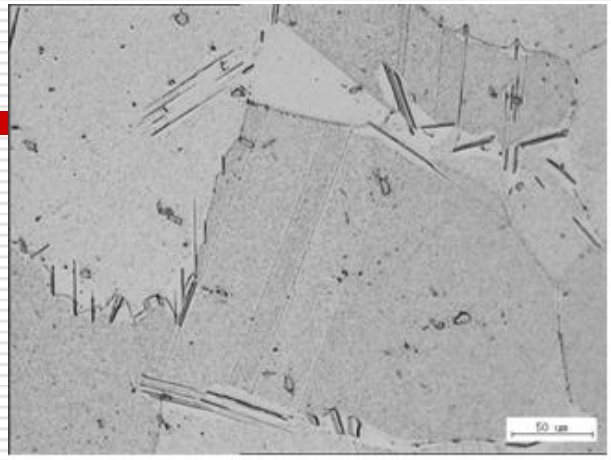


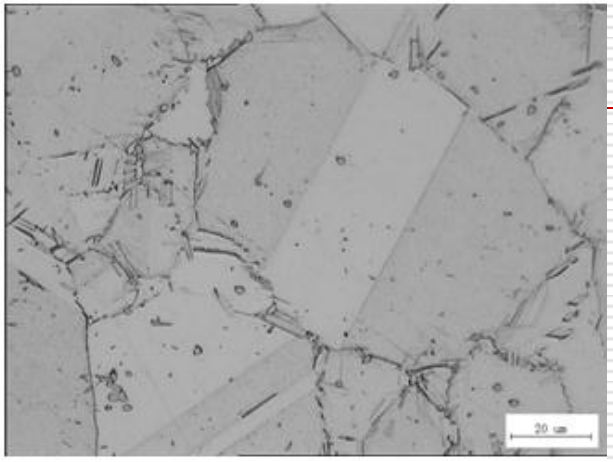


SEM images of GH984 sample aged at 800℃ for 570 h, showing a distinct γ′-denuded zone around lath-like η phase

