Development of High Strength Steel Boiler Tube (TEMPALOY AA-1)

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Recent boilers have been designed for higher temperatures and pressures than those in the past and require steels with high temperature strength that is greater than that of conventional 18-8 austenitic stainless steels. The effects of various alloying elements on the creep rupture strength of 18-8 austenitic steels were examined. As a result, a new heat resisting steel (0.1C-18Cr-10Ni-3Cu-Ti-Nb) was developed. The new steel has a creep rupture strength at 600–700℃ that is 30% higher than that of TP347H. This steel tube, called TEMPALOY AA-1, is expected to be a candidate material for ultra supercritical boilers.

1. Introduction

Recently, the design of thermal power plants has tended towards higher thermal efficiency, prompted largely by concerns over global environmental problems[1]. For coal-fired thermal power plants, in particular, USC (Ultra Supercritical) boilers, which use steam at very high temperatures and pressures to achieve higher thermal efficiency, are under construction[2]. In response to such severe requirements, a high temperature strength steel, KA SUS321J1HTB (TEMPALOY A-1) steel, is used for superheater tubes and reheater tubes for the USC boiler[2]. This steel offers high temperature strength that is superior to conventional 18-8 austenitic stainless steels. Now, even more severe steam conditions are under study[3], and a heat resisting tube will be demanded that has even greater high temperature strength and more stable long-term strength and microstructure to provide even higher economic efficiency.

It has been reported that if copper is added to 18-8 austenitic stainless steel, fine precipitates of Cu-rich phase that appears at service temperatures can be used with a resultant improvement of creep rupture strength[4]. NKK studied the effects of varying alloying elements such as Cu, P and C in KA SUS321JIHTB steel on creep rupture strength and ultimately developed a “new austenitic stainless tube with superior high temperature strength,” named TEMPALOY AA-1.

This paper discusses various properties of this new alloy and factors affecting high temperature strength.

2. Objective of development and effects of alloying elements

2.1 Objective of development

When used for superheater tubes with a 45.0 mm outside diameter and 11.25 mm thickness, KA SUS321J1HTB steel can accommodate a steam condition of 593℃–30 MPa. However, if the steam temperature is further raised to about 630℃, this alloy steel can no longer be used. Accordingly, the development objectives were set as follows.

(1) The new alloy can be used for superheater steam tubes under steam conditions of 630℃–30 MPa, while providing an allowable stress at 675℃ of at least 54 N/mm^2.

(2) Various properties of the new alloy, such as workability and welding properties, should be comparable to KA SUS321J1HTB steel.

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(3) The new alloy should have good economic efficiency.

These represented the basis of alloying element composition design.

2.2 Effects of alloying elements on creep rupture strength of the 18Cr-8Ni austenitic stainless steel

Precipitation strengthening, solution strengthening and a small amount element strengthening are possible methods for improving the creep rupture strength of austenitic stainless steel. Carbide precipitation in the form of $M_{23}C_6$

does not appreciably affect the $M_{23}C_6$ and MC solubility products at solution treatment temperatures above 1150℃. Therefore, the carbon content does not cause a difference in $M_{23}C_6$ or MC carbide precipitation. As a result, the content of C was set at 0.10% in view of the room temperature tensile strength and weldability.

3. Properties of test manufactured tubes

A tube with an outside diameter of 45.0 mm and a thickness of 9 mm was test manufactured from an alloy of the chemical composition shown in **Table 2** to evaluate various properties. Both a shot-blasted internal surface

