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

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Abstract: This paper briefly introduces the state-of-the-art of the research and development of heat resistant steels and alloys in China used for the manufacturing of boiler of 700℃ advanced ultra-super-critical (A-USC) fossil fuel power plants (PP) in the near future, especially, with the emphasis on the optimization of microstructure and property of G115 and Inconel740H.
Key Words: 700℃; A-USC; Steels and alloys; China;

1. Introduction

Boiler steel tube and pipe serve in the environment of elevated temperature and high pressure as well as various corrosions for a long time. The technology of ultra super-critical fossil fuel power plant plays a key role to improve Chinese electricity structure (as shown in Table 1) in the near future and is also the one of most important national strategies to achieve emission reduction goal.

Table 1 Chinese electricity structure in recent years

Year	Capacity(10^8 KW)	Fossil（%）	Hydro（%）	Nuclear（%）	Wind/solar（%）
2000	3.19	72.1	24.87	0.66	
2005	4.70	74.80	23.20	1.90	0.14
2006	6.22	77.82	20.07	1.20	0.10
2007	7.1329	77.73			
2008	7.9253	75.87	21.64	1.15	1.12
2009	8.7409	74.5	22.4	1.03	2.0
2010	9.62	73.44			
2020	13.40	65.0	23.0	4.0	

The steam parameters of Chinese fossil fired power plants had been in very low level in the very long term as plotted in Figure 1. However, the situation has been completely changed since 2006, when the very first 600℃ ultra super critical (USC) fossil fired power plant was launched in Yuhuan, Zhejiang Province. To the end of 2010, 44 sets of 600MW and 73 sets of 1000MW 600℃ USC power plants have been constructed or under constructing in the mainland of China. More 600℃ USC power

plants will be constructed in the near future.

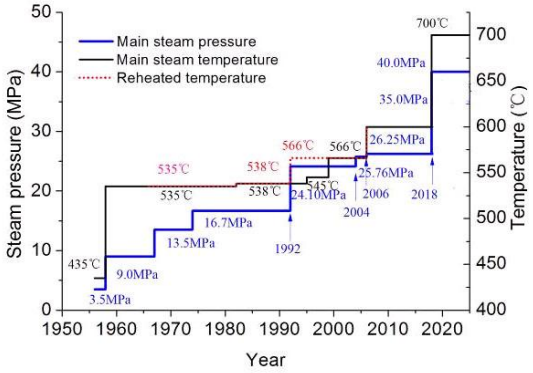

Figure 1 Steam parameter evolution of Chinese USC power plants

On July 23, 2010, Chinese government announced a national plan to build a demo 700℃ A-USC power plant in the near future, probably starting from the year of 2018, depending the availability and maturity of heat resistant steels and alloys. To fulfill such a goal, a national consortium has been organized by the Department of Energy of Chinese government, including seventeen research facilities, manufacturers and power plant operators. There are four technical sub-committees in the national consortium: Plant design, materials research and development, boiler and turbine.

2. Prime goal of the materials R&D sub-committee in China

The prime goal of the materials R&D sub-committee of the national consortium is to investigate imperative heat resistant steels and alloys and to manufacture necessary components associated with boilers and turbines of proposed demo 700℃ A-USC power plant in China. The major task of the sub-committee is to better organize the researchers, steel makers and boiler/turbine manufacturers together as a harmony chain, and therefore, to fulfill aforementioned goal as early and smoothly as possible.

From the viewpoint of candidate materials selection and determination to demo 700℃ A-USC power plant in China, four criteria were well discussed and agreed by the sub-committee. The first is localization, namely, the imperative materials and components should be developed and manufactured inside China mainland. The second is advancement, which means candidate materials must have the best performance among available materials. The third is open-up. That means the candidate materials should be from both inside China and overseas. The fourth is economical and competitive.

3. Candidate materials for 700℃ boiler of A-USC PP in China

Basically, those mature materials successfully used in 600℃ USC power plant will still be applied in 700℃ A-USC power plant, in where the working temperature is below 600℃. When the steam temperature increases from 600℃ to 700℃, different novel materials are necessarily required for various temperature scopes. According to published literature and our knowledge, the materials R&D

sub-committee of Chinese consortium for 700℃ A-USC power plant has discussed, evaluated and summarized the candidate materials spectra used for 700℃ boiler of A-USC power plant in China, as schematically plotted in Figure 2.