Y.U.Heo et al, Acta Materialia 57 (2009) 1176

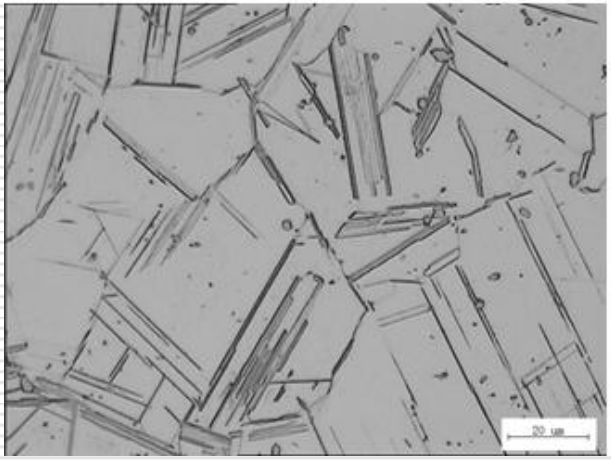
750℃

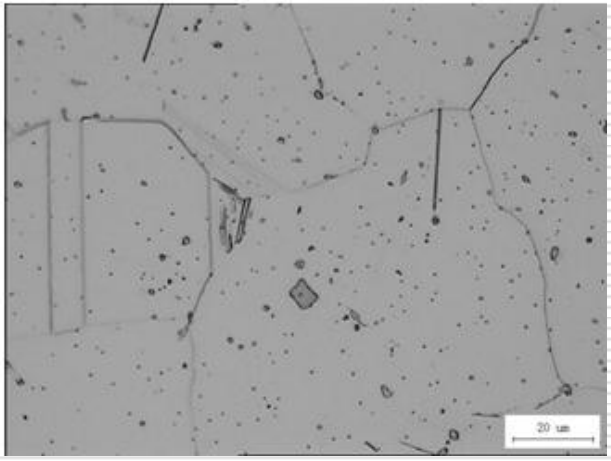




800℃

850℃

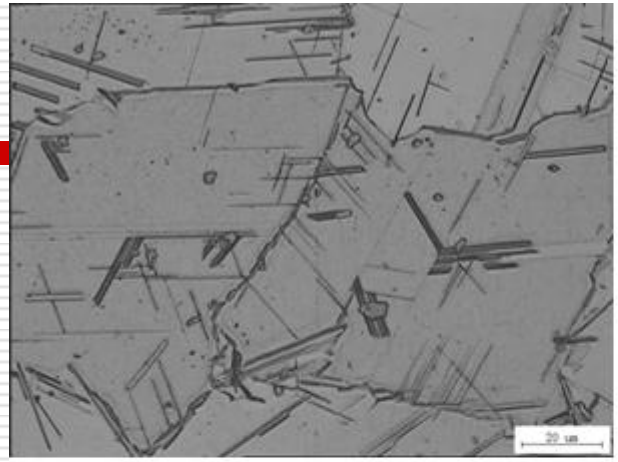


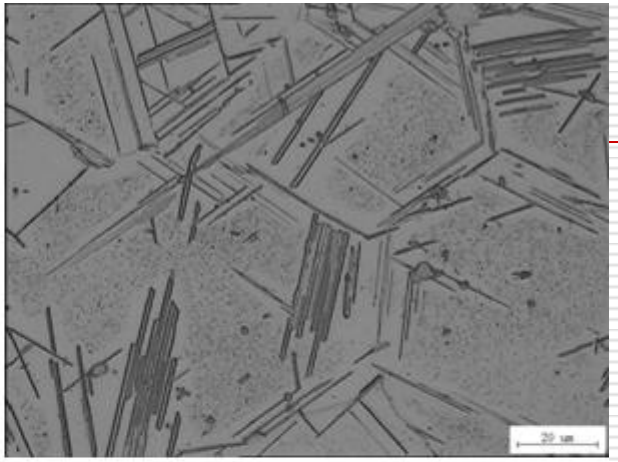


900℃

- η phase appeared after 545h aging

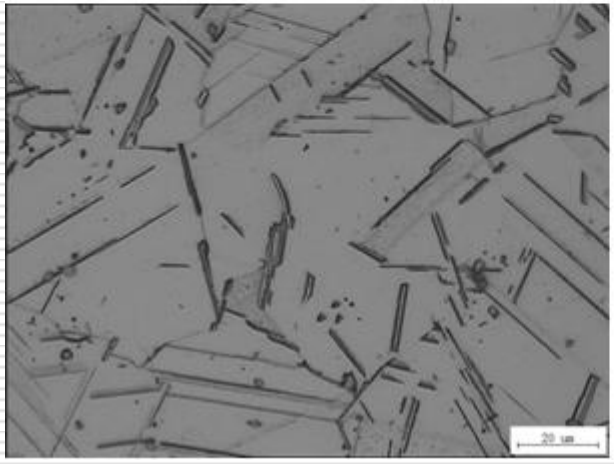
750℃

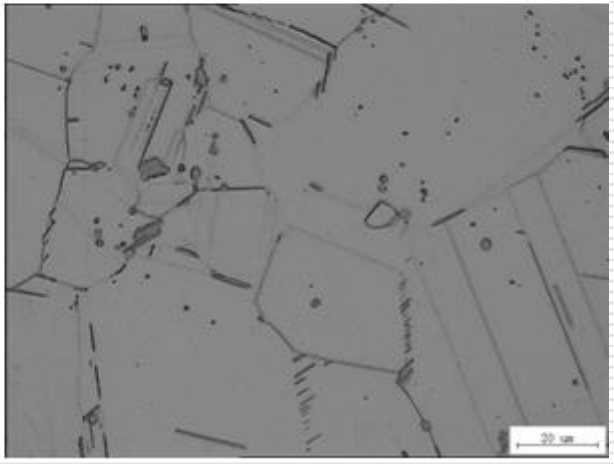




800℃

850℃



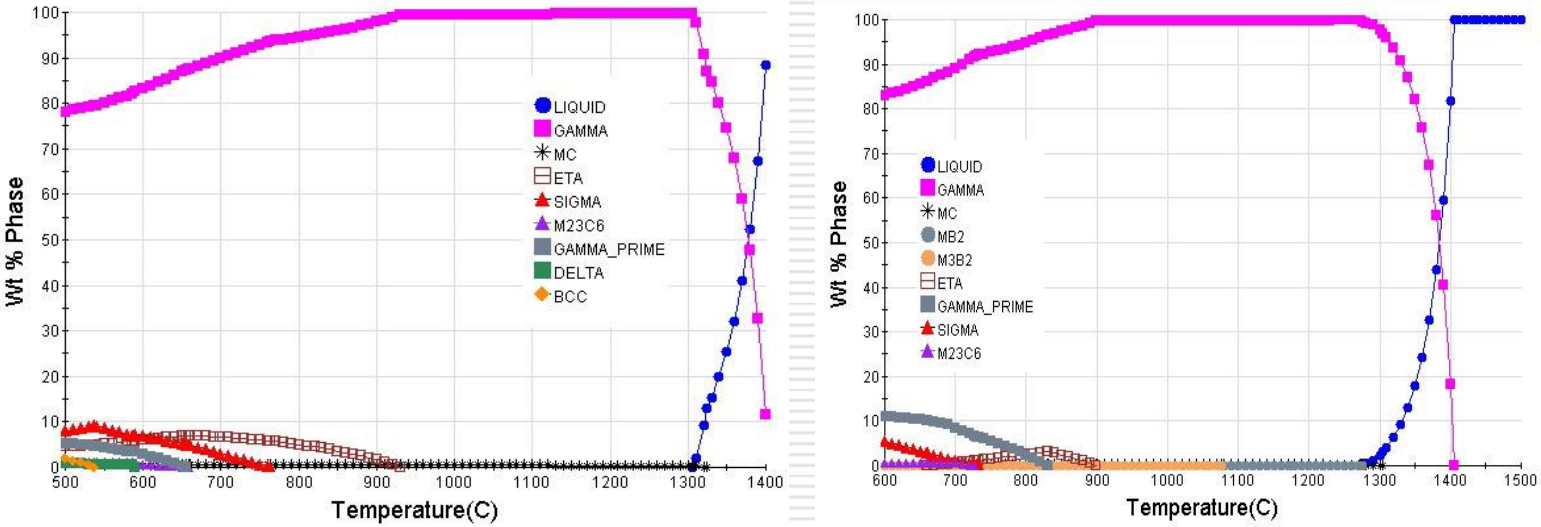


900℃

- η phase appeared after 5000h aging

