§2. Dislocation Evolution during Thermal Creep Deformation in V-4Cr-4Ti with Various Thermal and Mechanical Treatments

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Thermal creep deformation is one of the key issues of low activation V-Cr-Ti alloys, which can limit the upper operation temperature of the blankets. Possible means to enhance the thermal creep resistance are dislocation and precipitation hardening. Recently, creep properties and microstructures were examined for V-4Cr-4Ti with various thermal and mechanical treatments including two-step heat treatments with cold rolling for the purpose of introducing high density of small Ti-CON precipitates and dislocations[1,2]. The present study examines details of dislocation structure during thermal creep deformation.

The material used in this study was the reference V–4Cr–4Ti alloy named NIFS-Heat-2. Five thermal and mechanical treatments were applied to these plates, which are summarized in Table 1. Microstructures of the five types of specimens are shown in Fig. 1.

After the thermal and mechanical treatments, the specimens were cut or punched out from 0.25 mm thick plates. The creep test specimens had the gauge dimension of 5 x 1.2 x 0.25 mm^3 (SS-J size). The creep tests were conducted at 1023 K with the applied tensile stress of 176 MPa and 250 MPa using a uniaxial creep testing machine for miniaturized tensile test specimens. For microstructure analysis by TEM, 3 mm disks were punched-out from the gauge area of the specimens after the creep test to ~3%. TEM observations were carried out using JEM-2000FX of RIAM, Kyushu University.

Fig. 2 is the quantitative summary of dislocation structures for STD, STD-CW and SA-A-CW. In STD where both dislocation and precipitate densities were low, the dislocations introduced by the creep deformation were predominantly of a/2<111> type, although higher applied stress caused higher total dislocation density. In STD-CW, Burgers vector analyses of the as-prepared specimen (0 hr) were difficult because of very high density of dislocations and high residual internal strain. However, the fact that the specimens subjected to the thermal control and the short time (6 h) creep deformation showed mixture of a<100> and a/2<111> types of dislocations strongly suggests that the both types of dislocations existed in as-prepared STD-CW specimens.

The microstructure was compared of SA-CW-A as prepared and after creep deformation at 1023K with 176 MPa for 60 h. High density of dislocations remained after the creep deformation, which is completely different from the cases of STD-CW and SA-A-CW. The result demonstrated that dislocations induced by SA-CW-A treatment are stable during the thermal creep processes.

In summary, the dislocations in cold worked V-4Cr-4Ti were mixture of a<100> and a/2<111> types after thermal aging, but predominantly of a/2<111> type after the creep deformation. The loss of cold work-induced sessile a<100> type dislocations resulted in recovery of dislocations during the creep deformation. High density precipitation by aging prior to the cold work had small effects on stabilizing dislocations during the creep deformation. On the other hand, cold work followed by precipitation (strain aging) was effective in keeping dislocation structures during the creep deformation.

[1] P.F. Zheng, T. Nagasaka, T. Muroga, J.M. Chen, Y.F. Li, Fusion Eng. and Des., 86 (2011), 2561-2564.
[2] T. Muroga, T. Nagasaka, J.M. Chen, Y.F. Li, H. Watanabe, J. Nucl. Mater., 386-388 (2009) 606-609.

Table.1 The thermal and mechanical treatment conditions of the V-4Cr-4Ti (NIFS-HEAT-2)

Abbreviation	Treatment	Conditions
STD	Standard	1273 K, 2h
STD-CW	Standard and Cold-Worked	STD + 20% Cold Rolled
SA-A	Solution Annealed and Aged	1373 K, 1 h + 873 K, 20 h
SA-A-CW	Solution Annealed, Aged and Cold-Worked	SA-A + 20% Cold Rolled
SA-CW-A	Solution Annealed, Cold-Worked and Aged	1373 K, 1 h + 20% Cold Rolled + 873 K, 20 h

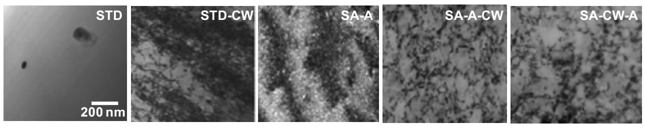

Fig. 1 Microstructure of V-4Cr-4Ti subjected to five thermal and mechanical treatments as defined in Table 1.

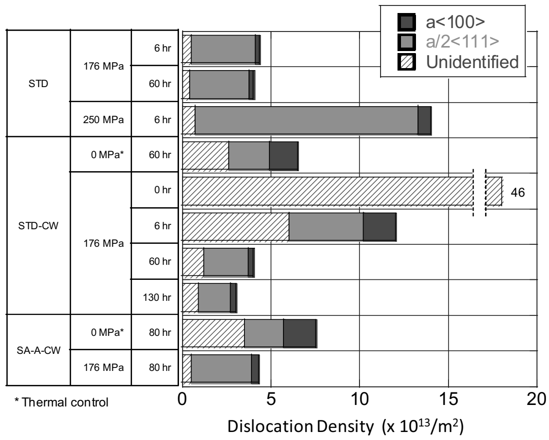

Fig. 2 Summary of quantitative dislocation density data for a<100> and a/2<111> types. Fraction of unidentified dislocations were high in cold-worked specimens because g x b = 0 analyses were difficult owing to high dislocation density and residual internal strain.