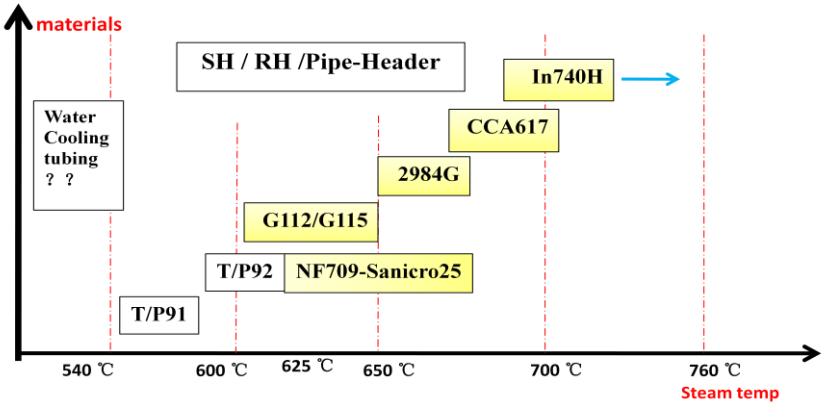

Figure 2 Candidate materials spectra used for 700℃ boiler of A-USC PP in china

For water cooling tubing, T91 and HCM12 are considered to be base-steel, on which some modification for the improvement of on-site welding performance during plant manufacturing and following maintain has to be carried out. G115/G112 was developed by the China Iron and Steel Research Institute (CISRI) in the past years on the basis of 9Cr3W3Co heat resistant steel, which are proposed to be used to make pipe or header up to 650℃. GH2984 was developed by Institute for Metals Research of Chinese Academy of Sciences some years ago, and 2984G will be an upgraded iron-nickel based super-alloy on the basis of GH2984, which is supposed to be used to make tube or pipe up to 680-700℃.

For the tube-making of super-heat (SH) and reheat (RH), the candidate materials spectra are T91, T92, NF709R, Sanicro25 (GH2984G), and Inconel740HM, with the increase of steam temperature from 580℃ to 700℃. For the pipe/header-making, the candidate materials spectra are P91, P92, G115/G112, (GH2984G), and CCA617CN, with the increase of steam temperature from 580℃ to 700℃.

Table 2 The time-table of R&D of materials used for 700℃ A-USC PP 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								→	→	→

The milestone and time-table of research and development of candidate materials used for 700℃ A-USC power plant in china were included in Table 2. Hopefully, the

final products of aforementioned candidate materials will be commercially available within five more years from now on, subject to the determination and certainty of designing requirements. The typical chemistry of candidate materials used for 700℃ A-USC power plant was listed in Table 3 and the typical mechanical property of candidate materials used for 700℃ A-USC power plant was listed in Table 4. The desirable creep rupture strength of candidate materials is around 100MPa under its service temperature for 10^5 hours. Correspondingly, the creep strength of candidate materials used for 700℃ A-USC power plant was plotted in Figure 3.

Table 3 Typical chemistry of candidate materials used for 700℃ A-USC PP

Alloy	C	Cr	Mo	W	Co	Nb	V	Al	Ti	B	Cu	Ni	Others
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

Table 4 Typical mechanical property of candidate materials used for 700℃ A-USC PP

