# INFLUENCE OF HEATS, HEAT-TREATMENTS AND TESTING METHODS ON HIGH TEMPERATURE FATIGUE OF 2.25Cr-1Mo STEELS

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ABSTRACT

Fatigue properties for three heats of normalized and tempered 2.25Cr-1Mo steel were investigated under axial strain-controlled test conditions. Comparing with reference data of annealed 2.25Cr-1 Mo steels, and under diametral strain controlled test conditions, the influence of heats, heat-treatments and testing conditions were cleared.

## 1 INTRODUCTION

High temperature NIMS Fatigue data sheets have been published since 1978. From the data sheets we can evaluate the heat-to-heat variations in low-cycle fatigue properties at high temperatures for normalized & tempered 2.25Cr-1Mo steels. In addition, comparing with the references data for annealed 2.25Cr-1Mo steels and the data of diametral strain controlled tests, the influences of heats, heat-treatments and testing conditions were investigated.

Fatigue design curve of 2.25Cr-1Mo steel in ASME code case N-201-4[1] was proposed after Brinkman's data[2] which the tests were done under diametral strain controlled for annealed 2.25Cr-1Mo steels. In this study, it makes clear that the ASME fatigue design curve is not conservative.

## 2 MATERIALS AND TESTING CONDITIONS

NIMS fatigue data sheet No.94 for 2.25Cr-1Mo steel has been published in 2004[3]. Past data sheets for 2.25Cr-1Mo steels had been published as NRIM FDS No.62 and No7, in 1989 and 1978, respectively[4,5]. From these data sheets we can evaluate the heat-to-heat variations in low cycle fatigue properties at high temperatures. The chemical composition and the conditions of normalizing, tempering and PWHT(stress relief) heat-treatments are shown in Table1. The fatigue tests were done under axial strain controlled at high temperatures in air. The specimens are cylindrical smooth with a diameter of 10 or 6 mm.

Table 1 Chemical composition and heat-treatment of 2.25Cr-1Mo steels

| Materials | Main chemical composition in mass.% | Heat-treatment |
|---|---|---|
| 2.25Cr-1Mo in NIMS FDS No.94(2004) | 0.08C-0.24Si-0.46Mn-0.007P-0.002S-0.26Cr-1.00Mo | 930℃/0.5 h AC+720℃/0.5 h AC+670℃/1 h FC |
| 2.25Cr-1Mo in NIMS FDS No.62(1989) | 0.13C-0.02Si-0.50Mn-0.007P-0.009S-2.43Cr-0.96Mo | 920℃/1.3 h AC+670℃/2.3 h AC+650℃/10.3 h FC |
| 2.25Cr-1Mo in NIMS FDS No.7(1978) | 0.11C-0.24Si-0.51Mn-0.005P-0.002S-2.29Cr-0.99Mo | 930 ℃ /1 h AC+700 ℃ /1 h AC+640℃1 h FC |

## 3 TEST RESULTS

As shown in Fig.1, all data at 400, 500 and 600℃ for normalized & tempered 2.25Cr-1Mo steels are plotted in ASME fatigue design curve figure. Brinkman's data[2] for three heats of annealed 2.25Cr-1Mo steels at 427 and 538℃ are also plotted. Because the design curves are based on his data by reducing 1/20 in life and 1/2 in strain. The cycle strain rate is $4x10^{-3}$/s. The rates of ours are $10^{-3}$/s and $10^{-2}$/s. The data band is very large and the fatigue design curves seems to be unconservative. The scatter is discussed in next section comparing with the references data for each temperature or each strain rate.