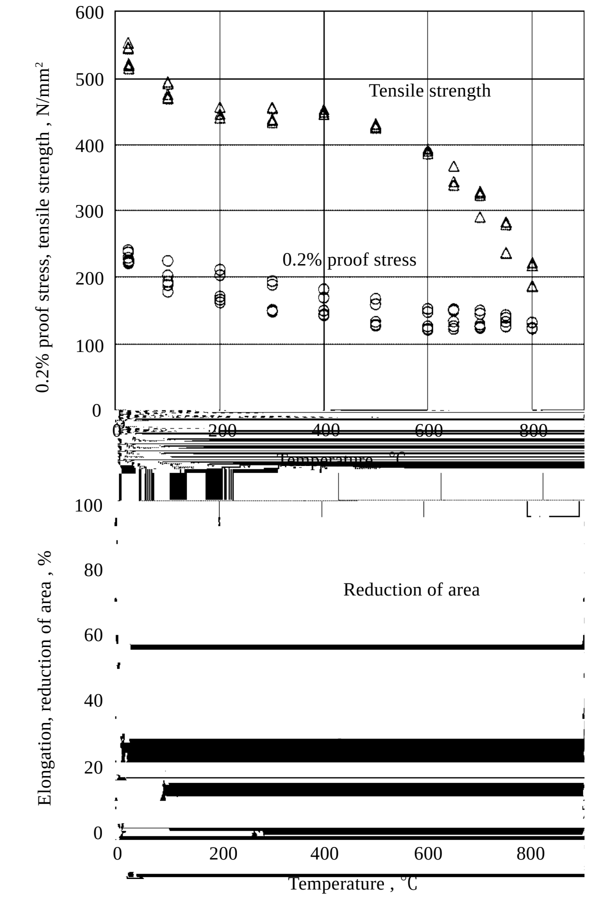


Fig. 5 Tensile properties at elevated temperature of developed steel tube

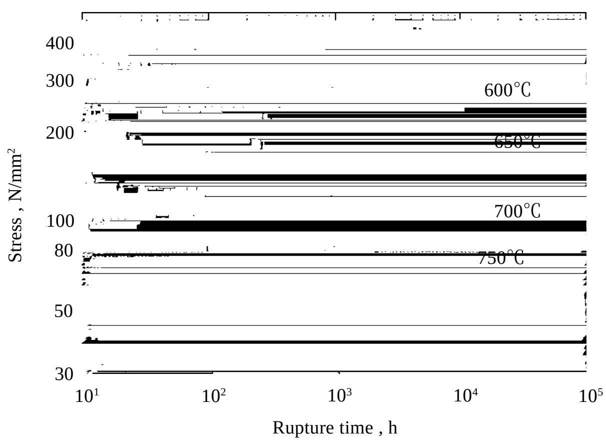


Fig. 6 Creep rupture strength of developed steel tube

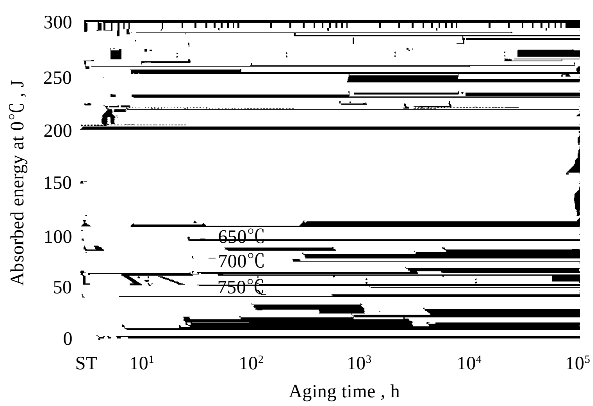


Fig. 7 Charpy impact test result after aging

3.2 Allowable stress

Fig. 8 compares allowable stress values for the developed steel at temperatures above 600℃ obtained by the calculation methods specified in the "Technical Standards for Thermal Power Generating Facilities" using the values obtained for KA SUS321J1HTB steel and TP347HTB steel. At high temperatures above 650℃, the developed steel showed allowable stress values that were about 1.4 times and 1.2 times those of TP347HTB steel and KA SUS321J1HTB steel, respectively. The allowable stress of the developed steel at 675℃ exceeds 58 N/mm², satisfying the target allowable stress of 54 N/mm² for development at that temperature.

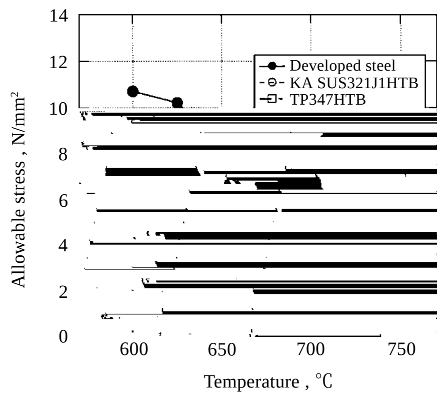


Fig. 8 Comparison of allowable stress

3.3 High temperature strength of welding joint

Boiler tubes must have sufficient high temperature strength at the welded joints. NKK has already developed a TIG wire and rod as welding consumables with the chemical composition modeled on the base metal. **Fig. 9** shows the results of creep rupture tests on tube joints welded with these welding materials. It may be noted from the figure that the observed creep rupture strengths of the welded joints are comparable to the mean rupture strengths observed for the base metal at the temperatures tested.