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

* Data based on published literature

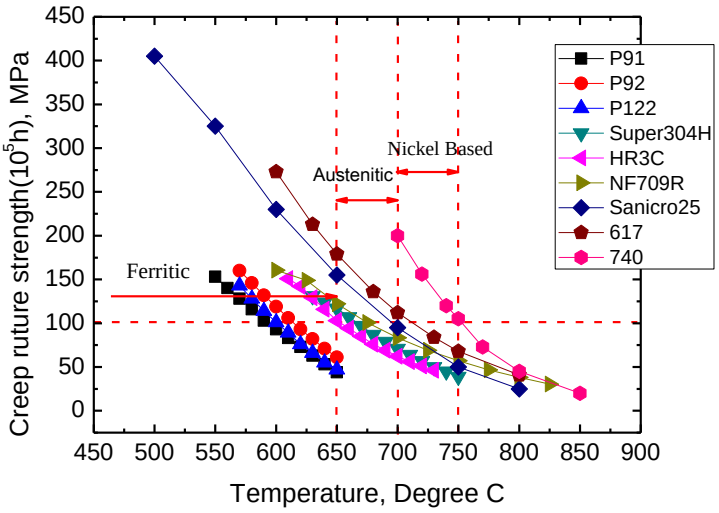

Figure 3 Creep strength of candidate materials used for 700℃ boiler of A-USC PP

4. Optimization of microstructure of G115 heat resistant steel

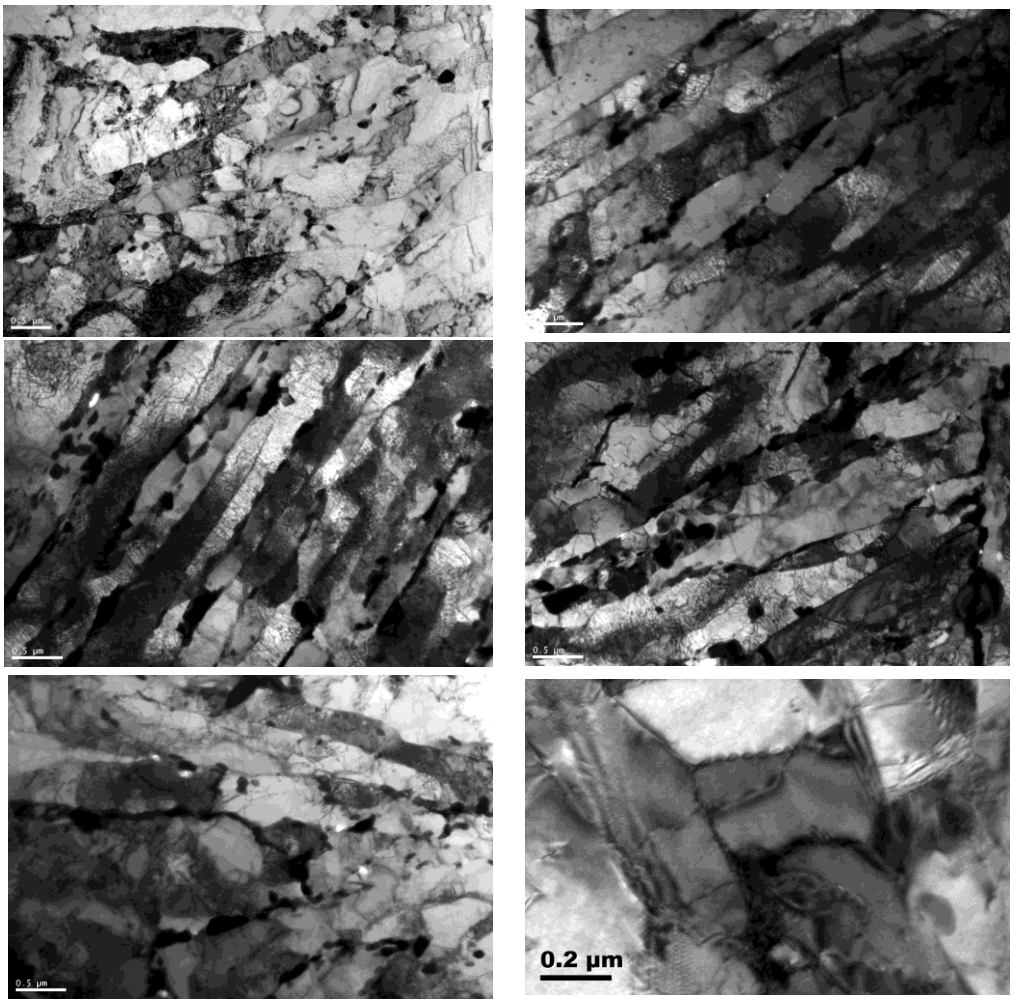

Figure 4 TEM photograph of G115 steel after 650℃ aging up to 3000hours
First row（left）as-tempered,（right）100h; second row（left）300h,（right）500h;
Third row（left）1000h,（right）3000h;

