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Selection and Creep Property of Alloy 617 for the IHX Application

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1. Introduction

Since the very high temperature reactor (VHTR) components such as hot gas ducts and intermediate heat exchanger (IHX) are operated during a design life of 30 to 60 years at 950°C and 3~8MPa in He impurities [1], their components are required to have good high temperature strength, creep-rupture strength, high-temperature stability, and good corrosion resistance. Among them, creep properties are the most important, because the integrity of their components should be preserved during a design life of over 30 years at the maximum operating temperature up to 1000°C [2].

So far, there are no materials approved by ASME III which is a nuclear code for temperatures reaching 1000°C, and until now, a material selection is still left as a key issue. Some leading candidate alloys can be selected from the high temperature materials approved by ASME VIII. Alloy 617 is considered as a prospective material for the IHX because it has an excellent combination of a high temperature strength and a good corrosion resistance, and also it is approved to 982°C by ASME VIII. Therefore, to select the best candidate alloys, it is necessary to investigate high-temperature strength properties of various nickel-base alloys. For a selected alloy, the data for creep properties is basically needed.

In this paper, the high temperature strengths for nickel-base superalloys were reviewed using the material properties of ASME II [3]. Alloy 617 was selected as a suitable material for the IHX application. Creep properties for alloy 617 were investigated from creep tests at 950°C.

2. Results and Discussion

2.1 Selection of Alloy 617

The IHX is an essential component to link the reactor to a combined hydrogen and electricity generating plant. Main issue of the IHX design for a hydrogen production is to have a high efficiency. So, the IHX needs to have both a high effectiveness and low pressure drop. This depends on the IHX type and the internal design. Also, in order to place the IHX inside the nuclear containment vessel, a compact technology is needed. A compact heat exchanger will probably limit the exchanger selection to a plate type heat exchanger. Among the currently available technologies to apply the VHTR system, the "Printed Circuit Heat Exchanger" (PCHE) will be one of the most suitable types to accommodate the mechanical, thermodynamic and environmental demands in a limit space.

In this paper, a primary selection is investigated on the basis of the ASME data for use at design temperatures equal to or greater than 898°C, because there is no materials approved by ASME III with a nuclear code for temperatures reaching 1000°C. The ASME design stress at 898°C is given for several candidate alloys: alloy 617, alloy 556, alloy 230, alloy Hastelloy-X (HX), alloy 800HT, alloy 800H, alloy 253MA, and alloy 330, etc [1,3]. Among them, alloy 617 showed the highest design temperature approved to 982°C and seven other alloys are approved to 898°C. Also, in allowable design stress (*S*) at 10^5 hours of 898°C, alloy 617 showed the highest value when compared with other alloys, as shown in Fig. 1.

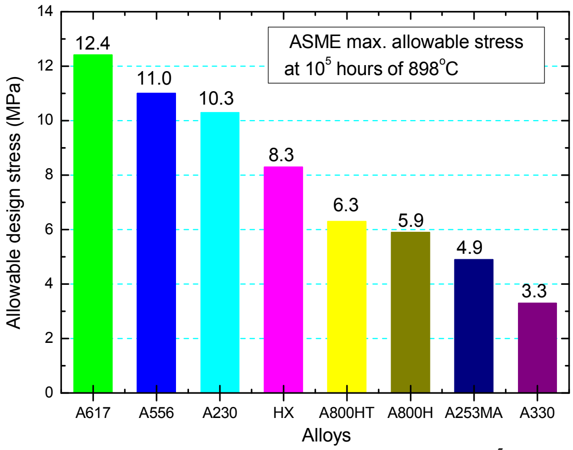


Figure 1. The allowable design stress (S) at 10^5 hours of 898°C for the eight candidate alloys

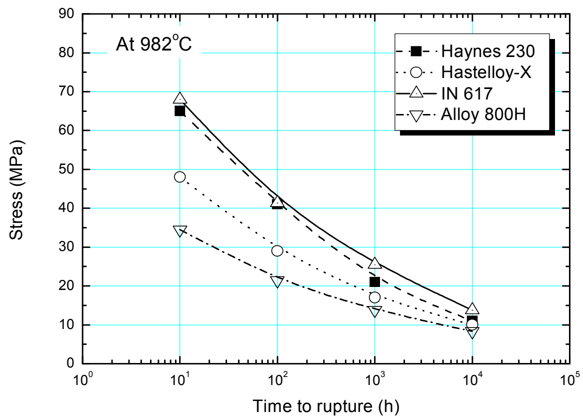


Figure 2. Comparison of the creep stress with time to rupture at 982°C for the candidate alloys

The design stress value for alloy 617 was 12.4MPa. In addition, for the value in the maximum allowable stress at the high temperatures over 800°C, alloy 617 showed the highest value when compared with other candidate alloys which obtained from material properties of ASME II.

