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Neutron irradiation hardening of ODS alloy tested by miniature disk bend test method

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Abstract

This paper briefly describes neutron irradiation hardening of an oxide dispersion strengthened (ODS) alloy tested by a miniature disk bend test (MDBT) method. After neutron irradiation to 1.73×10^{19} n/cm^2 at 290°C, the yield strength and the ultimate tensile strength of the material increased but the uniform elongation decreased. The MDBT method is available to estimate mechanical properties of materials. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

The miniature disk bend test (MDBT) method, with a specimen 3 mm in diameter and 0.3 mm in thickness, was developed and modified recently [1,2]. There are some advantages to performing mechanical properties using small specimens. In a reactor or an accelerator, for instance, it may be necessary to decrease specimen volume to reduce the dose from radioactive specimens. Simultaneously, if the material structure and properties are not destroyed while sampling, the method can also be used in other fields, such as welding lines, composite materials, ceramics, etc. oxide dispersion strengthened (ODS) stainless steels with low swelling and high strength properties are possible candidate materials for the first wall of a fusion reactor and fuel cladding of a fast breeder reactor. The focus of this paper is to examine the irradiation hardening of an ODS alloy irradiated to a low neutron dose with the MDBT method.

2. Experimental procedure

2.1. Experimental material

The ODS alloy used in this experiment was made by a complicated technique. Fig. 1 shows the flow chart for producing this ODS alloy. Table 1 gives its chemical composition. Original powders were mixed together by mechanical alloying (MA) under an argon atmosphere, and then thermal-extruded and rolled into rods after canistering and degassing. Finally, it was annealed for 2 h at 1400°C in vacuum and 0.35 mm thick slices were cut from annealed ODS rods, then polished to 0.3 mm thick. Specimens used for mechanical property tests were extruded into 3 mm in diameter disks. TEM investigation shows complex oxide ($Y_2Ti_2O_7$) particles are well distributed in the alloy base, with sizes less than 10 nm.

2.2. Miniature disk bend test method

Mechanical property tests were carried out on a MDBT apparatus [3] at room temperature. Fig. 2 gives a schematic illustration of loading. Strength and ductility of materials can be calculated by a central load–deflection curve. The MDBT method is based on the elastic–plastic bulge deformation principle of a medium-thick plate. It assumes that the fringe of a plate is fixed and the center of the plate is loaded. If the maximum central deflection is less than four times the plate

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Table 1
Chemical composition of ODS alloy (in wt%)

Cr	W	Ti	Y_2O_3	O	C	Fe
13.39	1.97	0.55	0.28	0.24	0.007	Bal.

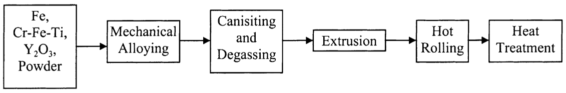

Fig. 1. Flow chart for producing ODS alloy.

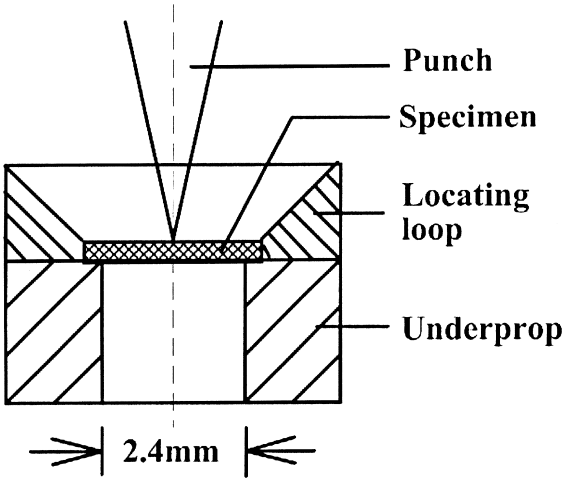

Fig. 2. Schematic illustration of loading.

thickness, and the plate thickness is about one-tenth of the diameter of the plate, the yield strength of the material, σ_Y, can be represented as [3]

$$\sigma_Y = 0.477 P_Y / h^2, \tag{1}$$

the ultimate tensile strength, σ_b, can be represented as

$$\sigma_b = \sigma_t e^{-\varepsilon t} \tag{2}$$

and the uniform elongation, δ_u, can be represented as

$$\delta_u = e^{-\varepsilon t} - 1, \tag{3}$$

where P_Y is the yield load determined by the method illustrated in Fig. 3, h is the thickness of plate, σ_t is the true stress, and ε_t is the true strain. σ_t and ε_t can be calculated with the central load–deflection curve by the method of Ref. [4]. Eq. (1) shows that the yield strength of the material is inversely proportional to the square of the plate thickness. Therefore, it is important to accurately measure the thickness for calculating yield strength precisely.