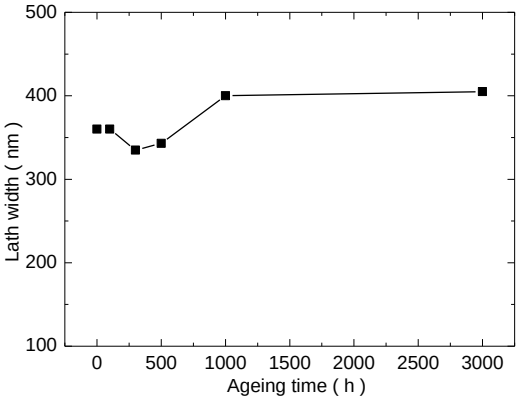

Figure 5 lath width change of G115steel during 650℃ aging

G115, which is supposed to be used in the situation of 650℃ steam temperature range, was developed and patented by CISRI in the past years based on 9Cr3W3Co

martensitic heat resistant steel. As shown in Figure 4, the microstructure of G115 steel is tempered martensite with laths inside grains during 650℃ aging and the change of lath width inside grains during aging was plotted in Figure 5. In general, the lath width keeps in the scope of 360nm to 400nm during 650℃ aging within 3000 hours.

5. Optimization of microstructure of Inconel740H

It was well known that the brittle eta (η) phase precipitates along the grain boundaries of Inconel740 during 750℃aging. It was found that the eta phase is rich Si-containing, which partly attributes to the degradation of creep strength. To improve the microstructure of Inconel740, the researchers from University of Sciences and Technology Beijing (USTB) and Special Metals Corporation (SMC) modified the content of critical elements (i.e. Nb, Al, Ti, Si, etc) and named the modified alloy as Inconel740H. After the modification, it was reported that there is no acicular eta phase in the microstructure of Inconel740H after 700-750℃ aging.

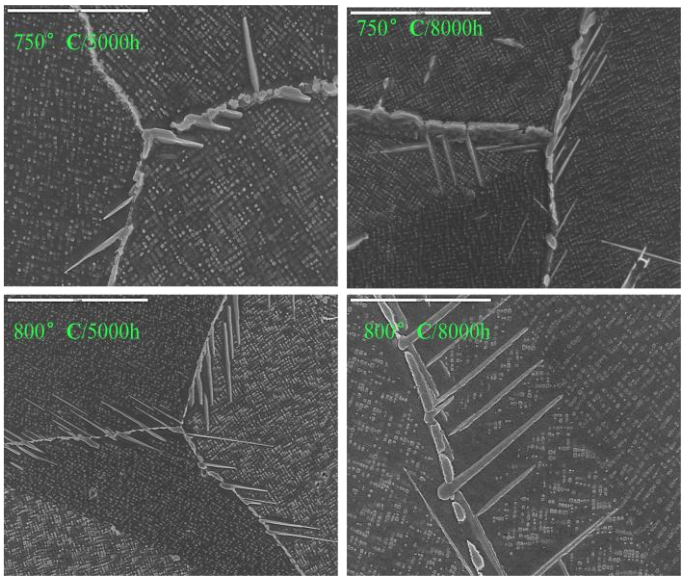

Figure 6 TEM photograph of Inconel740H during aging up to 8000hours

According to the modification of USTB and SMC, CISRI melted some heats of Inconel740H in Laboratory. Among them, one heat of Inconel740H contained 1.98%Nb, 1.08%Al, 1.64%Ti and 0.050%Si. As seen in Figure 6, acicular eta phase clearly exists along the grain boundaries after 5000-8000 hours under both 750℃ and 800℃, which implies that the microstructure of Inconel740H should be further modified and improved.

6. Conclusive summary

The Chinese government officially launched the national program to attempt to build 700℃ advanced ultra-super-critical (A-USC) fossil fuel power plants (PP) in the near future. The availability and maturity of heat resistant materials are the critical issues for the successfulness of the national program. The materials R&D sub-committee of Chinese consortium for 700℃ A-USC power plant has summarized

the candidate materials spectra used for 700℃ boiler. Meanwhile, the optimization of microstructure of G115 and Inconel740H was briefly discussed.

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