In the comparison of the creep strength at 982°C, alloy 617 showed the highest creep strength when compared with other alloys, as shown in Fig. 2, which was reported from a manufacturing company of superalloys [4, 5]. It is thus believed that alloy 617 is one of the most suitable materials for the IHX application. However, this result only considered the mechanical properties at a high temperature strength and creep rupture strength for the commercially available alloys. Also, corrosion and oxidation resistances in He impurities were not included here. Furthermore, the behavior of an alloy during a fabrication process such as forming plate or tube products and a welding should be considered as significant factors for an IHX application.

2.2 Creep properties of Alloy 617

Creep tests were conducted with different stress levels, 35MPa, 30MPa, 25MPa, 22MPa, 20MPa at 950°C. Creep curves were obtained for each stress level, respectively. As shown in Fig. 3, a primary creep strain was not observed nearly, and a tertiary creep was generated at an early stage for the full creep curve, as plotted in 20MPa. Relationship between the steady state creep rate (SSCR) and stress showed a good linearity, as presented in Fig. 3. Creep constants for Norton's law of $\dot{\varepsilon}_{sscr} = A\sigma^{n}$ were obtained; the A value was 2.82x10^{-15} (MPa^{-n} s^{-1}) and the n value was 5.17.

Creep fracture morphology for alloy 617 showed an intergranular fracture mode along grain boundaries. An oxidized substance was observed widely in the fracture surface, because the specimen was exposed by a long duration at 950°C, as shown in Fig. 5 (b). The observed specimen was for the rupture time of 4,943hrs.

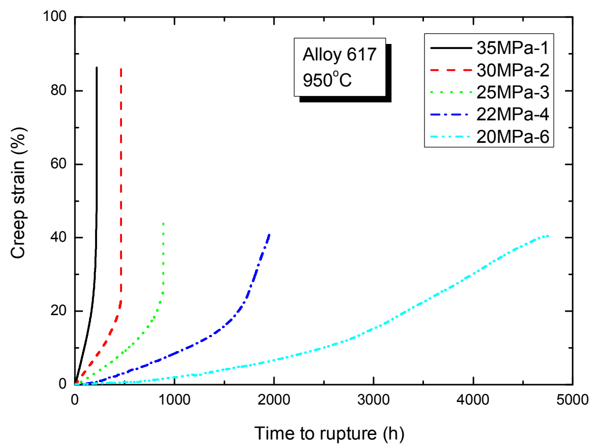


Figure 3. Creep curves of alloy 617 at 950°C

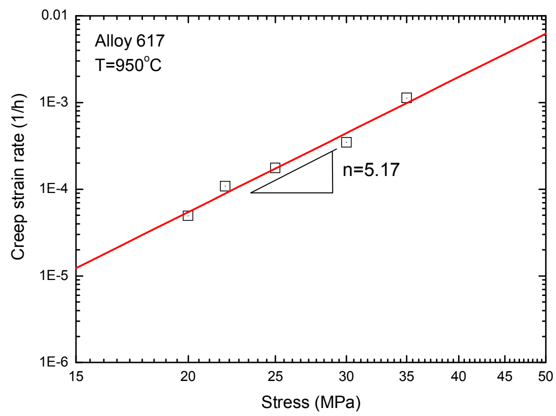
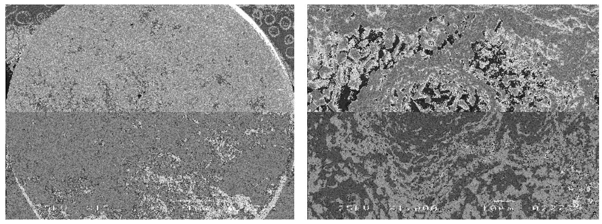


Figure 4. Relationships between creep strain rate and stress of alloy 617 at 950°C



(a) x15 (b) x1000

Figure 5. Typical SEM factrography for alloy 617 crept under 20MPa at 950°C

3. Conclusion

To select the best material for the IHX application, the high temperature materials approved by ASME VIII were reviewed. In allowable design stress (S) at 10^{5} hours of 898°C, alloy 617 showed the highest value when compared with other candidate alloys, and also it showed the highest value in the creep strength at 982°C. Creep curves of alloy 617 were presented that a primary creep strain was not observed nearly, and a tertiary creep was generated at an early stage to the full creep curve. Creep fracture morphology of alloy 617 showed an intergranular fracture mode along grain boundaries and an oxidized substance was observed widely in the fracture surface.

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