The research and development of heat resistant steels and alloys used for 700℃ A-USC-PP in china

Zhengdong LIU

China Iron and Steel Res. Inst. Group Co., Ltd

Liu_zhengdong@263.net

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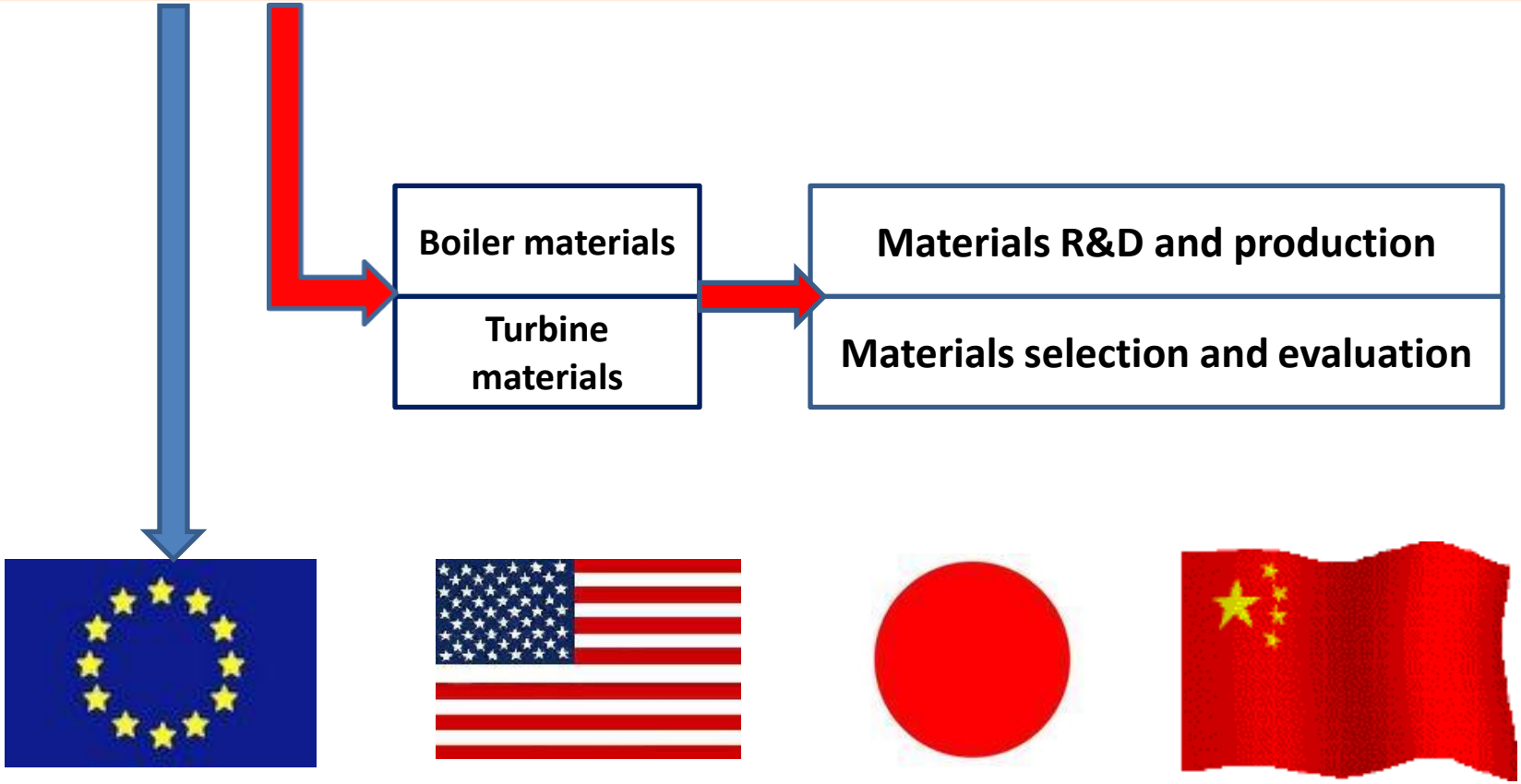
Outline

1. A-USC plans worldwide
2. Conception design and candidate materials of Chinese A-USC PP
3. Boiler heat resistant materials development
4. Remarking summary

1. A-USC plans worldwide

Heat resistant materials for 700 ℃ A-USC PP

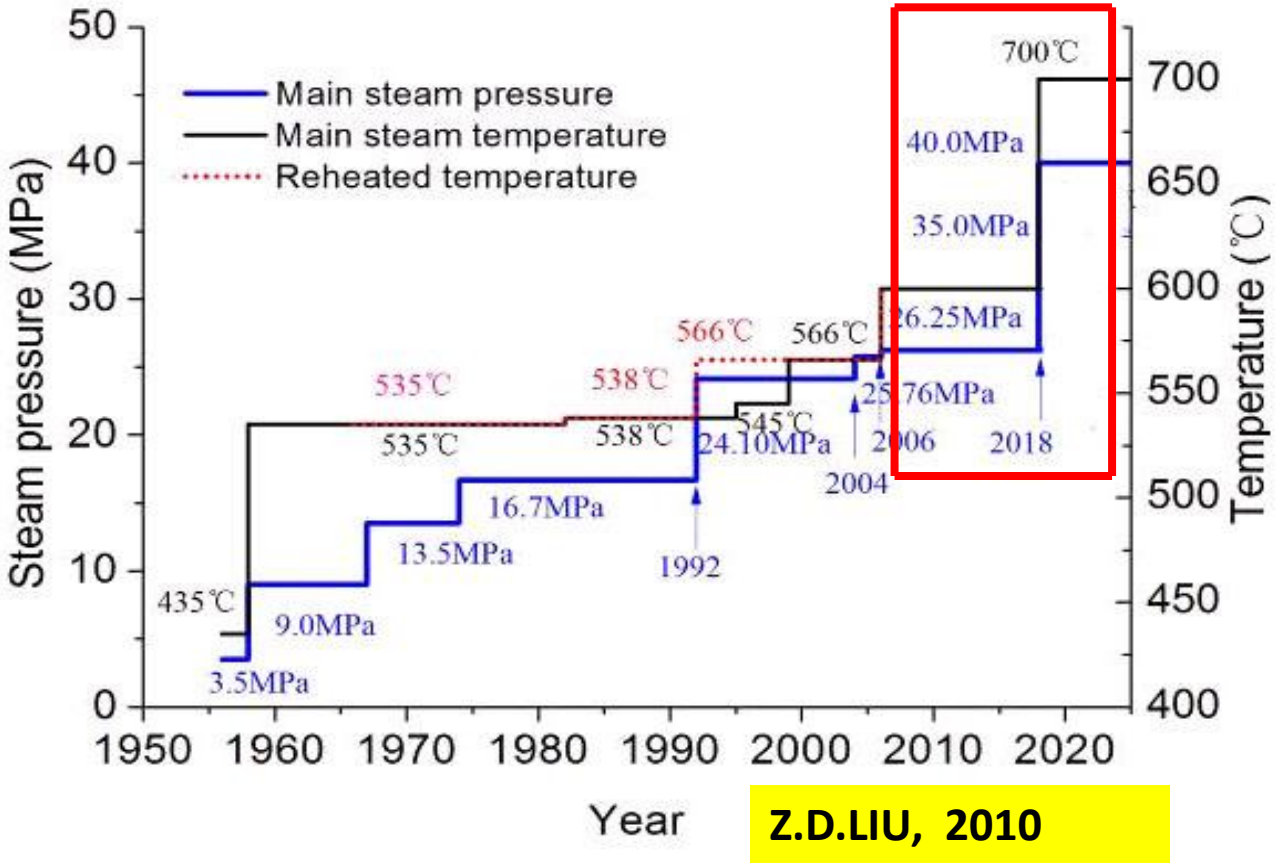
Steam temperature：600℃→ 625℃ →650℃ →700℃ →750+℃



Southern Korea (2012-), India(2011-)

