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Change of Mechanical Properties during Creep Deformation in Modified 9Cr-1Mo Steel

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1. Introduction

9-12% Cr-Mo ferritic/martensitic steels are widely used as high temperature materials in the power plants and chemical industries due to their high strength and thermal conductivity, low thermal expansion, and good resistance to corrosion.[1] Owing to the better irradiation characteristics (e.g. excellent irradiation swelling resistance) of these steels than austenitic alloys they have been receiving attention for the application to the fuel cladding or core structure of various advanced nuclear reactors. Since the operating temperature and pressure of advanced nuclear reactors are supposed to be higher than those of light water reactors,[2] high temperature mechanical properties and microstructural stability of cladding and core structural materials of advanced nuclear reactors is very important.

Material softening is the main physical phenomenon observed in the crept material. 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 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. [3]

In the present work, we evaluated material softening kinetics by measuring the change of mechanical properties during creep deformation with Indentation-typed Tensile Test System (AIS 2000) and Vickers hardness test.

2. Experimental Procedure

Modified 9Cr-1Mo steel with 2 wt% tungsten was examined. Interrupted creep testing was carried out at 600°C under the constant load condition. The load was 195 MPa. Time to rupture was 2,500 hours. Creep testing was interrupted after creep deformation for 1,000 hr, 1,500 hr, and 2,000 hr. After interrupted creep testing, tensile properties of the 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%. Yield and tensile strength can be obtained by this test, but information for elongation can't be obtained. Vickers hardness measurements (ten times each) were conducted at room temperature and the averages were obtained. 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.

3. Results and Discussion

3.1 Change of mechanical properties during creep deformation

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. The decreasing tendency of matrix yield strength may be occurred three form judging from kinetics point. First, the matrix yield strength linearly decreases with creep test. Secondly matrix yield strength does not decrease at the early stage of creep test, after this it sharply decreases at the end of creep. Finally, matrix yield strength abruptly decreases at the early stage of creep deformation, after this it's value is gradually saturated. Fig. 1 shows the change of matrix yield strength of modified 9Cr-1Mo steel with creep duration. The decreasing tendency of Modified 9Cr-1Mo steel was identical to the last case. Matrix yield strength ratio decreased to 0.926 at 1,000 hr (t/t_f = 0.4) creep deformation. This decrease was the 90% of total decrease of yield strength.

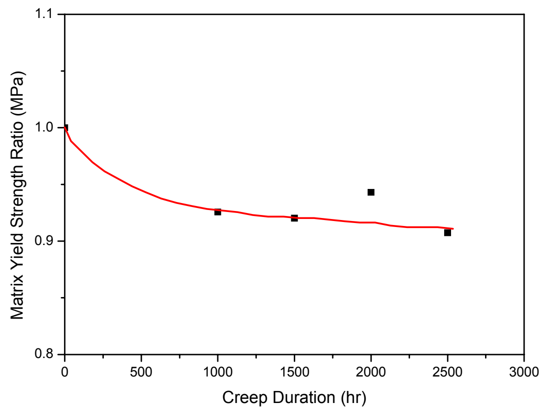

Fig. 1. Change of matrix yield strength with creep duration

The change of hardness with creep deformation is plotted in Fig. 2. The change of hardness during creep deformation was very similar to the change of matrix yield strength. When the hardness decreased to about 85% of initial hardness, the specimen was ruptured. But the hardness hardly decreased in the unstressed head part.

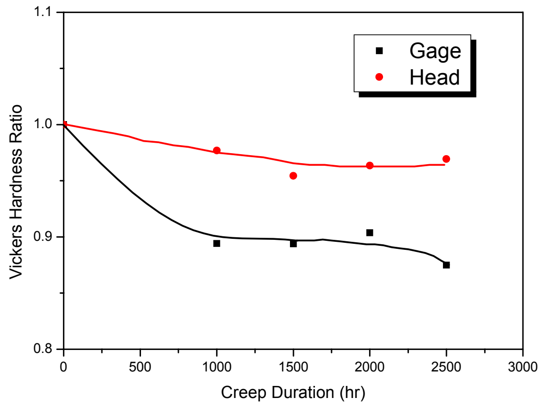

Fig. 2. Change of Vickers hardness with creep duration

3.2 *Change of lath width during creep deformation*

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]. Martensite lath width increased during creep deformation by the coarsening of precipitates and recovery of dislocations.

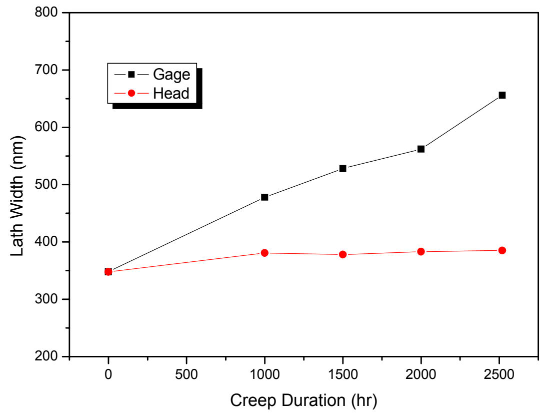

Fig. 3. Change of martensite lath width with creep duration

Fig.3 shows the growth of martensite lath width with creep deformation. The lath width was about 350 nm before creep test. As the creep deformation was progressed the lath width gradually increased to about 660 nm. The growth rate of martensite lath width was constant until tertiary creep, but the growth of lath width slightly increased during tertiary creep.

The change of lath width at the head region which was only thermally aged was very small. Creep test temperature (600 ^{o}C) was lower than tempering temperature (750 ^{o}C), so the recovery of microstructure by thermal aging was hardly occurred.

Precipitation radius was also increased with creep deformation. The growth rate was nearly constant during creep deformation.

4. Conclusion

The relationship between creep deformation and change of mechanical properties in modified 9Cr-1Mo steel has been studied. The following conclusions were obtained:

The matrix yield strength and hardness were abruptly decreased at the early stage of creep deformation, and gradually saturated to a certain value. On the contrary, growth rate of martensite lath width and precipitation size was nearly constant during creep deformation.

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