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Determination of Negligible Creep Curve for P92 Steel

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1. Introduction

Creep-resistant 9–12% chromium steels, used for large components such as turbines and boilers, are recognized as the key material to increase the thermal efficiency of steam power plants. The P92 (ASME Grade 92) steel, as improved version of P91 (ASME Grade 91) steel by the addition of W with reduced Mo, has been developed to achieve higher creep-rupture strength than P91 steel for long-term service at temperatures up to 600°C and above in high-temperature parts of boilers, steam lines and turbines of ultra-supercritical (USC) power plants. However, so far, a negligible creep (T_{NEC}) curve for defining and/or assessing creep design area of P92 steel has not been provided in the high-temperature design codes of RCC-MRx and ASME codes. For simplified design of the components operating at high temperatures, it is recommended to design in the "no creep" (NC) or "negligible creep" (NEC) temperature regimes of the material. Thus, the T_{NEC} curve for P92 steel 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 [1,2].

In the study, to determine the T_{NEC} curve for P92 steel, creep rupture data were collected through world-wide literature surveys, and then long-term creep life (or strength) prediction was carried out using Wilshire Equation (WE) model. The reference stress values and the stress correction factor (SCF) values, which are required to define the T_{NEC} curve, were determined at each temperature. Using the predicted creep rupture data, the T_{NEC} curve for the P92 steel was successfully determined, and its curve was compared with that of the P91 steel

2. Results and Discussion

2.1 Creep rupture data

The P91 and P92 steels were developed to achieve improved creep-rupture strength, and the two steels have been widely used as structural materials for elevated temperature applications in the chemical, petrochemical and fossil-fired power generating industries. The improved versions mainly include 9Cr-1Mo steel modified by the addition of strong carbide forming elements such as Nb and V known as P91 steels. The P91 steel was further modified by the addition of W with reduced Mo designated as P92 steel, as given in Table 1. Chemical compositions for the P91 and P92 steels are listed in Table 1. Creep rupture data were collected for the total data (n=176) at 550, 600, 650, 700, and 750°C for the P92 steel through literature surveys, as shown in Fig. 1. In Fig. 1, the creep rupture data in ECCC (European Creep Collaborative Committee) data were given for the long-term data reaching 200,000h. Using the collected data, long-term creep strength was predicted by WE model, and the negligible creep curve for the P92 steel was determined.

Table 1. Chemical compositions of the P91 and P92 steels

Elements	T/P91	T/P92
C	0.08 – 0.12	0.07– 0.13
Si	0.20 – 0.50	Max. 0.50
Mn	0.30 – 0.60	0.30 – 0.60
P	Max. 0.020	Max. 0.020
S	Max.0.010	Max.0.010
Al	Max. 0.020	Max. 0.020
Cr	8.00 – 9.50	8.50 – 9.50
Ni	Max. 0.40	Max. 0.40
Mo	0.85 –1.05	0.30 – 0.60
W	–	1.50 – 2.00
V	0.18 – 0.25	0.15 – 0.25
Nb (Cb)	0.06 – 0.10	0.04 – 0.09
B	–	0.0010 – 0.0060
N	0.030 – 0.070	0.030 – 0.070

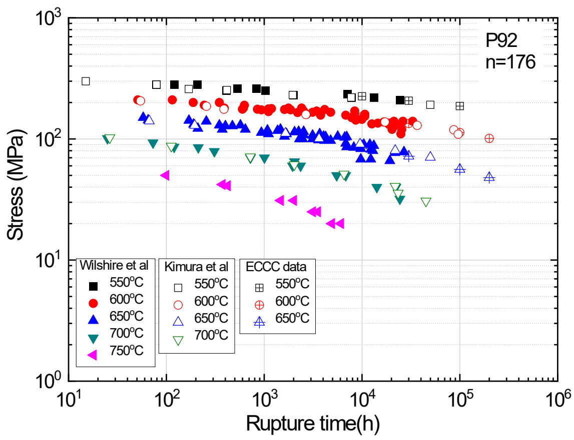

Fig. 1. Collected creep rupture data (n=176 points) through literature surveys for the P92 steel

2.2 T_{NEC} curve

To determine the negligible creep curve for the P92 steel, long-term creep life extrapolation was performed using collected creep rupture data of n=176, as shown in Fig. 1. To predict long-term creep rupture strength, Wilshire Equation (WE) model were used, and it is given as Eq. (1) [3,4].

$$\sigma/R_m = \exp\left[-k(t_r \exp(-Q/RT))^u\right] \tag{1}$$

In the results of creep life prediction, the WE model was identified to be superiority, as shown in Fig. 2. Each predicted curve, as presented in at 550, 600, 650, 700, and 750°C in Fig. 2, shows good agreement with the creep rupture data. In addition, the creep rupture strengths were predicted for the temperatures at 450, and 500°C to accurately obtain the T_{NEC} curve. The curves are indicated as the dotted lines in Fig. 2.

