Nano-scale Characterization of Temper-Softening Resistance in 9Cr-ODS Steel


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The 9Cr-oxide dispersion strengthened (ODS) steel is the most prospective cladding materials for the advanced fast reactor fuel elements, and has a great potential for the structural materials of the blanket systems of the advanced fusion reactor. It was revealed in the previous study that the distinguished creep rupture strength of 9Cr-ODS steel is attributed to a formation of residual-alpha ferrite grains, which contain ultra-fine and high-density oxide particles. In this study, a correlation with structure stability of 9Cr-ODS steel and formation of residual-alpha ferrite was investigated by means of micro and nano-scale hardness measurement during tempering at various temperatures.

The four kinds of specimens in 9Cr-ODS steels with a different volume of residual-alpha ferrite were prepared from claddings manufactured by hot-extrusion of the mechanically alloyed powders and cold-rolling. Basic chemical composition is 9Cr-0.14C-2W-0.2Ti-0.35Y2O3. After normalizing at 1423 K for 1 h, micro and nano-scale hardness were measured at tempering temperature of 773-1073 K by using micro-Vickers and nanoindentator. The X-ray diffraction analysis and TEM observation were also conducted for specimens tempered at each temperature. The conventional ferritic/martensitic steel cladding was also tested as a reference.

The area of micro-Vickers hardness measurement is a diamond shape of several ten micron-meters, which covers both residual-alpha ferrite grains and martensite grains. The hardness in this area for specimens with different volume fraction of residual-alpha ferrite shows suitable correlation with their creep rupture strength at 973 K. With increasing a volume fraction of residual-alpha ferrite, the micro-Vickers hardness and creep rupture strength are systematically increased. The direct measurement of individual grains of residual-alpha and martensite by nanoindentation technique reveals that softening of residual-alpha ferrite grains due to tempering is considerably reduced, compared with martensite grains. Moreover, X-ray diffraction and TEM observation at each step of tempering from 773 to 1073 K indicate the phase transformation from bct to bcc structures and dislocation structure change, which are associated with structure change of residual-alpha ferrite. From these results, it was found that the residual-alpha ferrite distinctly affected the microstructure stability of 9Cr-ODS steel at elevated temperature.

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