2. Conception design and candidate materials of Chinese A-USC

Steam parameter evolution of Chinese USC power plants



Conception design of A-USC demo PP in China

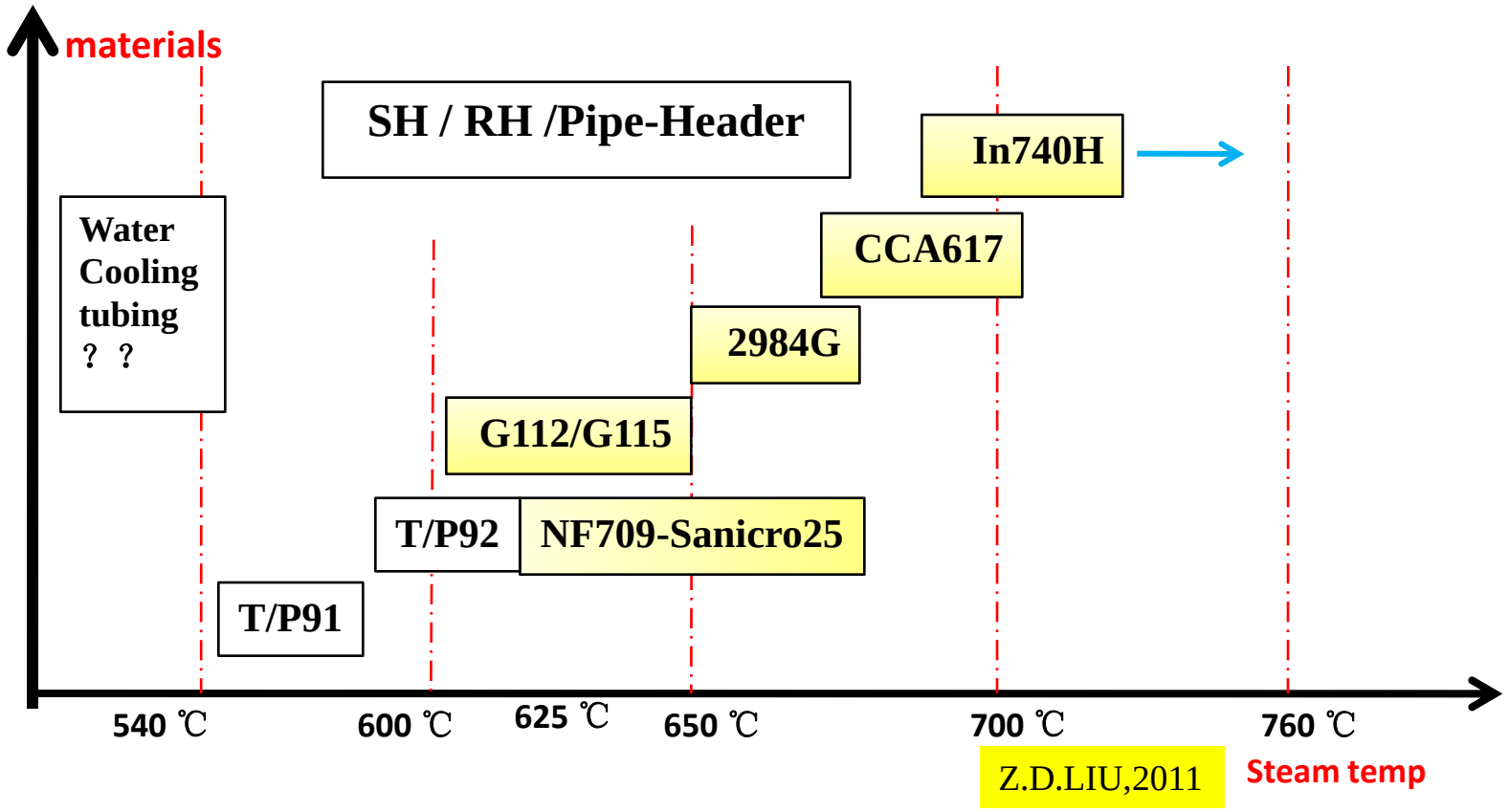
Main parameters

660 MW

35MPa

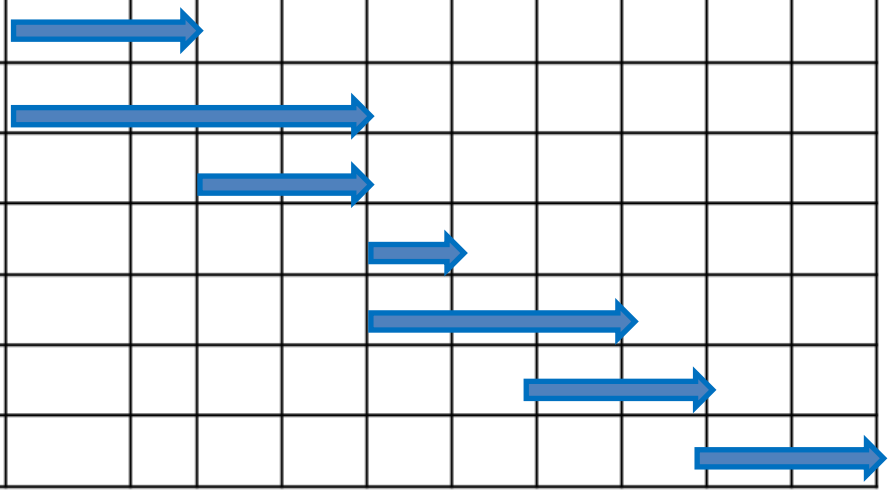
700℃/720℃/720℃

700C A-USC boiler materials spectra in China



A-USC boiler materials R&D time schedule in China

Phase	Task	2010	11	12	13	14	15	16	17	18	19
1A	Candidate material selection										
1B	Materials laboratory investigation										
2A	Materials pilot plant trial										
2B	Product industrial trial										
2C	Materials/product application study										
2D	Evaluation of product										
3	Product supply to the market										



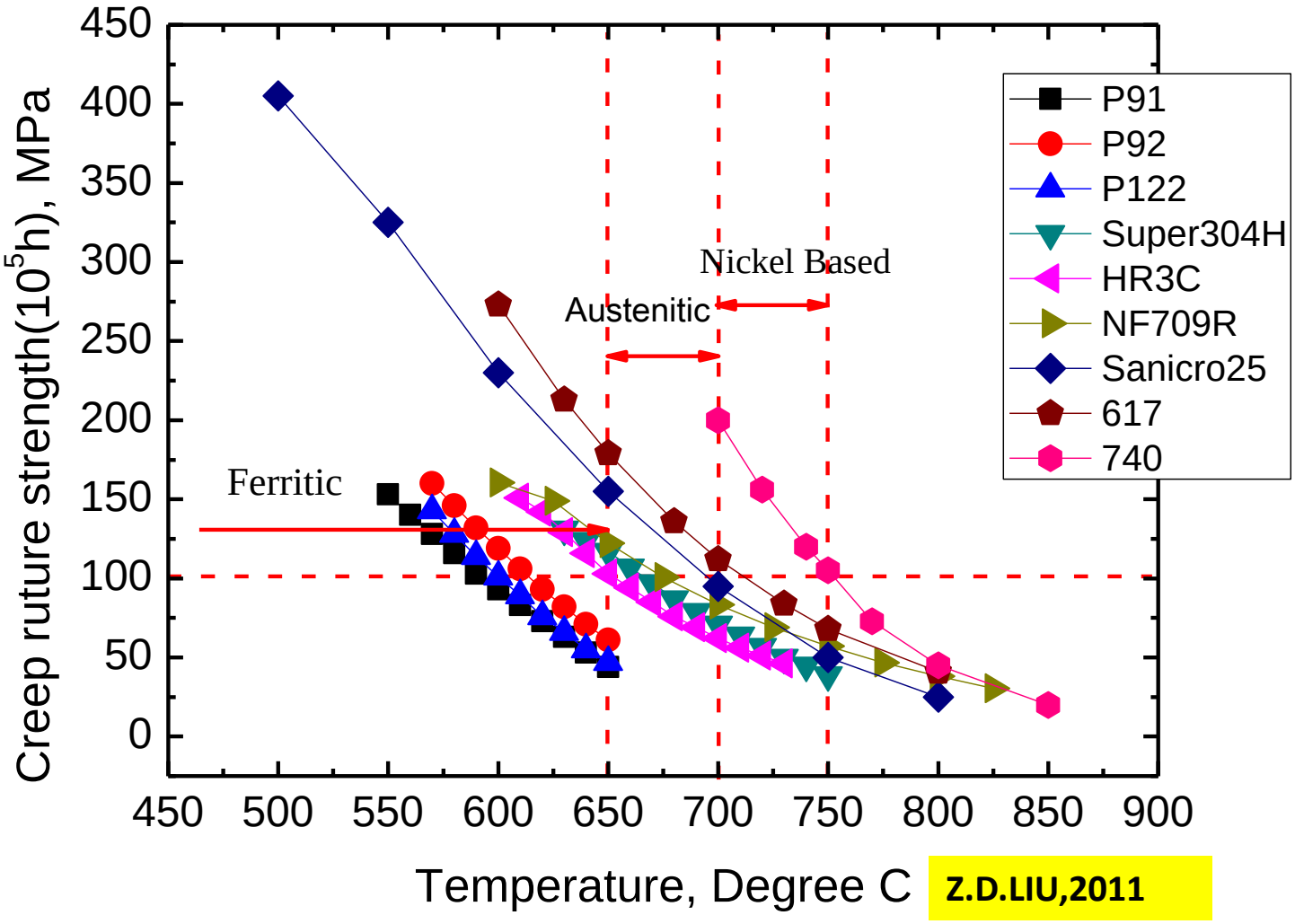
3. Boiler heat resistant materials development

