

Activation volume of martensitic ODS steel

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1. Introduction

Nano-sized oxide dispersion strengthened (ODS) martensitic steel has a high strength, low thermal expansion coefficient, high thermal conductivity, and a good swelling resistance. Martensitic ODS steel is a candidate material for fuel cladding of sodium cooled fast breeder reactor (SFR). Tensile strength and elongation of martensitic ODS steel decrease with the increase of temperature and the decrease of strain rate.

The plastic flow stress is determined through the interaction of dislocations with the obstacles encountered inside lattice. Dislocation movement through the lattice or past an obstacle requires surmounting of the energy barrier by a combination of applied stress and thermal activation. The plastic deformation of materials is a thermally activated process dependent upon time, temperature, and strain rate. Characterization of the rate controlling mechanism for plastic deformation due to dislocation motion in crystalline materials is done by the assessment of activation volume based on thermal activation analysis.

Among various experimental techniques to identify the true deformation mechanisms operative in a steel under a given applied condition, transient tests consisting of repeated stress relaxation and strain rate jump have been shown to yield reliable information about dislocation mobility in terms of activation volume. In this study, activation volume as a function of temperature and strain rate is evaluated for the plastic deformation of martensitic ODS steel.

2. Experimental procedure

Martensitic ODS steel was fabricated by mechanical alloying (MA) and hot isostatic pressing (HIP). Metallic powders and Y₂O₃ were mechanical alloyed by horizontal ball mill machine (Model CM-08) in high purity Ar (purity of 99.999%) environment. Mechanical alloying was performed at 240 rpm for 40 h. Ball to powder weight ratio (BPWR) was 10:1. MA powder was charged in S45C steel capsule and sealed. The sealed capsule was degassed at 400°C/3 h in <10⁻⁵ torr. The capsule was extruded after HIPping at 1100°C for 2h. Annealing temperature was 1100°C/1h and tempering temperature was 750°C/30 min. Chemical composition of ODS steel is shown in Table 1.

Sheet type specimen with 25 mm gage length, 3.7 mm width, and 1 mm thickness was machined for tensile test. Strain rate jump tests were carried out under displacement control at the temperature range of RT-

700°C with strain rate of 2x10⁻⁴/s-2x10⁻³/s and 5x10⁻⁶/s-2x10⁻³/s. Relaxation tests were conducted under displacement control at the temperature range of RT-500°C and load was relaxed during 30 second at a predetermined load.

Table 1. Chemical composition of ODS steel (wt%).

C	Cr	Mo	Ti	Zr	Y ₂ O ₃
0.13	9.61	1.11	0.23	0.05	0.34

2. Activation volume analysis

Mathematical formula of the apparent activation volume analysis is described as [1]

$$\Delta\tau = -\left(\frac{kT}{V_a}\right) \ln\left(1 + \frac{t}{C_r}\right)$$

Where V_a is apparent activation volume, Δτ is variation of shear stress, t is time, k is Boltzmann constant, T is the absolute temperature, C_r is the time constant.

In single stress relaxation, the apparent activation volume can be determined by fitting the stress relaxation curve.

The physical activation volume, V*, is defined as

$$V^* = kT \frac{\ln\left(\frac{\dot{\gamma}_{i2}}{\dot{\gamma}_{f1}}\right)}{\Delta\tau}$$

Where γ_{i2} and γ_{f1} are shear strain rate at onset of relaxation 2 and at the end of relaxation 1. V* can be determined by tensile tests changing strain rate.

V* is different from the apparent V_a. V* characterizes the stress sensitivity of dislocation velocity and is related with the dislocation processes that are rate-dependent, while the V_a incorporates the influence of mobile dislocation density.

Strain rate sensitivity is calculated according to

$$m = \frac{\partial \ln \sigma}{\partial \ln \dot{\epsilon}}$$

σ is flow stress, ε is strain rate.

