Review of ASME-NH Design Materials for Creep-Fatigue

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1. Introduction

To review and recommend the candidate design materials for the Sodium-Cooled Fast Reactor(1), the material sensitivity evaluations by the comparison of design data between the ASME-NH(2) materials were performed by using the SIE ASME-NH computer program(3) implementing the material database of the ASME-NH. The design material data provided by the ASME-NH code are the elastic modulus and yield Strength, Time-Independent Allowable Stress Intensity value, time-dependent allowable stress intensity value, expected minimum stress-to rupture value, stress rupture Factors for weldment, isochronous stress-strain curves, and design fatigue curves. Among these, the data related with the creep-fatigue evaluation are investigated in this study.

2. Review of Design Materials

The current design materials for ASME-NH Class 1 components are provided as follows;

- 304 Stainless steel
- 316 Stainless steel
- 2(1/4)Cr-1Mo steel
- Alloy 800H
- 9Cr-1Mo-V steel

Above design materials are the medium high-temperature alloys recommended to be used as the candidate structural materials for GEN-IV systems. For the very high-temperature alloys, the nickel-based alloys 617 and 230 are recommended and the draft ASME code case rules are prepared for the Alloy 617 material. Recently, the efforts on 316LN and Modified 9Cr-1Mo (Grade 92) steel are for the application to the medium high-temperature reactors and the nickel-based alloys 617 and 230 are for very high temperature gas-cooled reactors.

2.1 Expected Minimum Stress-to Rupture Value

The S_r values are the expected minimum stress-to-rupture strength required for the Level D Service Limits and the creep damage limits evaluation. As increasing the time and temperature, the creep resistance of the 9Cr-1Mo-V steel is not better than the 316 SS material. Over $1.0\text{x}10^5$ hours and 510°C, the 316 SS has higher values of expected minimum stress-to-rupture values than the 9Cr-1Mo-V steel. Fig.1 shows the comparison results of the allowable creep-rupture times between the austenitic stainless steels and 9Cr-1Mo-V steel at given temperatures. As shown in results, 316 SS has the better performance than the others. Fig.2 presents the comparison results of temperature vs. rupture stress at $1.0\text{x}10^5$ hours for the ASME-NH design materials. From the results, the 316 SS is recommended as the creep resistant design material when the design temperature is less than 550°C.

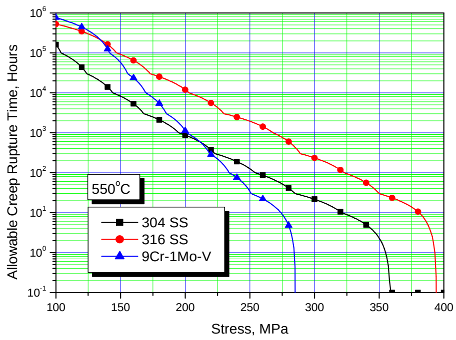

Fig. 1 Comparison of creep rupture time at 550°C

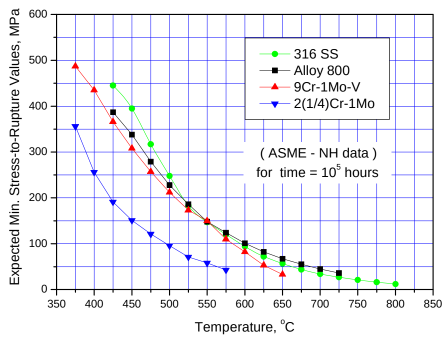

Fig. 2 Comparison of Allowable Creep Rupture Values at 10^5 hours

2.2 Stress Rupture Factors for Weldment

For the structural design evaluations at the weldment parts, the ASME-NH rules introduce the stress rupture factors, i.e. the weld strength reduction factors, which are the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength. Up to now, the time-dependent values are not provided for the 9Cr-1Mo-V steel yet. This factor is required to be used for the Level D Service limits for the primary stress and the creep damage evaluations for the weldment.

Fig.3 and Fig.4 show the results of the sensitivity evaluation of the allowable creep times calculated from the minimum expected stress-to-rupture values for 316 SS and 9Cr-1Mo-V steel respectively. As shown in the figures, the allowable time creep time for weldment based on 9Cr-1Mo-V steel is significantly reduced more rapidly as the stress values increase than the 316 SS.