Typical candidate materials used for 700℃ A-USC PP

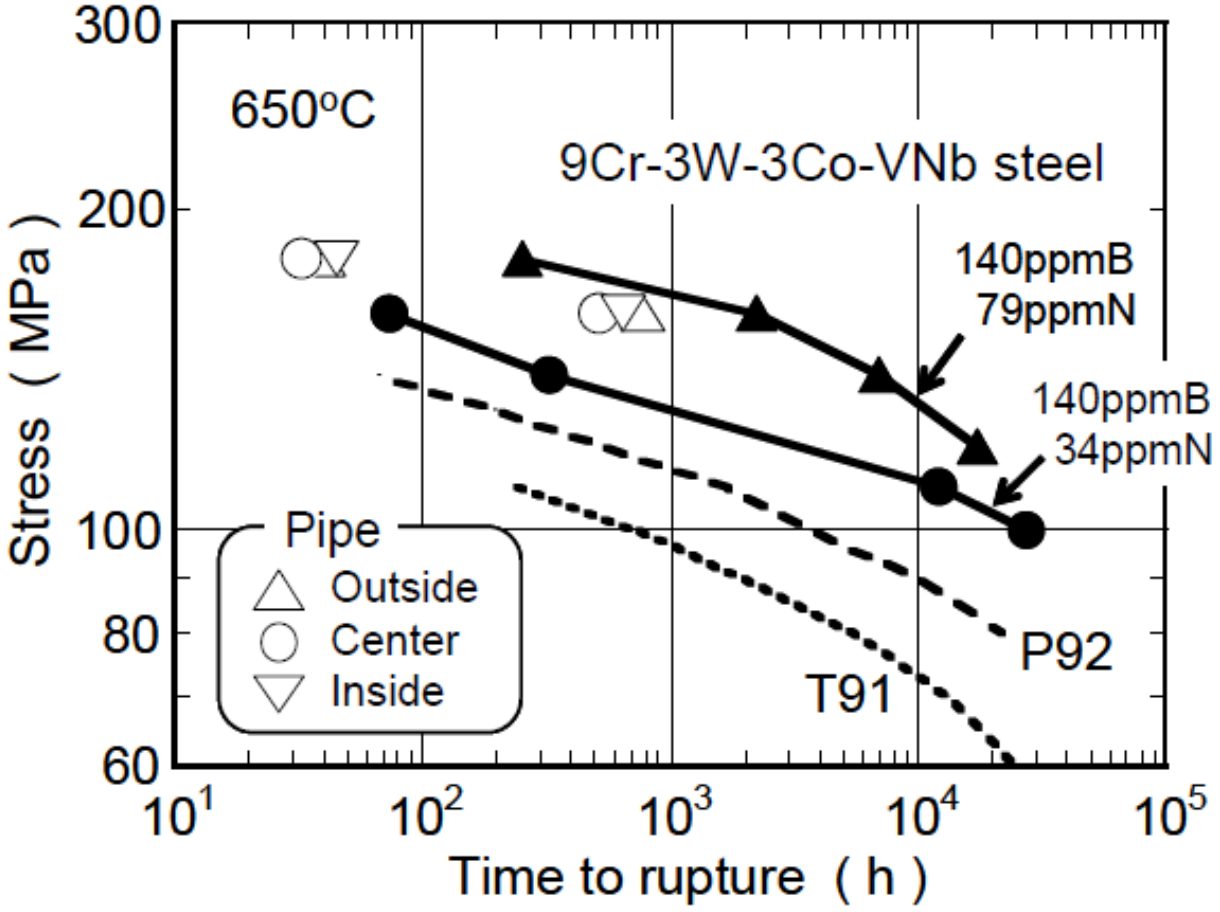
Alloy	C	Cr	Mo	W	Co	Nb	V	Al	Ti	B	Cu	Ni	Other
G115/112	0.08	9-12		3.0	3.0	0.05	0.20			0.015	1.0		Others
NF709R	0.08	21	1.5			0.25						25	Others
Sanicro25	0.08	22.5		3.6	1.5	0.50					3.0	25	Others
GH2984	0.06	19	2.0			1.00		0.4	1.0			43	33Fe
CCA617	0.06	22	9.0		12			1.0	0.4	0.003		55	Others
In740H	0.03	25	0.5		20	1.50		1.35	1.35			48	Others

Alloy	Room temperature				Elevated temperature				
	$Rp_{0.2}$	R_m	A	Z	$Rp_{0.2}$	R_m	A	Z	T, ℃
G115/112	623	763	23	72	325	375	30	83	650
NF709R	330	700	44.5	74.5	171	454	40	65	700
Sanicro25	>310	>680	>40		>180	>455			700
GH2984*?	686	1107	26.6	46.6	539	745	34.4	52.3	700
CCA617	330	750	66	70	188	555	80	56	700
In740H	705	1110	36	42	630	850	23	28	750

Creep strength of typical materials



Progress and frontier of creep-resistant ferritic steels



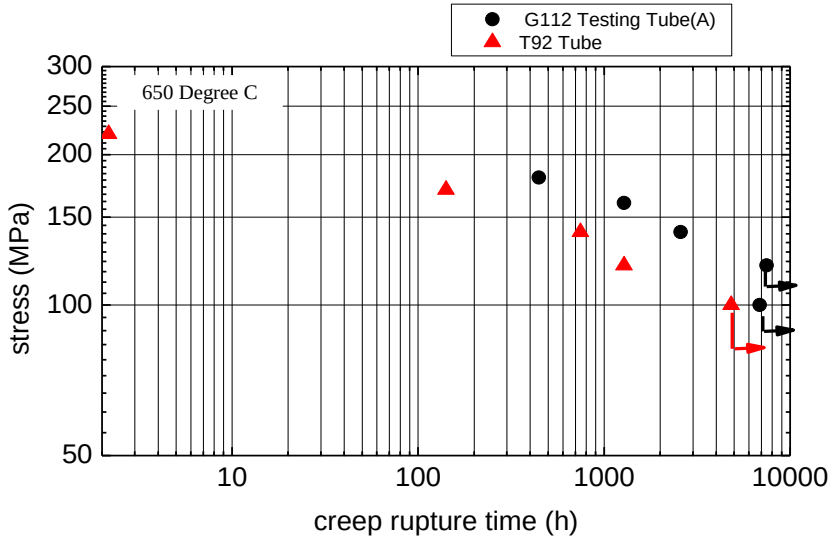
After F.Abe， NIMS

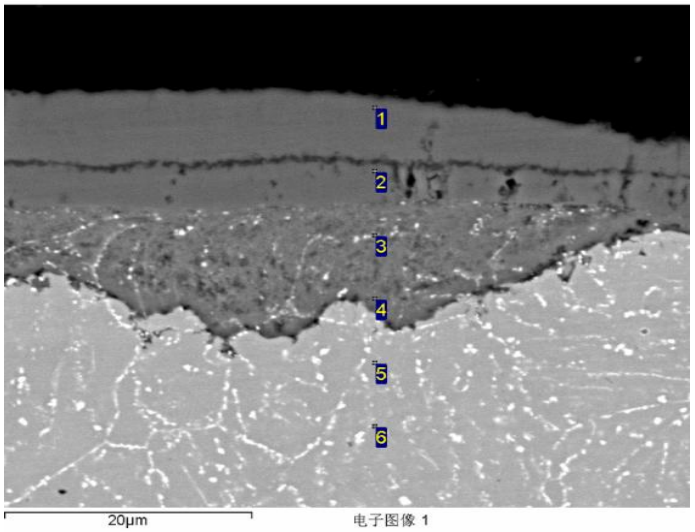
G112/G115: Piercing and hot rolling, 2008