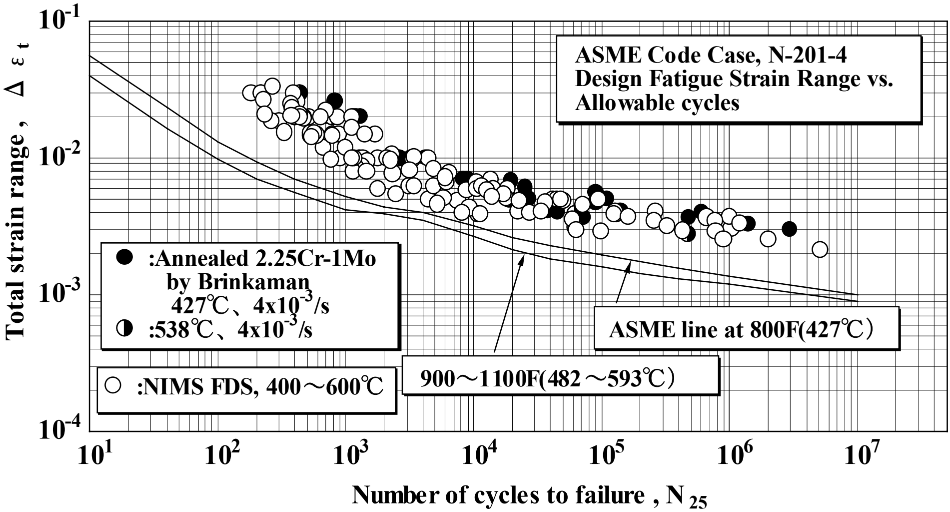


Figure 1 ASME fatigue design curves and the data for norm & tempered and annealed 2.25Cr-1Mo steels

## 4 DISCUSSIONS

### 4-1 Influence of heat-treatments

Tokimasa[6] investigated the influence of heat-treatment on the fatigue life between annealed and norm & tempered 2.25Cr-1Mo steels. Figure 2 shows the influence of heat-treatments of 2.25Cr-1Mo steels. From Fig.2, it is seemed that the heat-treatment do not affect the low-cycle fatigue lives.

As for tensile properties such as 0.2% proof stress and tensile strength, however, are dependent on the heat-treatments as shown in Figs.3 and 4.

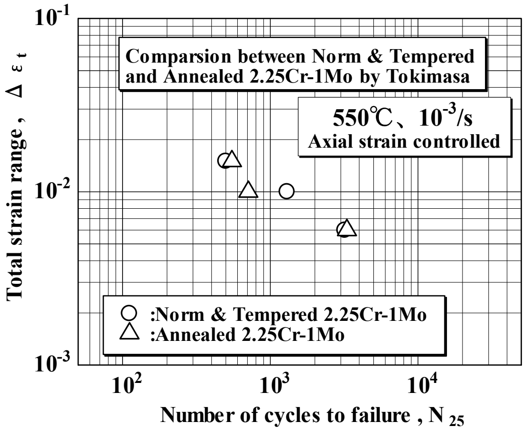


Figure 2 Influence of heat-treatment by Tokimasa.

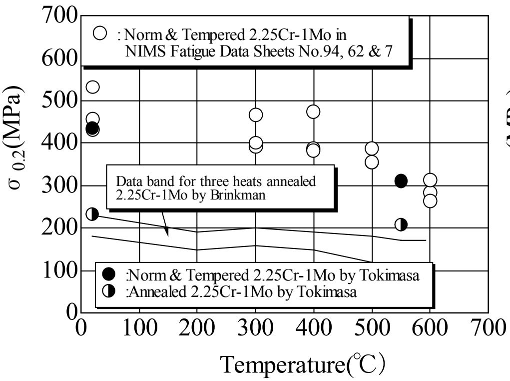


Figure 3 0.2% proof stress for 2.25Cr-1Mo.

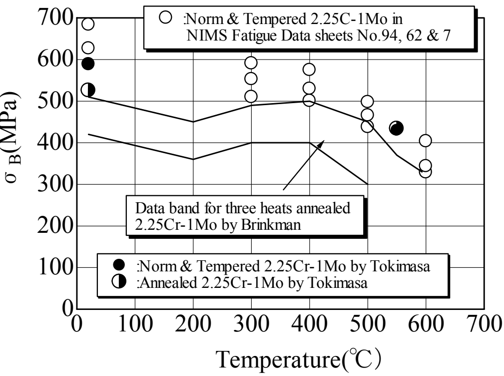


Figure 4 Tensile strength for 2.25Cr-1Mo.

4-2 Influence of strain rate

Figure 5 shows the S-N data for norm & tempered 2.25Cr-1Mo steel at strain rates of $10^{-3}$ and $10^{-2}$/s at 600℃ from NIMS data sheets No.94. The influence of the strain rate on the fatigue lives seems to be small.

4-3 Influence of heats

Figure 6 shows the S-N data for norm & tempered 2.25Cr-1Mo steels at 600℃ for four heats. The strain rates are between $10^{-2}$/s and $10^{-3}$/s. The influence of heats on the fatigue lives seems to be small.