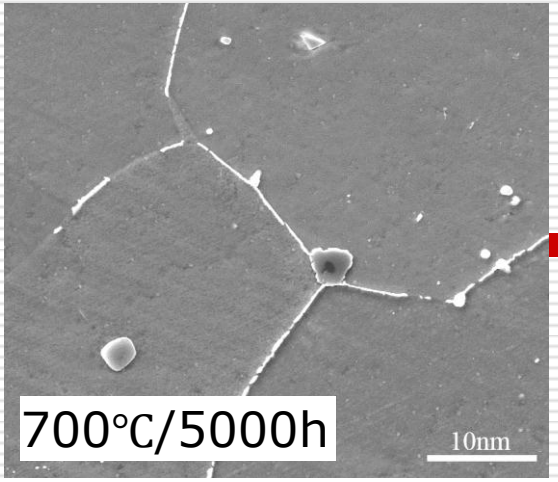
Improved microstructure stability

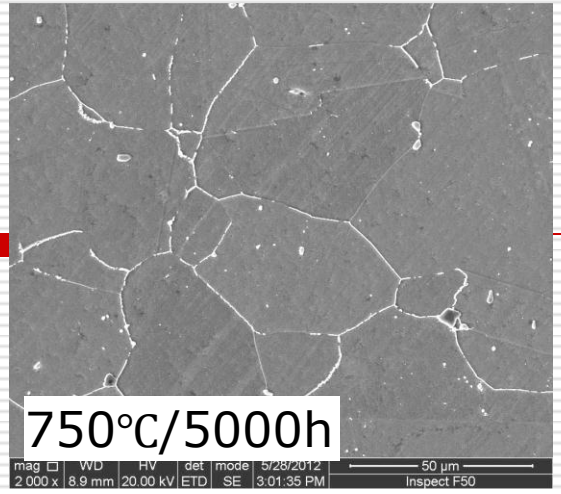
- Ti/Al ratio decreased from 3.4 to 1.5 without changing the total content of Ti and Al.
- Fe content is decreased to suppress sigma phase.

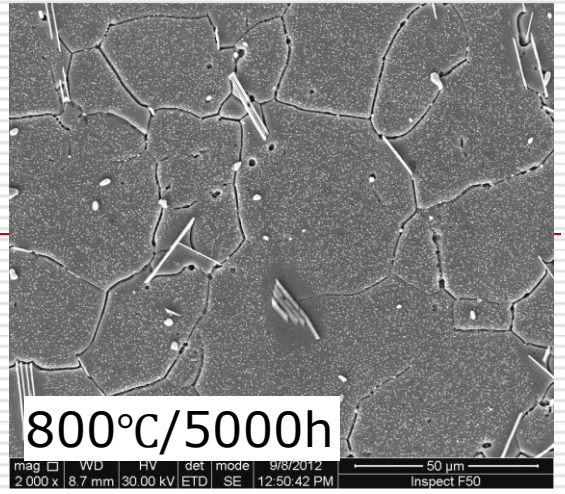


Thermo-Calculation phase diagram for GH984 and GH984G alloy

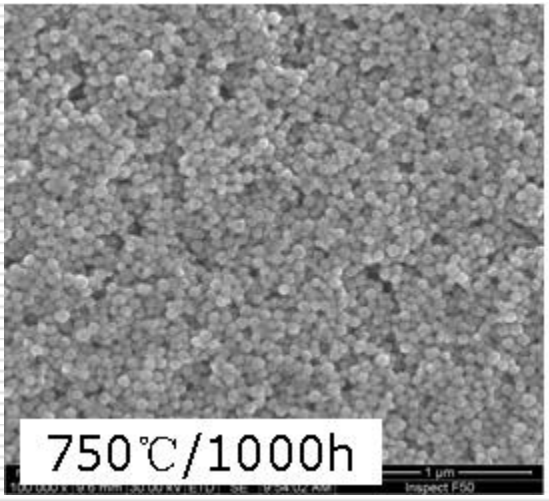
using the J-MatPro program and Ni database established by Thermo-Tech