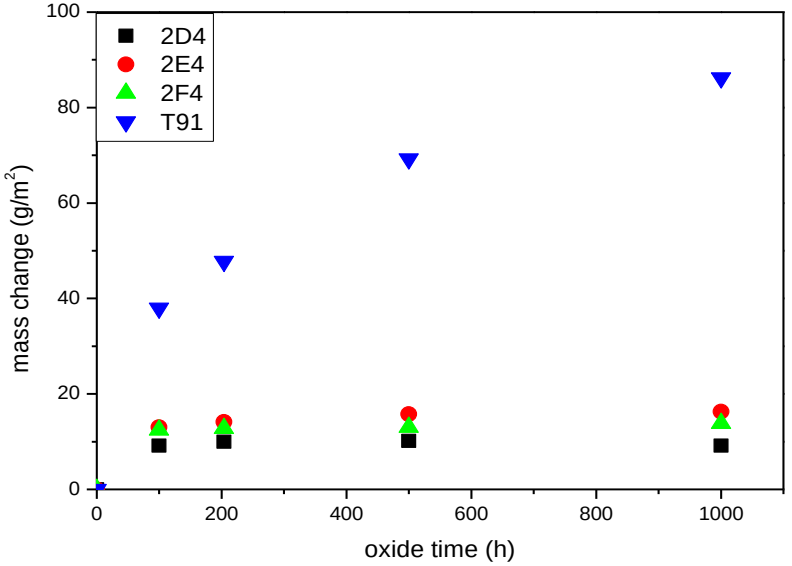
G112 and G115 steels were developed by CISRI in the recent years, which are proposed to be used to manufacture boiler pipes under steam temperature up to 650℃. The design of G112 steel was of emphasis on the steam corrosion and the design of G115 steel is of emphasis on the creep rupture strength. Size: Φ93×12.2×1840mm

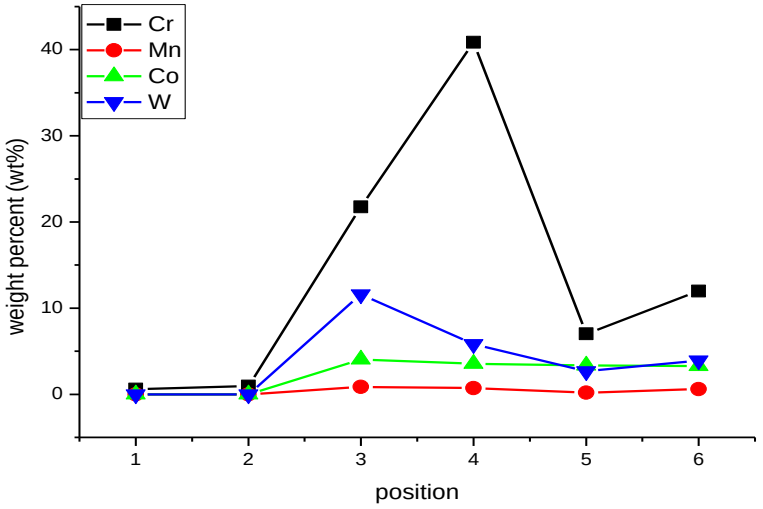
Courtesy of CISRI and BaoSteel, 2008

G112: Creep strength and steam corrosion







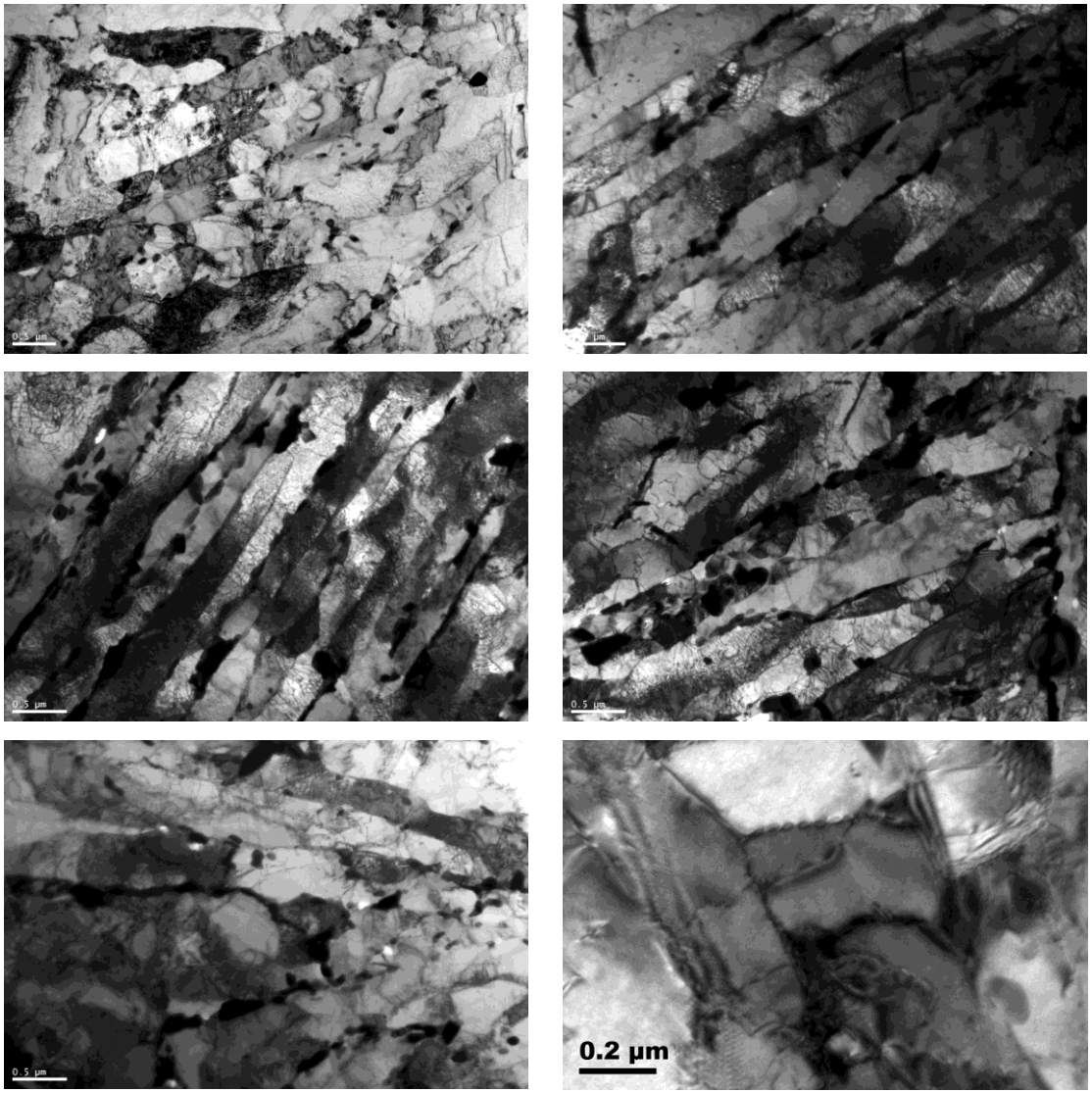


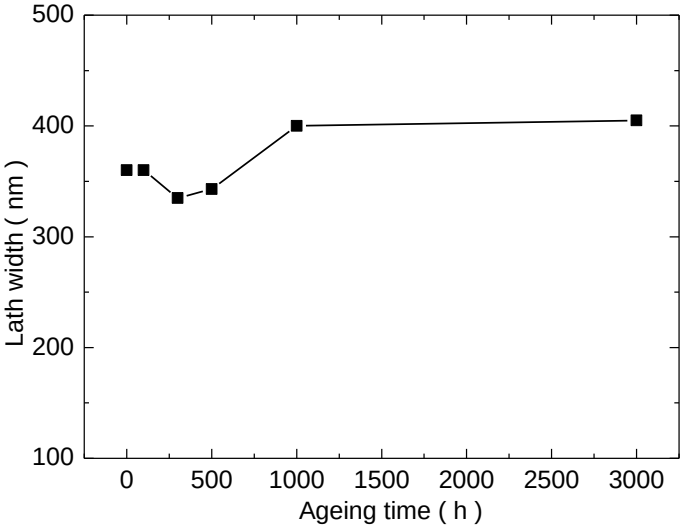
G115/G112 plant production： 2011

Plant production in BaoSteel, April, 2011. During the process of hot extrusion (left) and tempered pipes (right) . The size of hot-extruded pipes is ϕ254mm×25mm×3500mm。