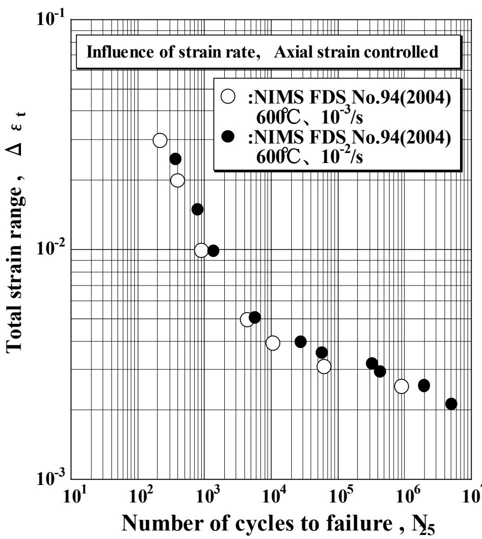


Figure 5 Influence of strain rate.

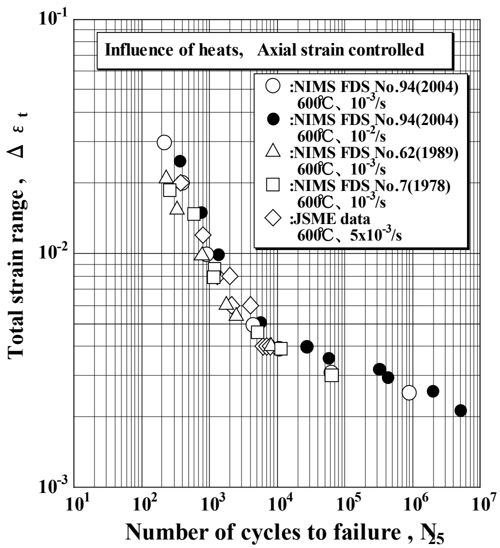


Figure 6 Influence of heats.

4-4 Influence of strain control mode

Figure 7 shows the influence of strain control mode on the fatigue lives. Single marks denote the norm & tempered 2.25Cr-1Mo steels under axial strain controlled tests. These data are as the same as Fig.6. Double marks denote the data tested under diametral strain controlled. The diametral strain controlled test data show longer lives in low and medium cycles regions below $10^6$ cycles. Over $10^6$ cycles both data seem to be are almost the same. By the way, it was cleared that the strain control mode affect the low-cycle fatigue lives at high temperatures.

From these results the large scatter in Fig.2 seems to be caused by the differences in strain control mode and testing temperature.

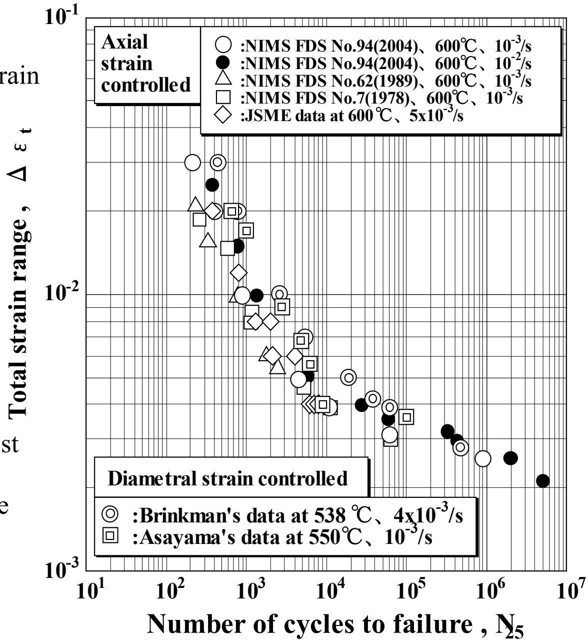


Figure 7 Influence of strain control mode.

4-5 Fatigue design curves for norm & tempered 2.25Cr-1Mo steels tested under axial strain controlled conditions

All the data between 400℃ and 470℃ including references data are plotted in Fig.8. The materials are seven heats, annealed and norm & tempered 2.25Cr-1Mo steels. In low-cycle region below $4x10^3$ cycles, axial strain controlled test data show shorter lives. ASME code line at 800F(427℃) for $4x10^{-3}$/s seems to be unconservative for norm & tempered 2.25Cr-1Mo steels at a strain rate of $10^{-3}$/s. In Fig.8 modified fatigue design curve at 400℃ for $10^{-3}$/s is added by dotted line.

