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Prediction of Long-term Creep Strength and Negligible Creep Curve for Eurofer Steel

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1. Introduction

The European RAFM (Reduced Activation Ferritic/Martensitic) steel called as "Eurofer" (or Eurofer97) was developed in the course of systematic optimization of 9%CrWTa, for application in DEMO and fusion power reactors for almost 2 decades [1,2]. In present, the high-temperature tensile and creep data in Eurofer steel were chosen in the French RCC-MRx code (Tome 6, probationary phase rules) [3]. However, the RCC-MRx code was only provided in the short-term creep data within 3x10^4h, and also it was not provided for the negligible creep (T_{NEC}) curve data for defining and/or assessing creep design area of Eurofer steel. Thus, its T_{NEC} curve should be prepared to judge disregard creep as design criterion during normal service operation if the temperature, stress and time limits of negligible creep are respected [4]. To generate the T_{NEC} curve, it is necessary to obtain the long-term creep strength data above 10^6 h.

In this study, to obtain the long-term creep strength data above 10^6h for Eurofer steel, the creep life prediction was performed by Larson-Miller Parameter (LMP) and Wilshire Equation (WE) model using the limited RCC-MRx code data. The long-term creep data for Eurofer steel were reasonably predicted by finding a better one in LMP and WE model. The predicted results for its creep strength were compared with those of typical heat resistance steel called as P91 steel. From the predicted creep rupture data, a T_{NEC} curve for Eurofer steel was successfully generated, and its curve was compared with that of P91 steel.

2. Results and Discussion

2.1 Creep strength data

The RAFM steel is evaluated as a strong candidate material for the structures of fusion power reactors, and the materials of fusion structures have an alloy composition in which high-radiation alloy elements such as Mo and Nb are replaced with low-radiation alloy elements such as W and Ta in the existing heat-resistant steel for thermal power generation with excellent creep characteristics, and usually (8~9)Cr-(1~2)W-(0.05~0.15)Ta-0.1C(wt.%) are composed of major alloy elements. The low-radiation steel material is a tempered martensite microstructure including Cr-based $M_{23}C_6$ carbides and Ta-based MX deposits showing high strength, toughness, and excellent creep properties.

In creep life prediction of Eurofer steel, creep strength data were used for French RCC-MRx code data at 425, 450, 500, 550, 600, 650, and 675°C, as shown in Fig. 1. It is well shown that RCC-MRx code was only provided in the short-term creep data within 3x10^4h. To generate the T_{NEC} curve, it is required to obtain the long-term creep strength data above 10^6h. Thus, in this study, using the limited RCC-MRx code data of Fig. 1, the long-term creep strength data were obtained by finding a better one in LMP and WE model. From the results, a negligible creep curve for Eurofer steel can be finally generated.

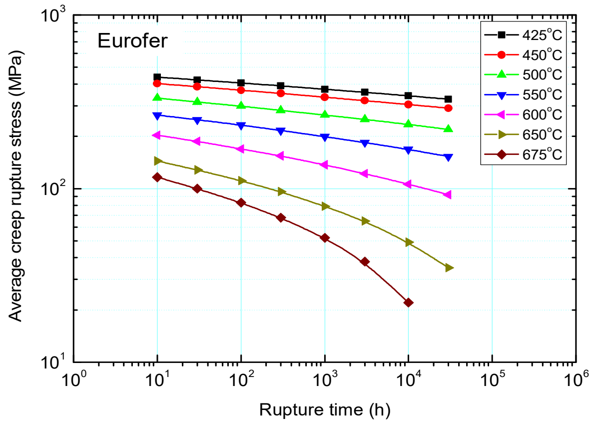

Fig. 1. Creep strength data for Eurofer steel

2.2 Generation of T_{NEC} curve

To find a better method in creep life prediction for Eurofer steel, two methods of LMP and WE model were used. Each equation for LMP and WE model can be given as Eqs. (1) and (2) [5,6].

$$LMP = T\,(\log t_r + C) \quad (1)$$

$$\sigma/R_m = \exp\,[-k(t_r \exp(-Q/RT))^u] \quad (2)$$

In the results of creep life prediction, the WE model was identified to be superiority compared with the LMP method. In generation of the T_{NEC} curve, long-term creep strength data were used for the predicted results by the WE model. The predicted curves at each temperature show good agreement with the creep rupture data, as shown in Fig. 2.