Courtesy of CISRI and BaoSteel, 2011

CISRI,G115: Microstructure

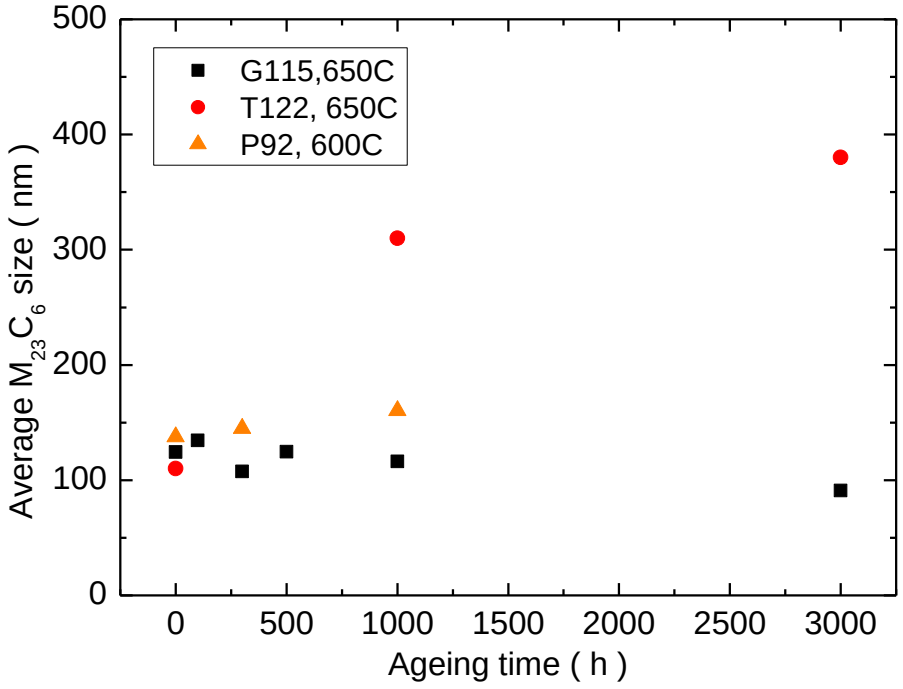




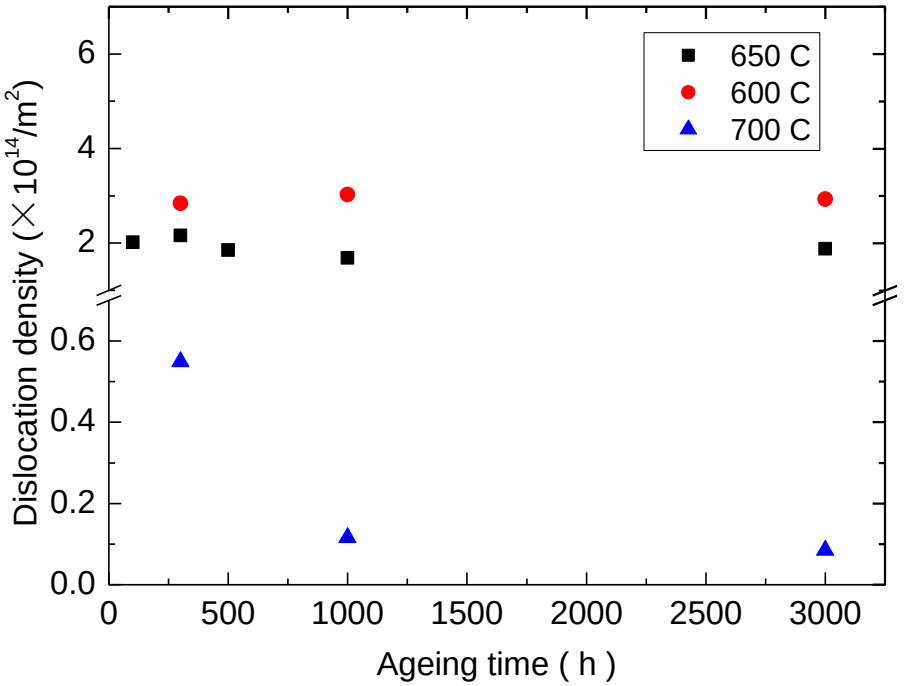
Tempered martensite Lath width keeps in 360 to 400nm during 650℃ aging

TEM photograph of G115 steel after 650℃ aging up to 3000hours
First row（left）as-tempered,（right）100h；second row（left）300h,（right）500h；Third row（left）1000h,（right）3000h;