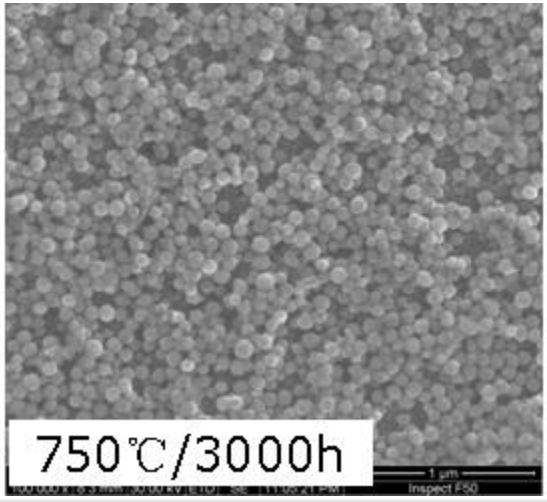


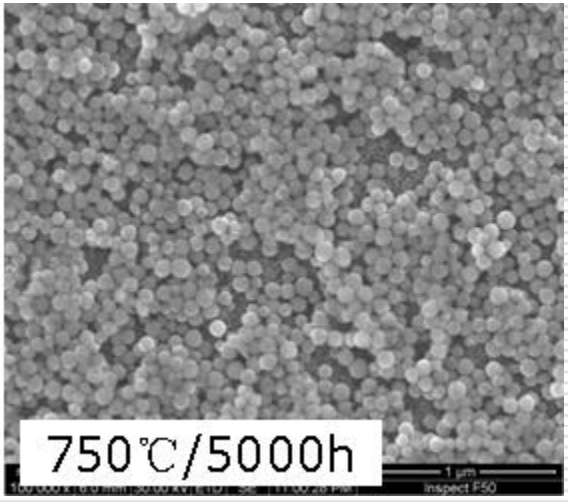




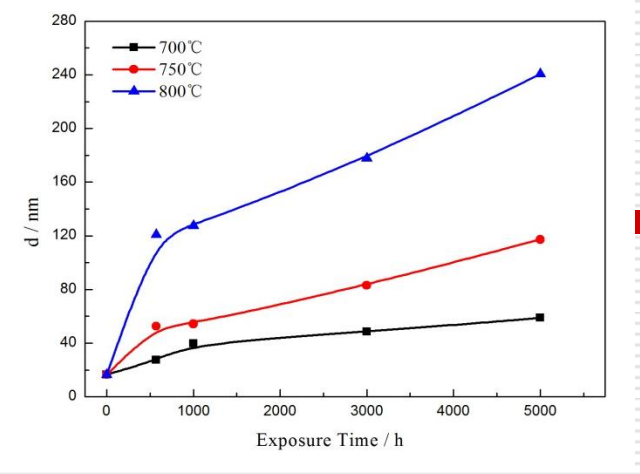
SEM micrographs of GH984G after aging 5000h