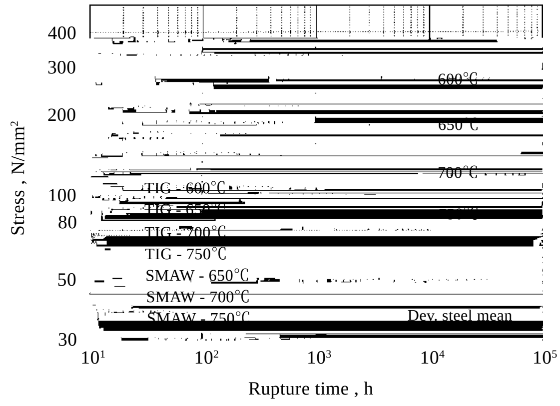


Fig. 9 Creep rupture strength of welded joint of developed steel tube

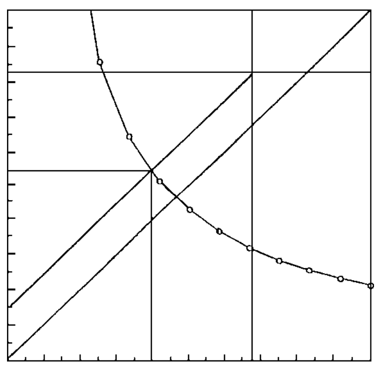
3.4 Corrosion resistance

The high temperature corrosion properties of the outside surface and the steam oxidation properties of the inside surface of the developed tube were tested to confirm their corrosion resistance as boiler tubes. The high temperature corrosion test was done on test piece coupons, each measuring 10 x 15 x 5 mm, that were cut from the test tube. The test pieces were subjected to high temperature corrosion tests with heavy-oil ash at 600℃ and 650℃ for 1000 hours. As a control, SUS321HTB steel with a composition of 17Cr-10Ni-0.4Ti was also used. The results of the high temperature corrosion test are shown in **Fig. 10**. The developed steel and the control are almost equal in corrosion resistance, because the high temperature corrosion resistance is determined basically by the chromium content in the steel.

4. Discussion

The developed steel tube represents a marked improvement in high temperature strength over KA SUS321J1HTB steel. **Fig. 12** shows the relationship between the amount of precipitated carbides and the solid solution temperature of the developed steel tube. The straight line at 45° represents an atomic ratio of (Ti+Nb) to C of 1:1. Stabilized austenitic stainless steels (SUS347, SUS321) show atomic ratios almost on this line. The area below this line represents excess (Ti+Nb) relative to added C, where the precipitation of $M_{23}C_6$ carbide does not take place.

The developed steel tube contains small amounts of Ti and Nb that place its composition on the upper side of this 45° line. In other words, there would be excess C if all the added (Ti+Nb) combined with C to form MC carbide. Point A represents a steel with 0.1 weight percent of C, 0.18 weight percent of Ti and 0.28 weight percent of Nb. The line representing this steel composition meets the solubility line at Point B if solution treatment is done at 1190℃. The amount of C corresponding to (Ay-By) remains as undissolved MC carbide, preventing growth of the grains. The amount of C corresponding to (By-Dy) precipitates as MC car-



bide during creep, improving the high temperature strength.

Further, the amount of C corresponding to (Dy-0) precipitates as $M_{23}C_6$ carbide, contributing to improvement of creep rupture strength, together with the MC carbide mentioned above. The $M_{23}C_6$ carbide, in particular, contributes to the long-range improvement of creep rupture strength as exemplified by the fact that SUS304H steel has stable long-term creep rupture strength.

As may be noted from **Fig. 6**, the developed steel does not show an abrupt decline of strength in the long-term region at any temperature tested, which may be attributable to the effect of $M_{23}C_6$ carbides. The composition was designed under the following considerations. As a measure against sensitization, the precipitation of M