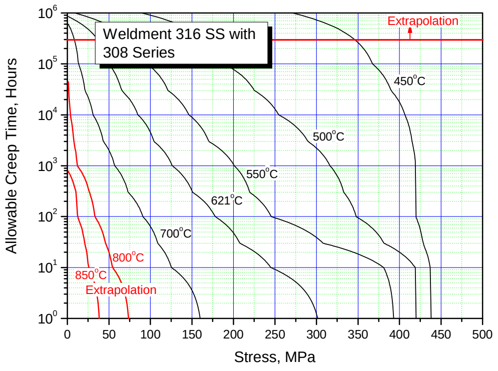

Fig. 3 Allowable creep rupture time for weldment of 316SS

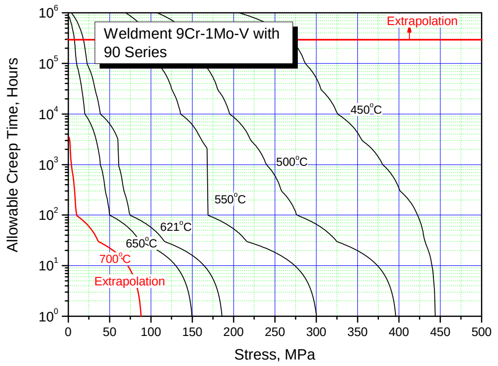

Fig. 4 Allowable creep rupture time for weldment of 9Cr-1Mo-V steel

2.3 Isochronous Stress-Strain Curves

The isochronous stress-strain curves in ASME-NH are very important data for the structural integrity evaluations calculating the stress relaxation strength and stress relaxation time history generation. From the comparison data of the isochronous stress-strain curves between the austenitic stainless steel and 9Cr-1Mo-V, the 9Cr-1Mo-V steel reveals much more stiff characteristics than the austenitic stainless steels due to the their higher yield strength. From the isochronous stress-strain curves, the stress relaxation time history data used for the creep damage evaluation and the relaxation strength, S_{rH}, can be determined. Fig.5 shows the obtained stress relaxation strength, S_{rH} corresponding to the initial stress level of $1.5S_m$ at given temperatures and time durations for 9Cr-1Mo-V steel. As shown in the results, for example of 510°C case with 10^4 time duration, the stress relaxation strength is about 156 MPa for 316 SS and 180 MPa for 9Cr-1Mo-V steel. As the time duration and the temperature increase, the S_{rH} for 9Cr-1Mo-V steel decreases rapidly and become lesser than those of 316 SS.

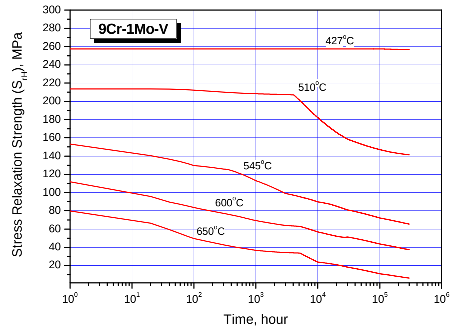

Fig.5 Stress Relaxation Strengths for 9Cr-1Mo-V steel

2.4 Design Fatigue Curves

For the design fatigue curves at a design temperature 510°C of the ABTR, Fig.6 shows the comparison results between the ASME-NH design materials. As shown in the results, 304SS and Alloy 800H materials reveal a good fatigue strength but 9Cr-1Mo-V material is relatively not good in lower cycle regions. In general, all ASME-NH design materials have almost the same fatigue strength at high cycle regions.

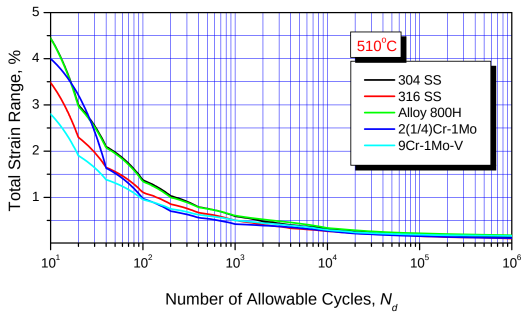

Fig. 6 Comparison of Fatigue Strength Curves

3. Conclusions

In this study, the ASME-NH design materials are investigated in point of time-dependent creep-fatigue characteristics. Tentatively, the 316 SS and the 9Cr-1Mo-V steel are recommended as the primary candidate design materials for SFR design. As second primary candidate materials, the 316LN and NF616 are considered as component structural material.

REFERENCES

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[3] G.H. Koo, J.H. Lee, 2008, "Development of an ASME-NH program for Nuclear Component Design at Elevated Temperatures, Int. J. of PVP, Vol. 85, pp.385-393.