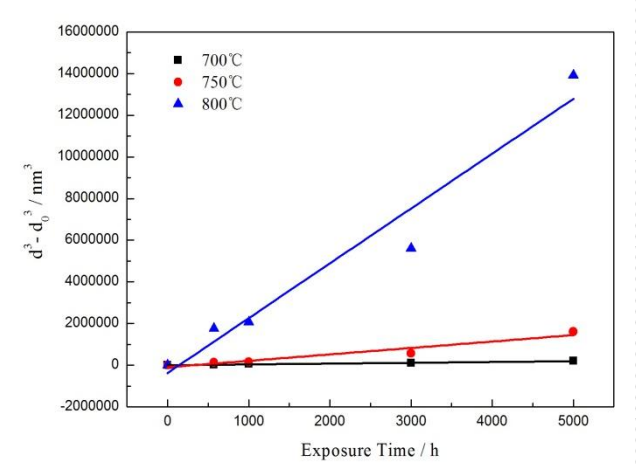




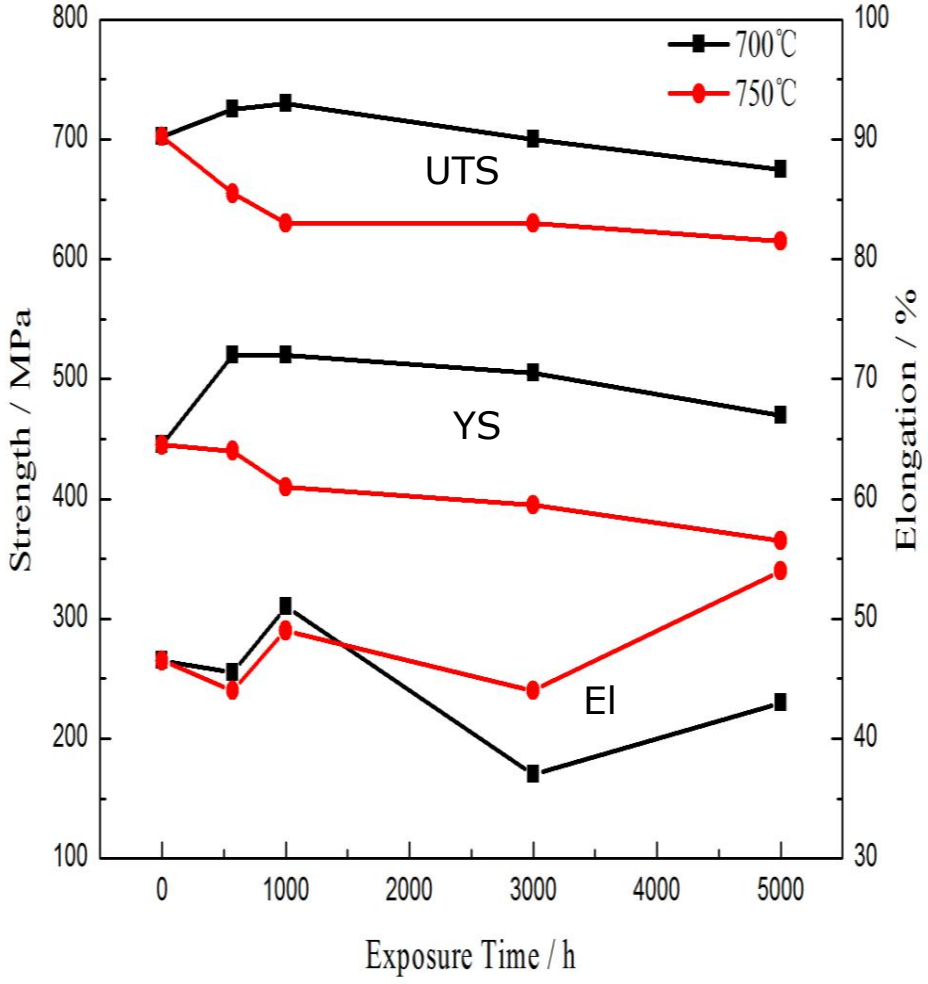


γ' morphology in GH984G aging at 750℃ (deep etched)