3. Results and Discussion

Activation volumes of V* and V_a as a function of temperature are shown in Fig. 1. Activation volume

decreased with increasing temperature. V^* was scarcely changed with decreasing strain rate. V_a was higher than V^* .

Physical activation volume as a function of temperature was $69b^3-18b^3$ at $2 \times 10^{-4}/s-2 \times 10^{-3}/s$ strain rate change tests and $89b^3-19b^3$ at $5 \times 10^{-6}/s-2 \times 10^{-3}/s$ strain rate change tests. Apparent activation volume as a function of temperature was $86b^3-42b^3$. In general, the rate process involving cross slip can lead to activation volume between $1b^3$ and $100b^3$ [2].

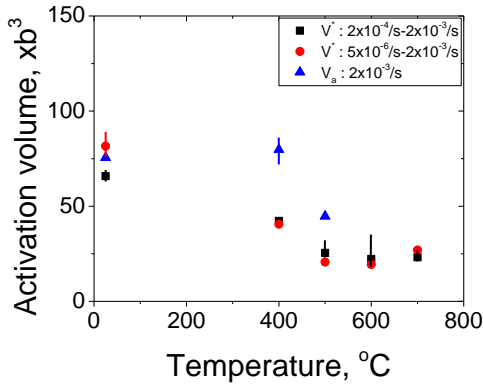


Fig. 1. Activation volume as a function of temperature and strain rate. (b is Burgers vector)

Pole figures as a function of temperature and strain rate are shown in Fig. 2. Slip systems distribution mode of $(110)\langle 111 \rangle$ and $(112)\langle 111 \rangle$ were scarcely changed as temperature increased and strain rate decreased.

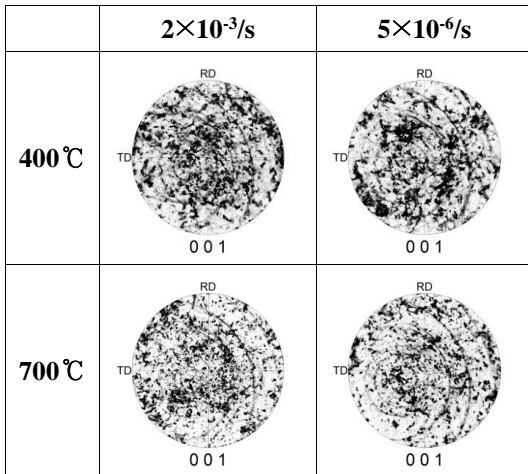


Fig. 2. Pole figures as a function of temperature and strain rate.

Strain rate sensitivity as a function of temperature and strain rate is shown in Fig. 3. Strain rate sensitivity increased with decreasing strain rate and increasing temperature.

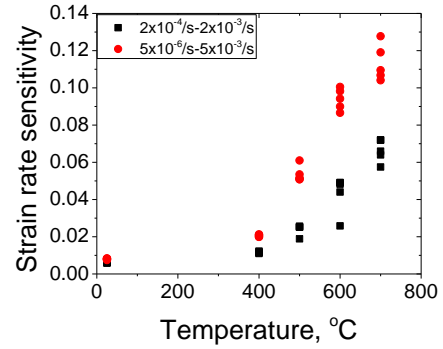


Fig. 3. Strain rate sensitivity as a function of temperature and strain rate.

4. Conclusions

Physical activation volume as a function of temperature is $69b^3-18b^3$ at $2 \times 10^{-4}/s-2 \times 10^{-3}/s$ strain rate change tests and $89b^3-19b^3$ at $5 \times 10^{-6}/s-2 \times 10^{-3}/s$ strain rate change tests. Apparent activation volume as a function of temperature is $86b^3-42b^3$. Activation volume decreases with increasing temperature. Activation volume changes scarcely with decreasing strain rate. Strain rate sensitivity increases with increasing temperature and decreasing strain rate.

REFERENCES

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- [2] A.G. Evans and R.D. Rawlings, Phys. Stat. sol. Vol. 34, pp. 9-31, 1969.