The reference stress has been set at 1.5Sm for Eurofer steel. It has been known that the reference stress values of yield stress (0.2% YS) value can be widely used as a reference stress, but it would seem more physical to use allowable stress (S_m) for F/M steels. Hence, S_m is a maximum allowable stress at specified temperature. The S_m values with temperatures were given in RCC-MRx code. This study applied a semi-graphical method for determining the T_{NEC} curve. This method uses tabulated values of creep rupture strength at specified rupture times and temperatures as well as the corresponding S_m value for defining the T_{NEC} curve. The creep rupture strengths $R_{u/t/T}$ (MPa) to time t at temperature T of durations of 1,000h, 3,000h, 10,000h, 30,000h, 100,000h, 300,000h, 500,000h, and 1,000,000h are divided by the same correction factor SCF (stress correction factor) of 1.5. The safety on creep rupture is induced by keeping the rupture time the same but lowering the stress by $R_{u/t/T}$ /1.5. The modified rupture and yield curves are plotted against temperature to localize the intersection points. A T_{NEC} curve from intersection points of a reference stress and SCF curves is determined. A T_{NEC} curve for Eurofer steel was obtained from Fig. 3 showing a plot of stress vs. temperature showing reference stress and SCF curves.

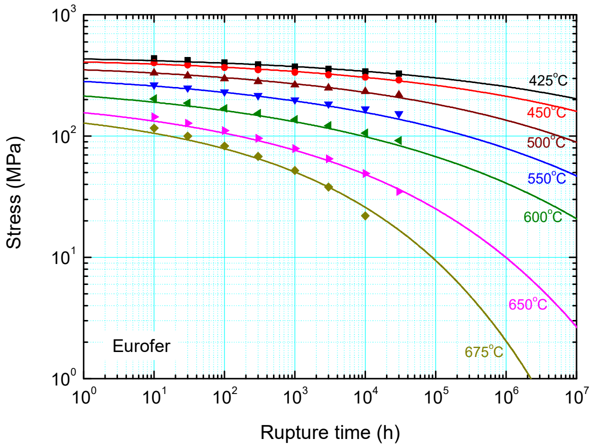

Fig. 2. Predicted curves at each temperature of Eurofer steel

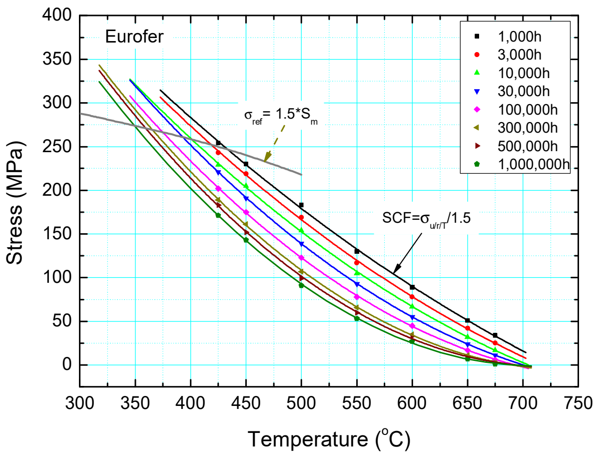

Fig. 3. A plot of stress vs. temperature showing reference stress and SCF curves for Eurofer steel

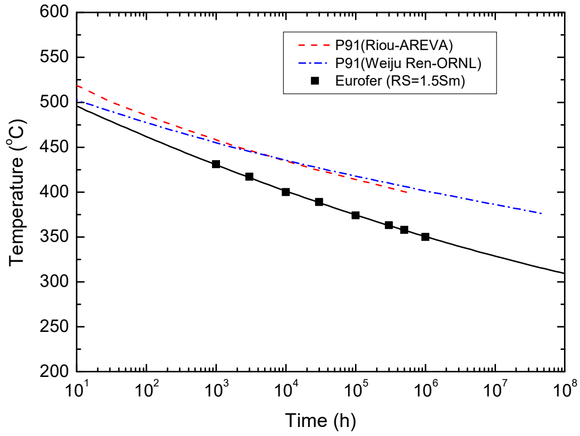

Fig. 4. Comparison of T_{NEC} curves for Eurofer and P91 steels

Fig. 4 shows the T_{NEC} curve obtained for Eurofer steel. A black line indicates the negligible curve for the Eurofer steel, and dotted lines are for P91 steel. In comparison of Eurofer and P91 steels, it is seen that P91steel was located at higher position than that of Eurofer steel. It means that Eurofer steel was lower in creep strength than P91 steel. It can be identified that Eurofer steel is shorter in negligible creep time than P91 steel. It is here noted that the T_{NEC} curves for P91 steels were collected from reported papers in literature surveys.

3. Conclusions

In creep life prediction, the WE model was identified to be superiority compared with the LMP method. Long-term creep strength data above 10^6h for Eurofer steel were extensively obtained for various temperatures using the limited RCC-MRx code data of short-term creep strengths. Using the predicted creep strength data, a T_{NEC} curve for Eurofer steel was successfully generated and proposed. It was identified that, in the plot of the negligible curve of temperature vs. time, Eurofer steel was located at a lower position than P91 steel. The reason for this is that Eurofer steel was lower in creep strength than P91 steel.

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