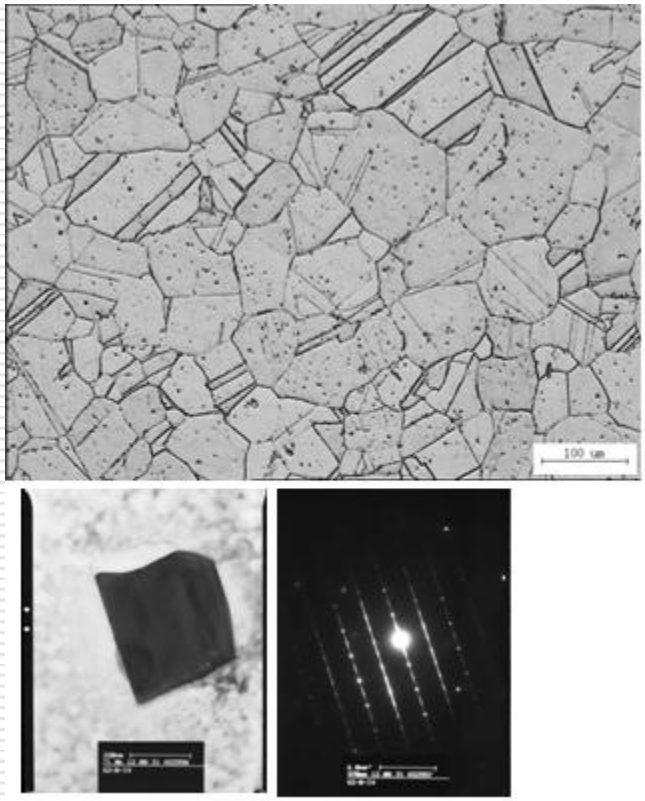


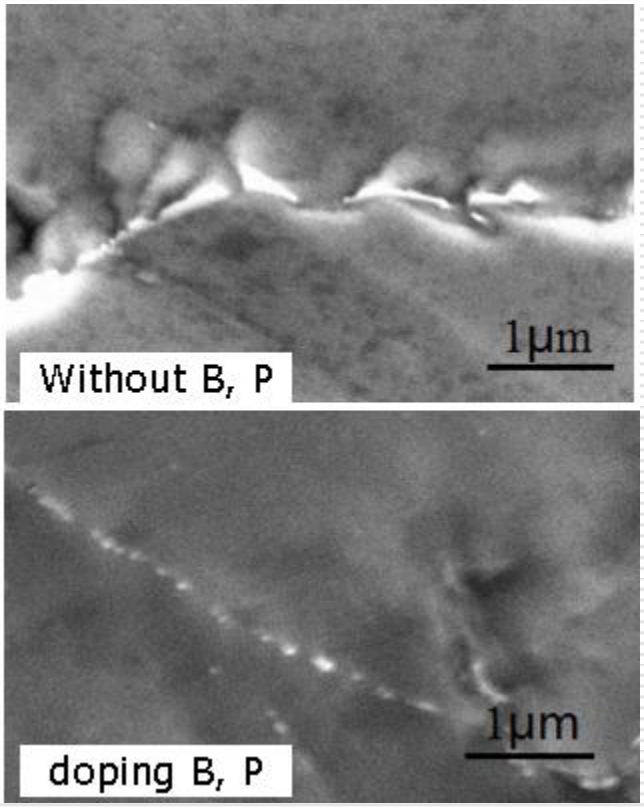
γ′ coarsening follows d3∝time kinetics of diffusion-controlled particles growth



700℃ tensile properties after aging at 700℃ and 750℃

3.2 Influence of B, P addition on microstructure and mechanical properties





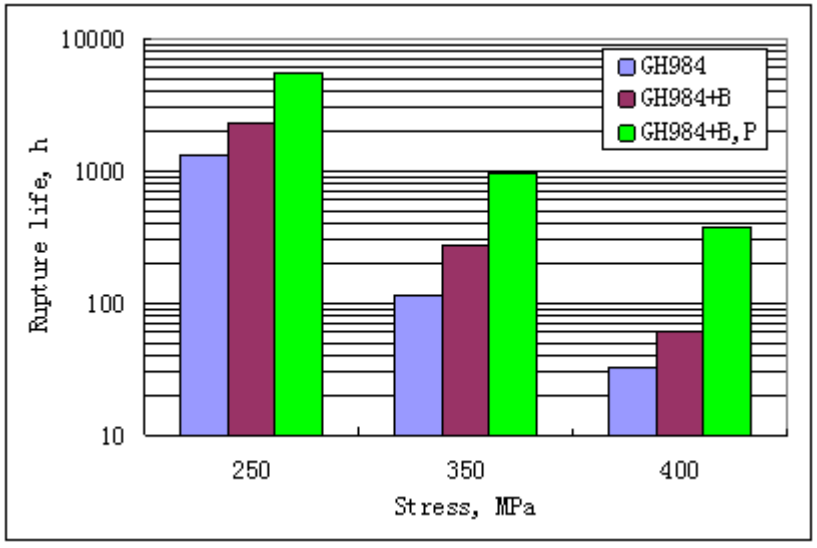
- images of GH984 with 60 ppm B and 200 ppm P additions, and influence of B and P additions on the morphology of $M_{23}C_6$

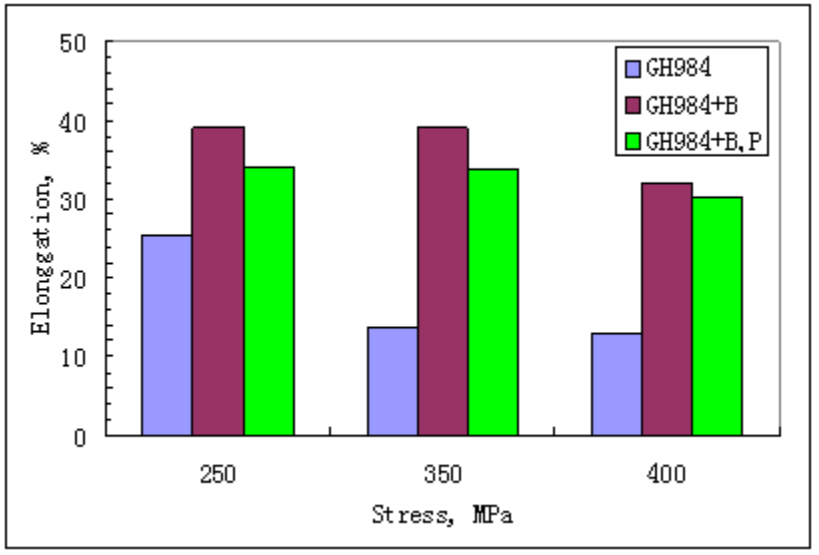
Effect on tensile property

Samples	Temp.	UTS (MPa)	YS (MPa)	El (%)	RA (%)
Free B, P	RT	945	540	30.0	44.0
+B		920	510	32.8	55.0
+B, P		920	525	34.0	50.5
Free B, P	700℃	680	475	22.5	22.5
+ B		665	455	46.3	51.0
+ B, P		685	460	43.0	48.0

