Creep Deformation of High Cr-Mo Ferritic/Martensitic Steels by Material Softening

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1. Introduction

High Cr (9-12%Cr) ferritic/martensitic steels represent a valuable alternative to austenitic stainless steel for high temperature applications up to 600 °C both in power and petrochemical plant, as well as good resistance to oxidation and corrosion. Material softening is the main physical phenomenon observed in the crept material. Thermally-induced change (such as particle coarsening or matrix solute depletion) and strain-induced change (such as dynamic subgrain growth) of microstructure degraded the alloy strength. These microstructural changes during a creep test cause the material softening, so the strength of the materials decreased. Many researches have been performed for the microstructural changes during a creep test [1-2], but the strength of crept materials has not been measured.

In the present work, we measured the yield and tensile strength of crept materials using Indentation-typed Tensile Test System (AIS 2000). Material softening was quantitatively evaluated with a creep test condition, such as temperature and applied stress.

2. Experimental Procedure

Five kinds of modified 9Cr steels with different levels of nitrogen were used. Creep rupture testing was carried out at 600°C and 650 °C for up to 13,000 hours under the constant applied stress. After testing, the longitudinal cross section of the specimens was observed metallographically by a 200 kV transmission electron microscope (TEM). The growth of martensite lath width was measured on TEM micrographs. The number of lath measurements was about 250. Tensile properties of crept specimens were measured using AIS 2000 (five times each) at room temperature. It is a kind of ball indentation system. The deviation of results between this test and uniaxial tension test was within ± 5% [3]. Yield and tensile strength can be obtained by this test, but information for elongation can't be obtained.

3. Results and Discussion

3.1 Microstructural Changes after Creep

Martensite lath boundaries represent hard regions during creep of ferritic/martensitic steels. So the material with smaller lath width in the as-tempered state shows higher creep resistance [4]. Fig.1 shows the growth of martensite lath width with creep deformation. Martensite lath width in the crept specimens increased with increasing time to rupture. The lath width rapidly grew with time to rupture up to 10^3 hr, after that time the growth rate of lath width slowed down. N08 steel, which showed the highest creep rupture strength, had the smallest lath width in the same time to rupture. In other words, it took longer time to have the same lath width in N08 steel at the same creep temperature.

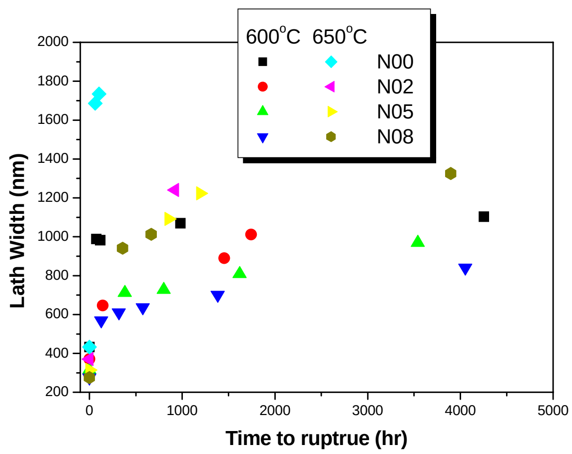

Fig. 1. Growth of martensite lath width during creep deformation

3.2 *Change of mechanical properties after Creep*

Martensite lath width increased during creep deformation by the coarsening of precipitates and recovery of dislocations. The increase of lath width had a relation with matrix yield strength of creep ruptured specimens. Fig.2 shows that martensite lath width of creep ruptured specimens gradually decreased with increasing matrix yield strength. The martensite lath width was a good match for matrix yield strength of crept specimens. It indicates that the change of martensite lath width may represent the material softening during creep deformation.

The yield strengths measured by AIS 2000 at room temperature were converted to the value at high temperature (600℃ and 650℃) using uniaxial tensile test results at room and high temperature. The converted high temperature matrix yield strength, similar to the matrix yield strength at room temperature, was also proportional to the applied stress. To find out the quantitative relationship between yield strength of creep ruptured specimens and applied stress, yield strength of the matrix was divided by applied stress. The calculated results are shown in Fig.3. The ratio had a good relationship with applied stress. As the applied stress increased, the ratio gradually decreased. The ratio changed from 1.35 at high applied stress to 2.45 at low applied stress. That is, if the matrix yield strength decreases up to about two and a half times of applied stress by creep deformation at low applied stress, the specimen will rupture.

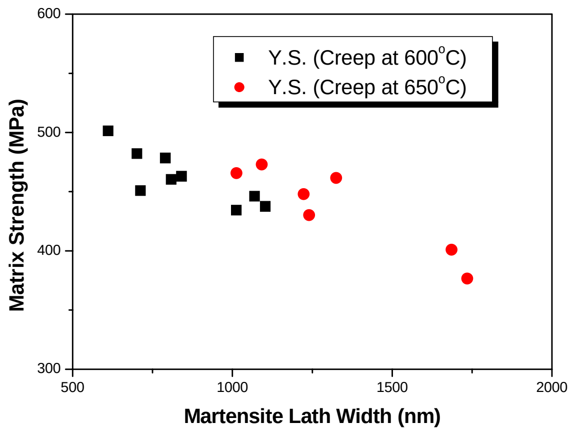

Fig. 2. Relationship between matrix yield strength and martensite lath width

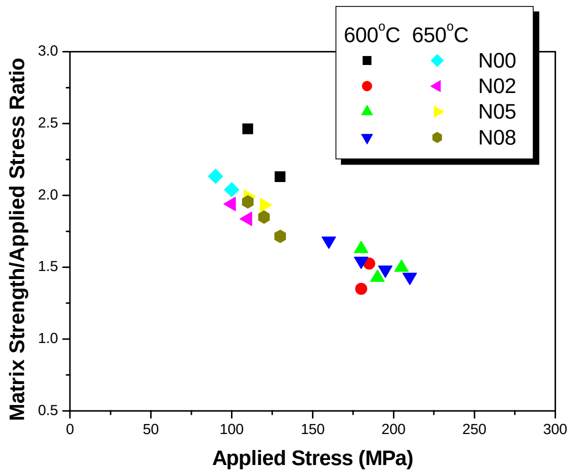

Fig. 3. Relationship between high temperature matrix yield strength divided by applied stress and applied stress

4. Conclusion

Material softening of crept ferritic/martensitic steels was investigated. The following conclusions were obtained:

Martensite lath width increased during creep deformation by the coarsening of precipitates and recovery of dislocations. Martensite lath width in the crept specimens increased with increasing time to rupture. The martensite lath width was also a good match for matrix yield strength. It shows that the change of martensite lath width may represent the material softening during creep deformation.

The decrease of the matrix strength by the material softening occurred during creep deformation. When the strength of the matrix decreased to a certain value by creep deformation, the specimen ruptured. The limited strength changed with applied stress. The ratio of matrix yield strength to applied stress changed from 1.35 at high applied stress to 2.45 at low applied stress.

The softening behaviors, such as the growth of martensite lath width and the decrease of matrix strength, were irrelevant to the creep test temperature.

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