The data between 538℃ and 600℃ are plotted in Fig.9. The materials are ten heats, annealed and norm & tempered 2.25Cr-1Mo steels. Axial and diametral strain control test data are included. ASME code line at 900～1100F(482～593℃) for $4x10^{-3}$/s seems to be unconservative in almost all cycles region for both norm & tempered and annealed materials. In Fig.9 modified fatigue design curve at 600℃ for $10^{-3}$/s is added by dotted line.

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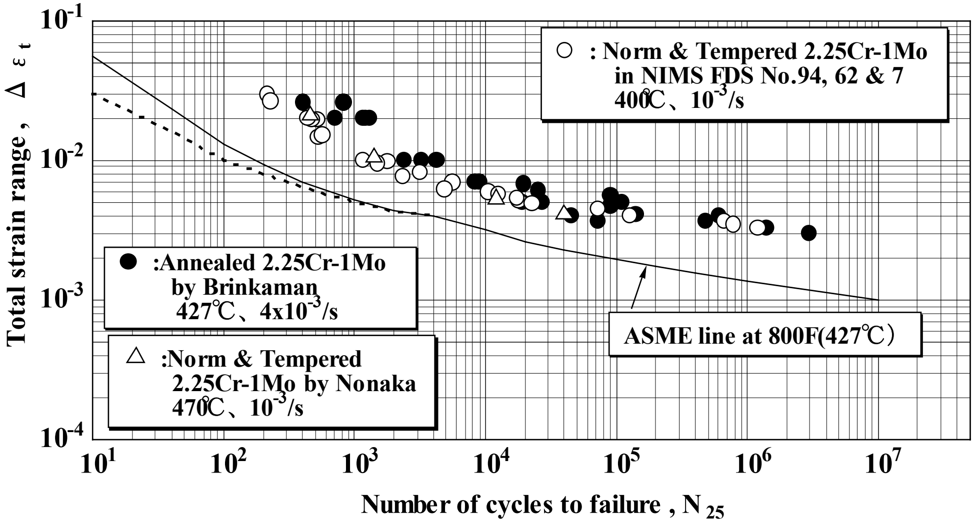


Figure 8 ASME fatigue design curve and modified line for 2.25Cr-1Mo steel at 400℃.

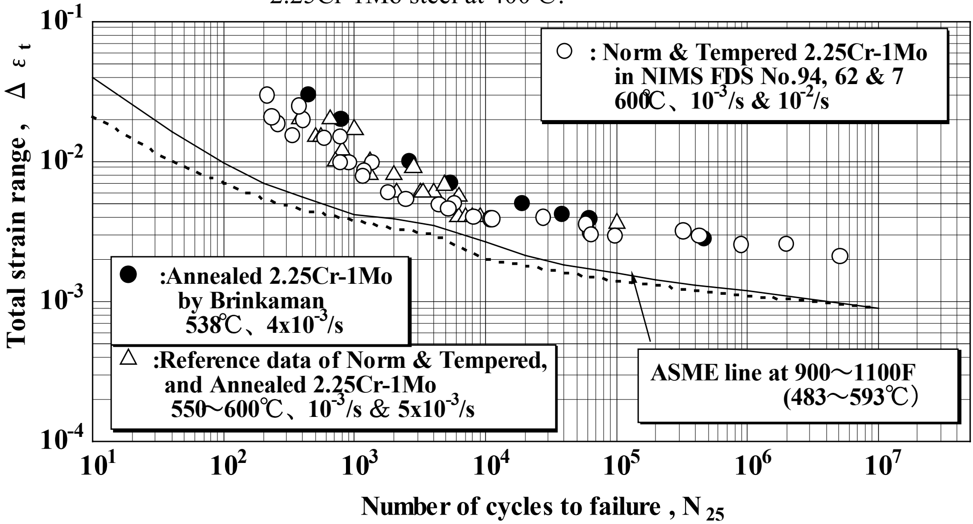


Figure 9 ASME fatigue design curve and modified line for 2.25Cr-1Mo steel at 600℃.