The reference stress has been set at $R_{p02}/1.5$ for the P92 steel. It has been known that the reference stress values of 1.5 R_{p02} for austenitic stainless steel and $R_{p02}/1.5$ for ferritic/martensitic steels were adopted. Hence, R_{p02} is defined as yield stress (MPa) at specified temperature. 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 yield stress for the definition of 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, 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 σ_{ref} curve and SCF curves is determined. The T_{NEC} curve of the P92 steel was obtained from Fig. 3.

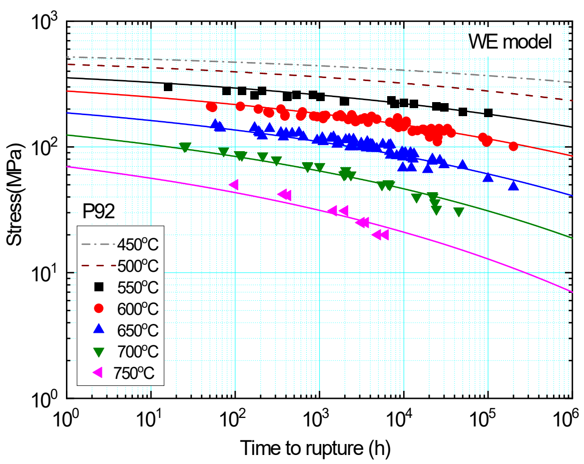

Fig. 2. Predicted curves at 450°C, 500 °C, 550 °C, 600 °C, 650 °C, 700 °C, and 750°C for the P92 steel

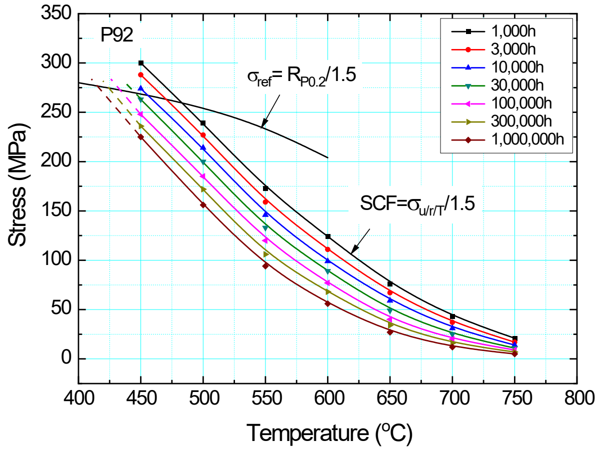

Fig. 3. A plot of stress vs. temperature showing reference stress and SCF curves for the P92 steel

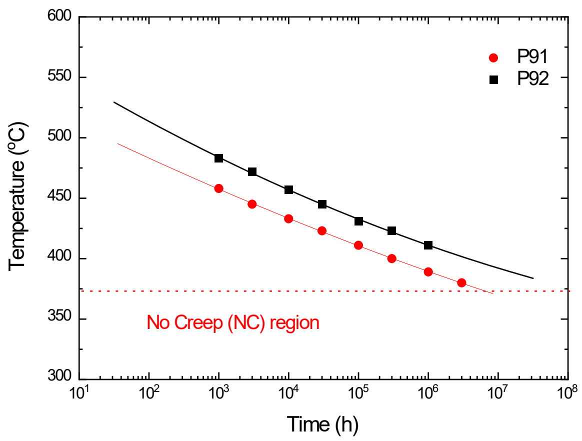

Fig. 4. Comparison of the T_{NEC} curves for the P92 and P91 steels

Fig. 4 shows the T_{NEC} curve obtained for the P92 steel. A black line indicates the negligible curve for the P92 steel, and a red line is for the P91 steel. In comparison of the P92 and P91 steels, it is seen that the P92 steel was located at higher position than that of the P91 steel. It means that the P92 steel was higher in creep strength than P91 steel. Thus, it is identified that the P92 steel is reasonable to be longer in negligible creep time than the P91 steel. It is here noted that the T_{NEC} curve for the P91 steel was done in author's previous study [5].

3. Conclusions

To determine the negligible creep curve for the P92 steel, long-term creep life extrapolation was performed using the collected creep rupture data through world-wide literature surveys. Using the predicted creep rupture data, the T_{NEC} curve for the P92 steel was successfully determined. In the plot of the negligible curve of temperature vs. time, the P92 steel was located at higher position than that of the P91 steel. It means that the P92 steel was longer in negligible creep time than the P91 steel. The reason for this is that the P92 steel was higher in creep strength than the P91 steel.

Acknowledgements

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