Development of high strength 15Cr creep resistant steel for low emission power plant

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Creep strength property of a full-annealed 0.1C-15Cr-1Mo-3W-0.2V-0.05Nb-0.07N-0.003B steel and the effects of tungsten and cobalt on that have been investigated. Contrary to a tempered martensite microstructure of the conventional ferritic creep resistant steels, microstructure of full-annealed 15Cr steel is mainly ferrite. Increases in creep strength at 923K with increase in tungsten content and addition of cobalt have been obviously observed, especially with a combination of increase in tungsten content and addition of cobalt. Higher Cr content of full-annealed 15Cr steel than those of the conventional ferritic creep resistant steels is desirable for better oxidation resistance. It has been concluded that full-annealed 15Cr ferritic creep resistant steel should be one of the candidate materials for a low emission power plant.

Keywords : creep, creep resistant steel, low emission, power plant, oxidation resistant

I. INTRODUCTION

In order to solve the global warming problem, emission of greenhouse effect gases such as CO₂, CH₄ and N₂O must be reduced. Especially, suppression of CO₂ emission is very important, since the effect of it on the global warming is about 2/3 of the total effects of various greenhouse gases,¹ due to its huge amounts emission. Electrical power generation is one of the main source of CO₂ emission and it has exhausted about 1/3 of the total amounts of CO₂ emission in Japan² (1999 Fiscal Year) as shown in Fig.1, as a result of combustion of fossil energy resources such as oil, coal and natural gas. From such point of view, improvement of energy efficiency is most important problem in electrical power generation, especially in fossil fired power plant. Therefore, many efforts to develop high strength creep resistant steel, which can increase operating temperature and pressure of steam turbine, have been done.³

9-12Cr ferritic creep resistant steels with a

Fig.1. Origin of the CO₂ emission in Japan.² (1999 Fiscal Year).

tempered martensite microstructure are widely used for large components of power plant, such as header and main steam pipe. Such materials are serviced at the elevated temperatures up to about

873K, and the creep strength of those decreases with increase in exposure time as a result of microstructural change.⁴ Recently, it has been reported that improvement of long-term creep strength may be achieved not only by tempered martensite microstructure, but also by full annealed stable microstructure.⁵

In order to obtain a full martensite microstructure, chromium concentration is restricted to be less than about 12mass%. However, higher chromium concentration than those of conventional ferritic creep resistant steels with a tempered martensite microstructure is suitable to obtain a full annealed ferrite microstructure. Improvement of oxidation resistance is also very important problem must be attained to increase operating steam temperature of power plant. Higher chromium concentration is desirable also for better oxidation resistance. Aim of the present study is to develop a new type high strength ferritic creep resistant steel, and a possibility of improvement of creep strength has been investigated on full annealed 15Cr ferritic steel.

II. EXPERIMENTAL PROCEDURE

Chemical compositions of the steels are shown in Table 1. Steels were melted in a vacuum induction furnace. The ingots were hot forged into bars with a diameter of about 13mm and annealed for 1.8ks at 1473K followed by furnace cooling. Creep tests were conducted at 923K. Microstructures of the steels in the as annealed condition and after creep ruptured were examined using by scanning electron microscope (SEM) and transmission electron microscope (TEM).

Table 1. Chemical compositions (mass%) of the steels studied.

Steels	C	Si	Mn	Cr	Mo	W
3W-0Co	0.110	0.24	0.49	15.21	0.98	2.95
6W-0Co	0.095	0.20	0.50	15.10	0.98	5.96
3W-3Co	0.096	0.20	0.50	15.11	0.99	3.01
6W-3Co	0.096	0.18	0.50	15.10	0.99	5.94

Steels	V	Nb	Co	N	B
3W-0Co	0.20	0.051	-	0.071	0.0028
6W-0Co	0.19	0.059	-	0.083	0.0030
3W-3Co	0.19	0.060	3.01	0.083	0.0030
6W-3Co	0.18	0.064	3.00	0.082	0.0027

III. RESULTS AND DISCUSSION

III-A. Precipitation strengthening

Creep rate vs. time curves of the 3W-0Co steel at 923K are shown in Fig.2. Creep deformation consists of transient and acceleration creep stages and some stress dependence of the creep deformation behaviour is observed in the transient creep stage. Slope of the curves in the transient creep stage increases with increase in time and, therefore, large drops in creep rate are observed after about 100h under stresses of 70MPa and 60MPa.

Bright field TEM images of the 3W-0Co steel in the as annealed condition, after crept for

Fig.2. Creep rate vs. time curves of the 3W-0Co steel at 923K.

100h and 1,000h at 973K-70MPa are shown in Fig.3. Precipitates are observed mainly on grain boundary in the as annealed condition. A small amount of particles are observed within grain after crept for 100h, however, large amounts of precipitates and subboundaries are observed after crept for 1,000h. According to such changes in microstructure, a large decrease in creep rate was observed. Consequently, large decrease in creep rate observed in the latter stage of transient creep at 70MPa and 60MPa is caused by the effect of precipitation strengthening.

Fig.3. Bright field TEM images of the 3W-0Co steel (a) in the as annealed condition, after crept for (b) 100h and (c) 1,000h at 923K-70MPa.

III-B. Strengthening by tungsten and cobalt

Stress vs. time to rupture curves of the steels at 923K are shown in Fig.4, together with those of the conventional steels of ASME T91 and T92 grade steels. Increases in creep rupture strength with increase in tungsten content and addition of cobalt are clearly observed. Moreover, significant improvement in creep rupture strength has been attained by a combination of those. Creep rupture strength of the 6W-3Co steel is almost the same as that of ASME T92 grade steel, which possess the highest creep rupture strength in the conventional ferritic creep resistant steel with tempered martensite

microstructure.

Secondary electron images of the specimens creep ruptured at 973K-100MPa are shown in Fig.5. No obvious change is observed within grain of the 3W-0Co steel. On the other hand, a lot of precipitates are observed within grain of the 6W-0Co, 3W-3Co and 6W-3Co steels. Increases in creep strength with tungsten and cobalt, particularly in the 6W-3Co steel, have been attained by the effect of precipitation strengthening. Good rupture ductility and better oxidation resistance than that of the conventional steel have been also observed. It has been concluded that full annealed 15Cr ferritic steel is one of the candidate materials for a new high efficiency and low emission power plant in the 21st century.

Fig.4. Stress vs. time to rupture curves of the steels at 923K.

IV. CONCLUSION

Investigation on the effects of tungsten and cobalt on creep strength of full annealed 15Cr ferritic steel has shown that:

- (1) Increase in creep strength with precipitation of particles has been observed during creep deformation in the transient creep stage.
- (2) Improvement of creep strength has been attained by increase in tungsten concentration, addition of cobalt and a combination of those.
- (3) Creep strength of full annealed 15Cr ferritic steel may be increased to the same as or higher than that of the conventional ferritic creep resistant steel with tempered martensite.

- a) 3W-0Co, $t_r = 36.0h$
- b) 6W-0Co, $t_r = 346.6h$
- c) 3W-3Co, $t_r = 1,111.9h$
- d) 6W-3Co, $t_r = 4,947.6h$

Fig.5. Secondary electron images of (a) 3W-0Co, (b) 6W-0Co, (c) 3W-3Co and (d) 6W-3Co steels after creep ruptured at 973K-100MPa.

(4) It has been concluded that full annealed 15Cr ferritic steel is one of the candidate materials for a new high efficiency and low emission power plant in the 21st century.

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