CISRI,G115: Microstructure

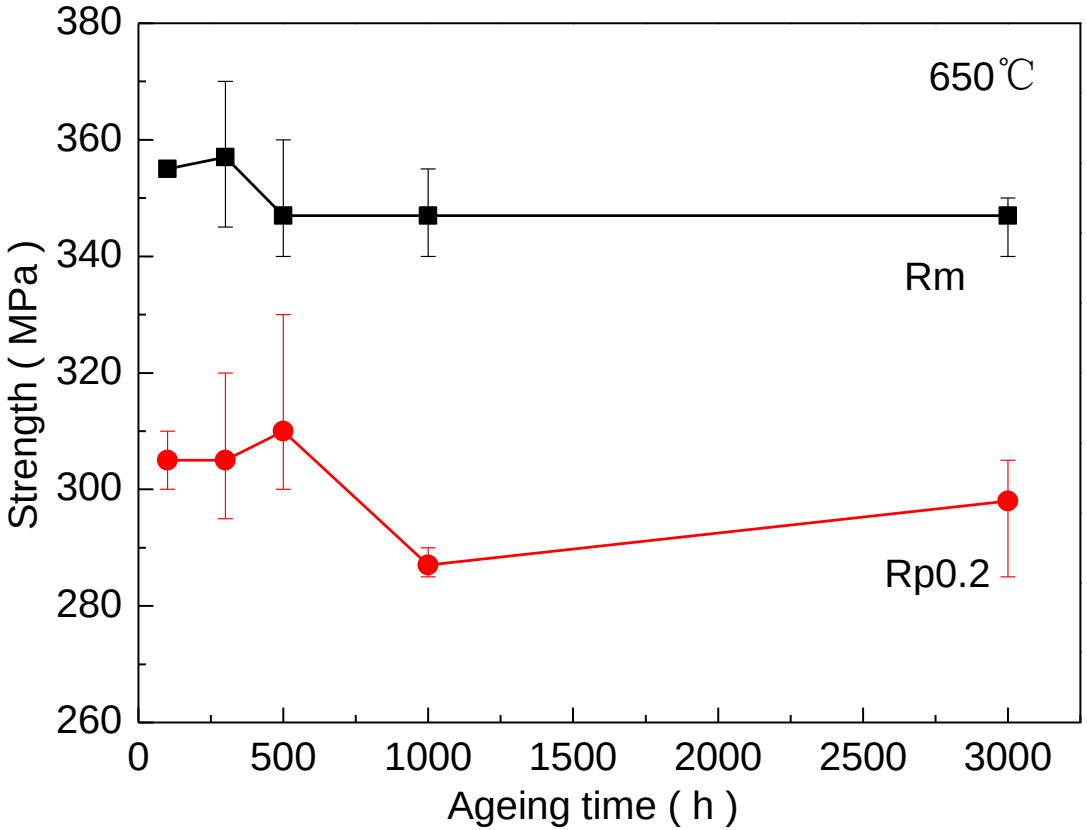


Change of average size of $M_{23}C_6$ in G115, T122 and T92 steels during aging



Change of dislocation density of G115 steel during aging

CISRI,G115: Strength at 650℃

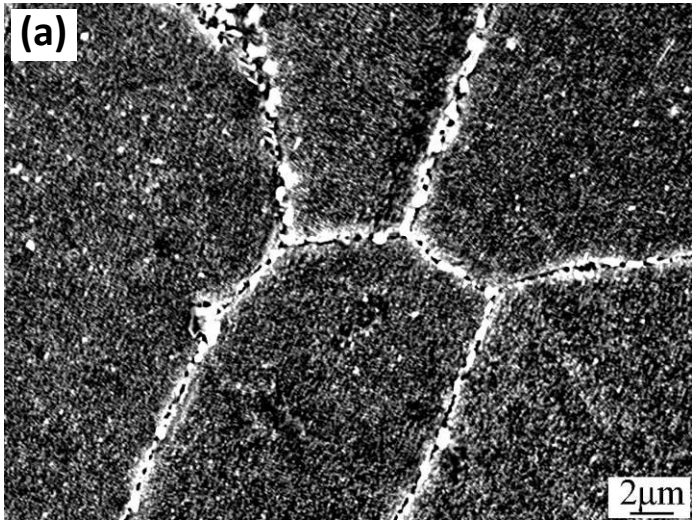


ϕ254×25×3500mm

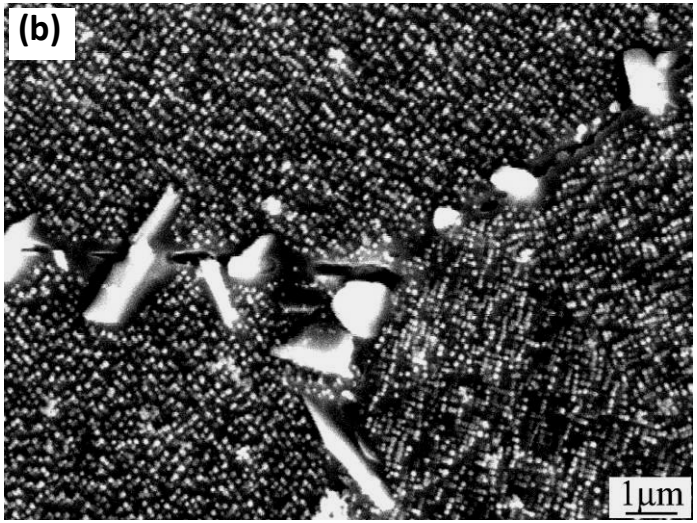
Change of strength at 650℃ of G115 steel after 650℃ aging up to 3000 hours

Long term creep and corrosion tests are undergoing

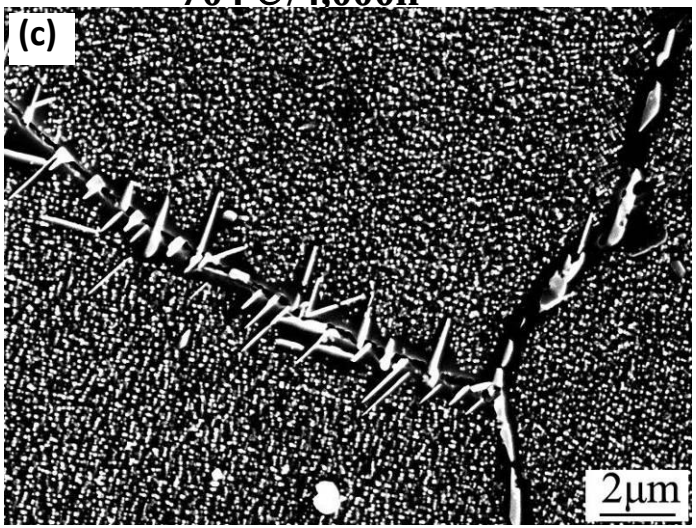
Inconel740: Microstructure during Aging



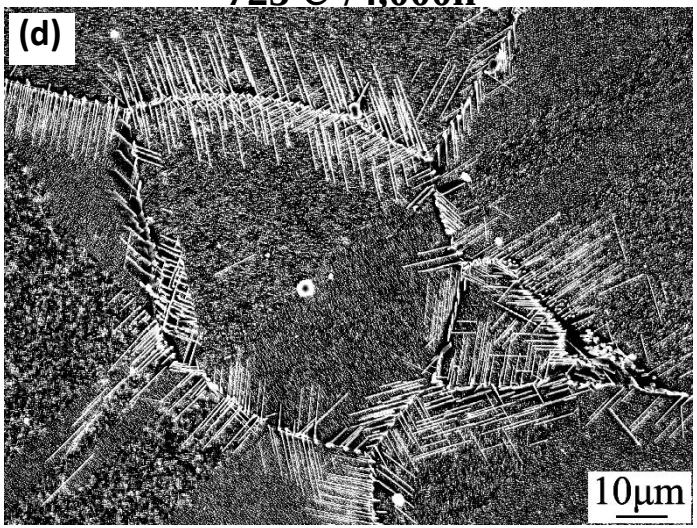
704℃/4,000h



725℃ /4,000h



750℃/1,000h



750℃ /5,000h

After aging at 750℃ for 1000 hours, small amount of Ni3Ti type η phase was observed near the grain boundaries. After 5000 hours, not only η phase initiates at grain boundaries but also a significant amount of η phase forms inside the grains as Widmanstatten pattern structure.

SMC-USTB

Inconel740: Modification of chemistry design

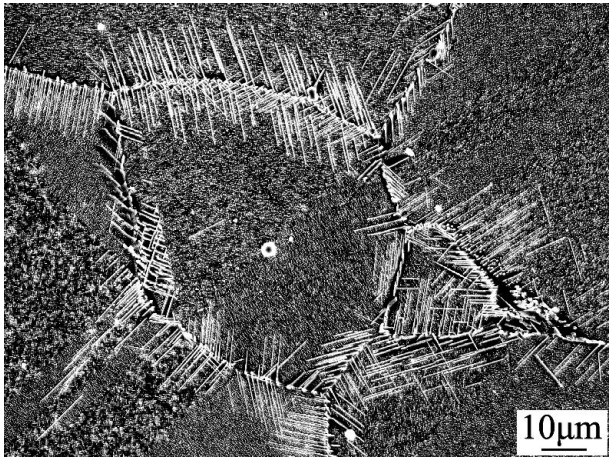
The idea to improve Inconel740: (1) to raise γ′ solvus temperature and to increase γ′ fraction; (2) to avoid η phase formation; (3) to restrain G phase.

Thermodynamic calculation indicates that Al can extensively raise γ′ solvus temperature and increase γ′ fraction, Ti strongly promotes η phase formation.

SMC-USTB proposed

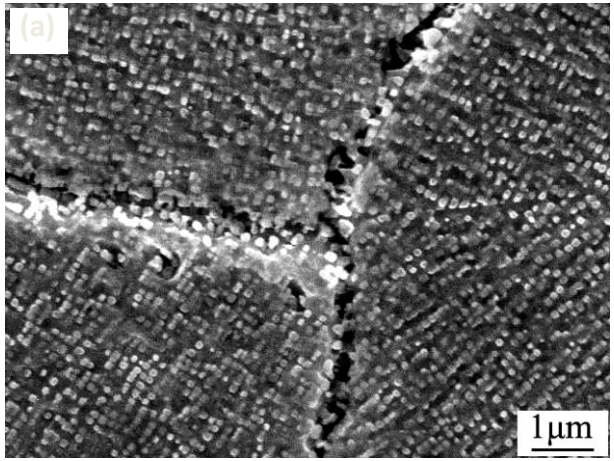
Heat	C	Cr	Co	Nb	Ti	Al	Fe	Mn	Si	Mo	Ni
1	0.016	25.45	20.37	1.99	0.67	1.21	0.066	0.001	0.009	0.001	Bal
2	0.014	25.80	20.40	1.99	1.38	1.25	0.070	0.001	0.011	0.010	Bal