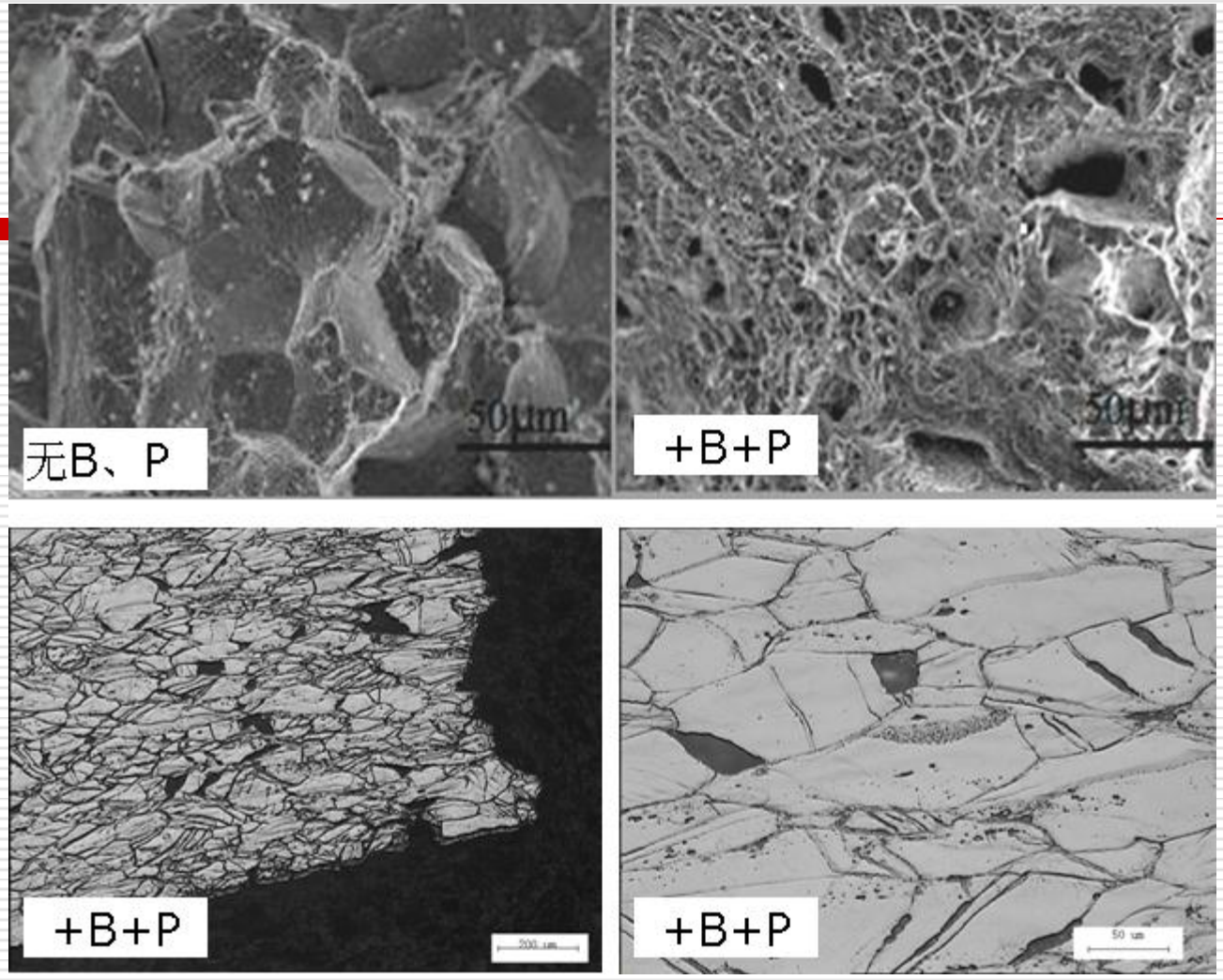
- Tensile ductility at 700℃ increase markedly after B, P addition

Effect on stress-rupture property at 700℃





- Rupture life at 700℃/250MPa increased from 1127h to 5541h after B and P addition。
- Without B and P addition, rupture life at 700℃/180MPa is only 4635 h。