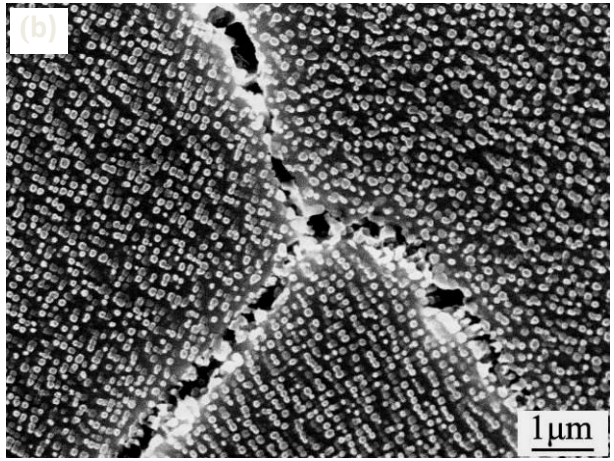
SMC-USTB, 2009, In740: Modification of chemistry design



Inconel 740

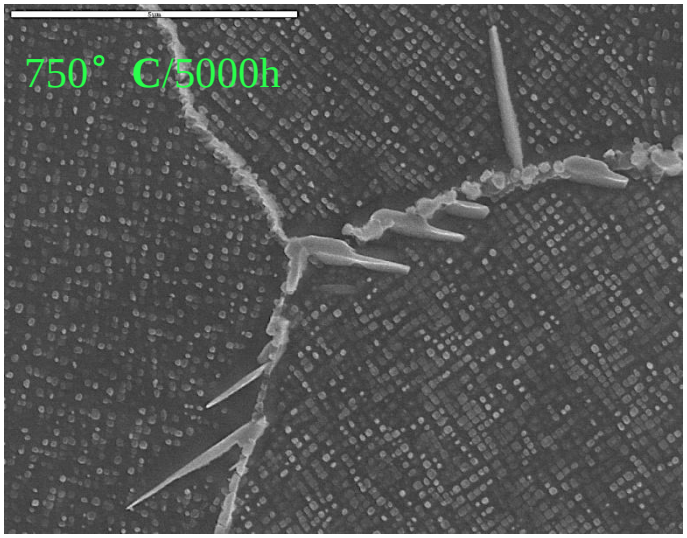
750℃ /5,000h

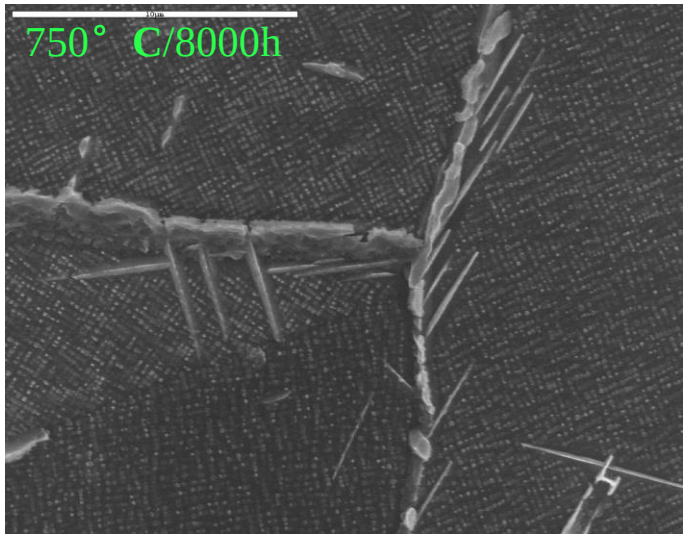


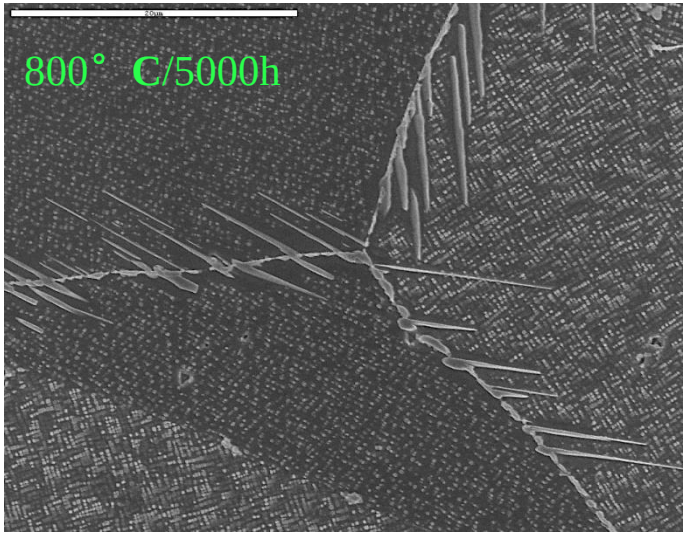


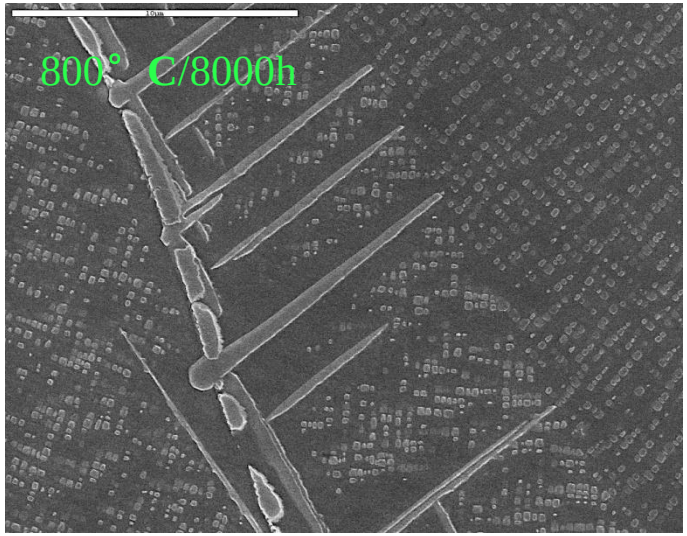
SEM images of the modified alloys aged at 750℃ for 5,018h (Heat 1 (a), Heat 2 (b))