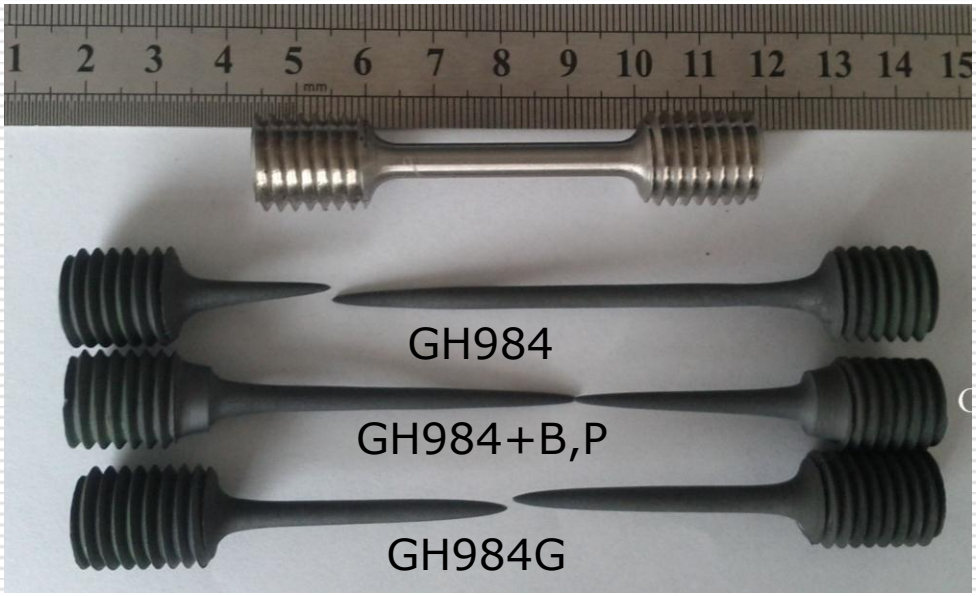
- Fractured surfaces of the samples without/with B and P addition crept at 700℃/350MPa

Comparison of stress-rupture property

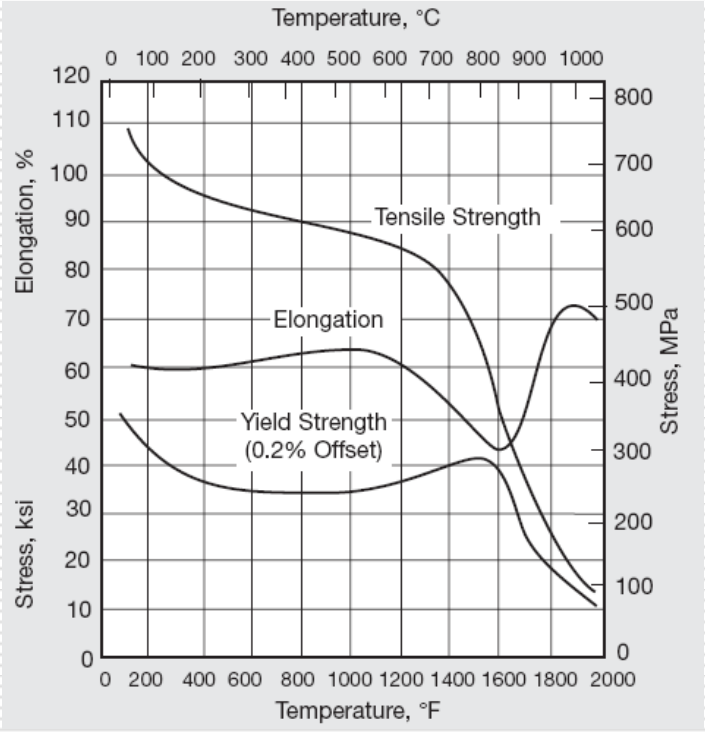
Alloy	Temp.	Stress, MPa	Life, h
GH984+B,P	700℃	250	5541
HR6W		120	2057
H230		200	1517
CCA617		250	~6000
IN740		350	5227

Data from BOILER MATERIALS FOR ULTRASUPERCRITICAL COAL POWER PLANTS , USC Materials - Quarterly Report , August 1, 2005

Good plasticity at high temperature



Samples tensile tested at 1100℃ with initial strain rate of 0.17, showing elongation for all the samples is ~200%, much larger over IN617 alloy. UTS for all samples is ~60MPa.



High temperature tensile properties of solution-annealed, hot-rolled IN617 rod

Summary

- after exposed at above 700℃, η-Ni_3Ti phase appears in GH984 alloy, and subsequently degrades stress rupture properties.
- B and P microalloying can obviously improve the stress-rupture life and ductility of GH984.
- The thermal stability is improved by adjustment of Ti/Al ratio, and the optimized alloy GH984G is a promising material for A-USC coal-fired power plants.

Thanks for your attention