CISRI, 2012: Microstructure of In740H





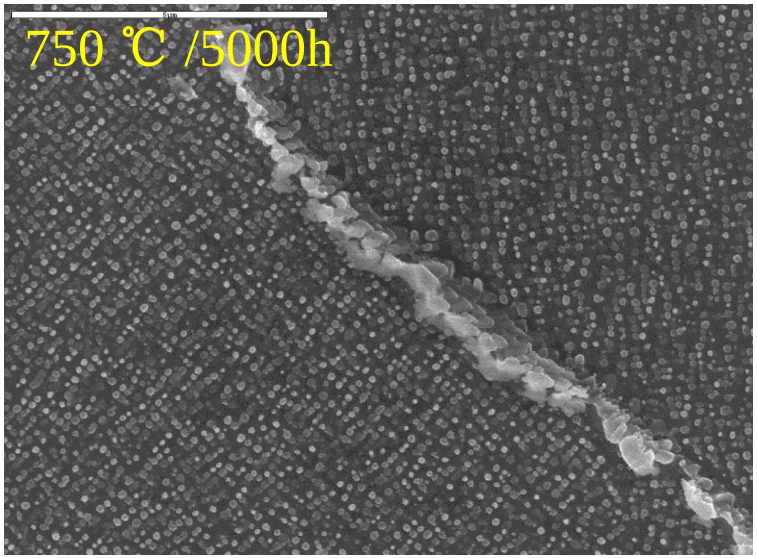


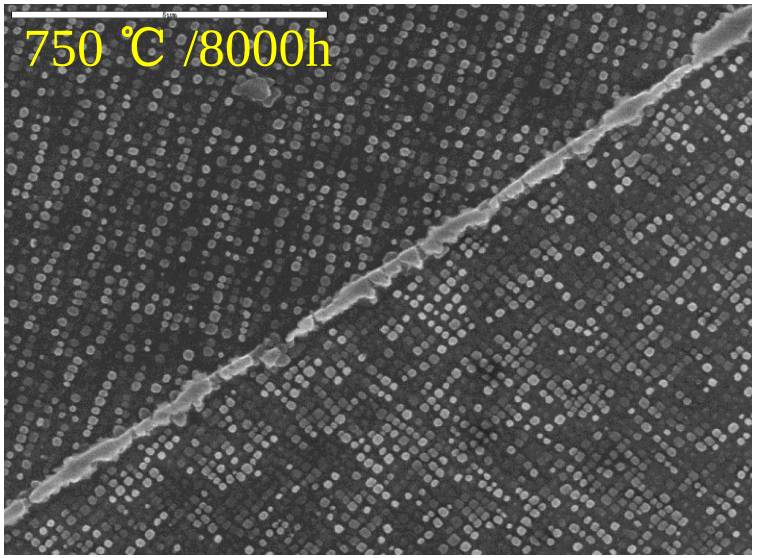


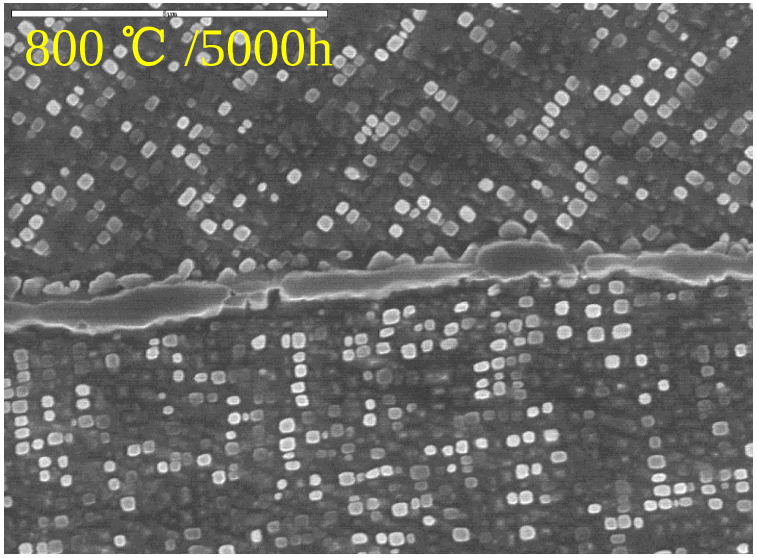
401#
Acicular η

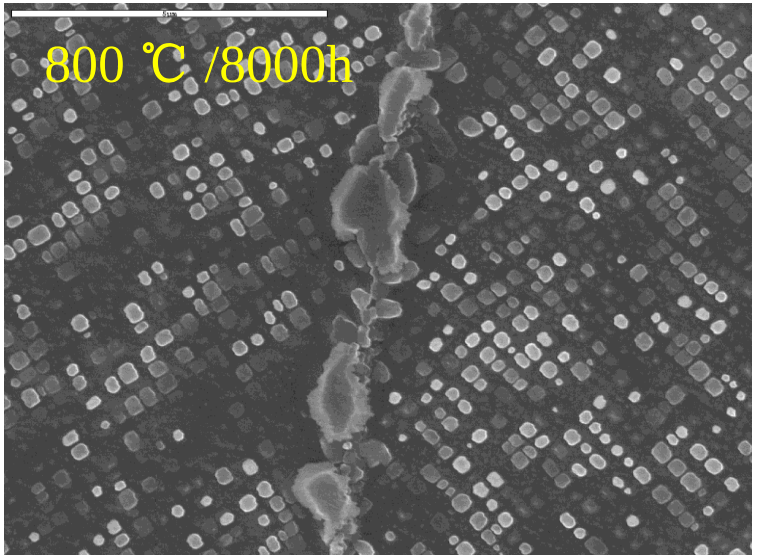
Nb: 1.98%, Ti: 1.64%, Al: 1.08%

CISRI, 2012: Microstructure of In740H





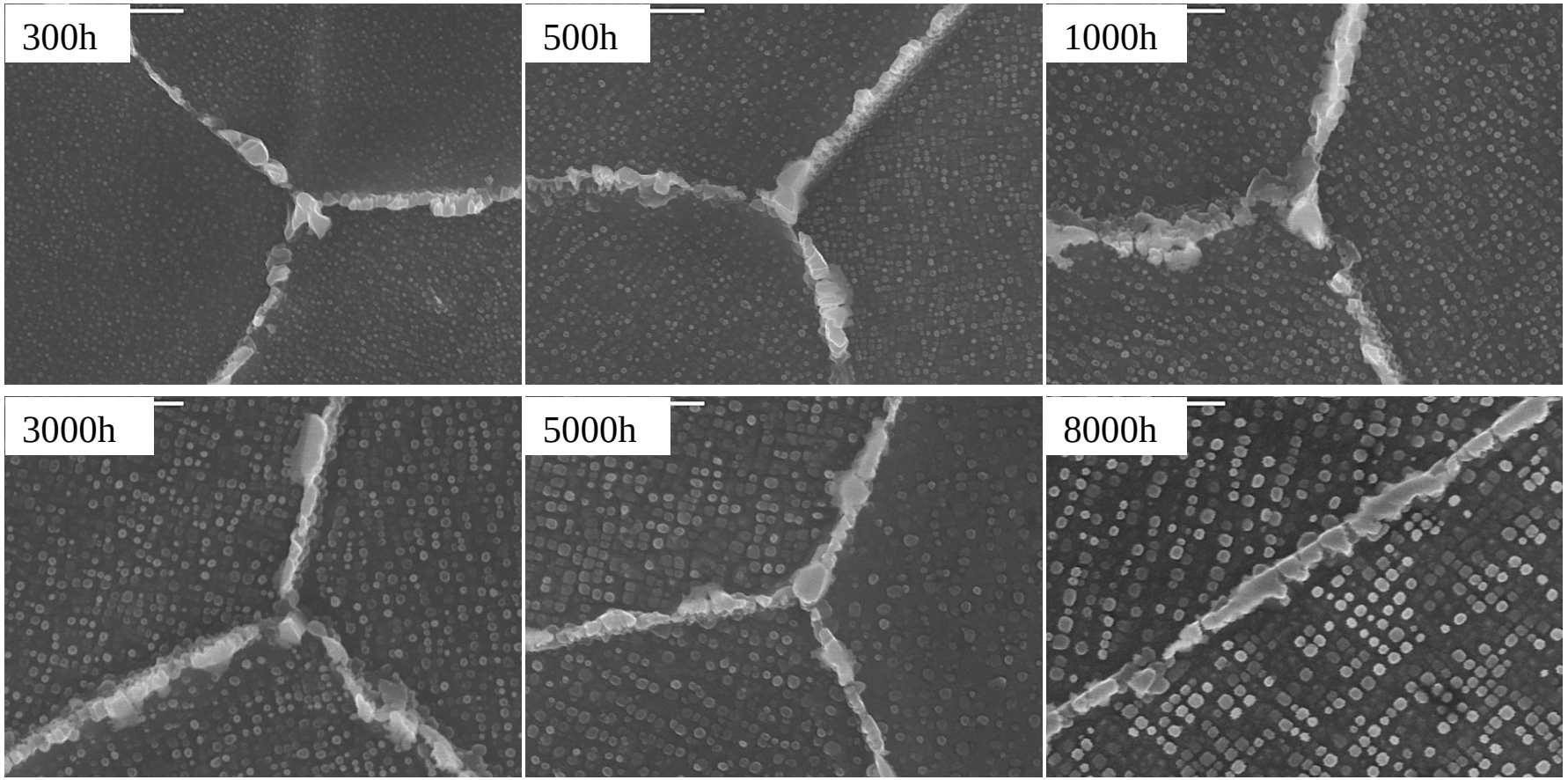




405# aging

Nb: 1.48%, Ti: 1.38%, Al: 1.47%

CISRI, 2012: Microstructure of In740H



Nb: 1.48%, Ti: 1.38%, Al: 1.47%

With the increase of aging time, coarsening rate of γ' is faster than that of $M_{23}C_6$
Microstructure stability in matrix and G.B.s is still needed to be improved and it also has been found that the stability can be improved.

4. Remarking summary

1. **G115™/G112™ should be candidate materials for the making of boiler pipes up to 650 ℃**
2. **Today's Inconel740H can be further modified to improve performance, which will be published soon**
3. **The materials R&D sub-committee of Chinese consortium for 700℃ A-USC PP has summarized and selected the candidate materials spectra used for 700℃ boiler and their full-scale industrial trials are under the way now**

Thanks !

Acknowledgements: Financial support from MoST and DoE of China is highly appreciated. The author's appreciation extends to all co-workers from steel and boiler makers.