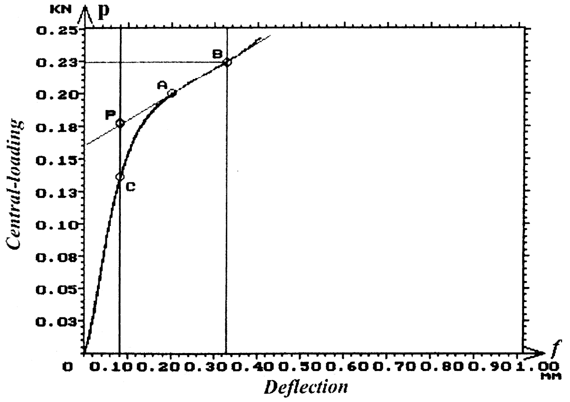

Fig. 3. Experimental central load–deflection curve coming from MDBT and illustrations to determine yield load and to locate points giving values of P and f for calculating σ_b and δ_u.

2.3. Neutron irradiation experiment

ODS disk specimens were irradiated by neutrons in a light water experimental reactor in China. Neutron energy was more than 1 MeV. Irradiation temperature was maintained at 290°C. The neutron flux was 1.11×10^{13} n/cm^2/s, and the fluence was 1.73×10^{19} n/cm^2.

3. Experimental results and discussion

3.1. Mechanical properties of unirradiated and irradiated ODS alloy

For unirradiated ODS alloy, the uniaxial yield strength was 848 MPa, the ultimate tensile strength was 980 MPa, and the total elongation was 17.5%. Table 2 shows the experimental results using the MDBT method. It indicates that the unirradiated ODS alloy has good strength properties and modest ductility. In comparison to the results of tensile tests, the yield and ultimate tensile strengths of the ODS alloy tested by the MDBT method are lower by 1.1% and 7.2%, respectively. Hence within this error range, it is possible to estimate mechanical properties of materials with the MDBT method instead of uniaxial tension tests. Generally, material fracture does not occur with the MDBT method, in order to meet the condition that the maximum central deflection is less than four times the disk thickness. Therefore, it should only be used to obtain the uniform elongation δ_u.

Table 2
Mechanical properties of ODS alloy tested by the MDBT method[a]

Specimens No.	σ_Y (MPa)		σ_b (MPa)		δ_u (%)	
	Unirrad.	Irrad.	Unirrad.	Irrad.	Unirrad.	Irrad.
1	828	888	875	928	4.7	4.1
2	837	898	885	936	5.0	3.9
3	828	888	890	931	5.3	3.7
4	859	884	874	940	3.7	5.2
5	833	867	911	929	6.0	5.0
6	856	867	956	935	4.2	5.4
7	839	898	912	970	5.9	5.0
8	866	883	918	935	5.0	4.6
9	805	893	906	942	6.9	4.5
Mean	839	885	900	938	5.2	4.6
S.D.	±19	±11	±19	±13	±0.92	±0.6
Relative S.D.	±2.3%	±1.3%	±2.1%	±1.4%	±18%	±13%

[a] δ_u is the uniform elongation.

3.2. Mechanical property changes after neutron irradiation

Table 3 shows that the yield strength and the ultimate tensile strength of the irradiated specimens increased by 5.5% and 4.2%, respectively, and uniform elongation decreased by 12% after neutron irradiation to 1.73×10^{19} n/cm^2 at 290°C. In general, there are few dislocations in the original ODS alloy annealed at high temperature. In the course of neutron irradiation, vacancies, vacancy clusters, dislocations and dislocation networks form in the crystal. These defects hinder further dislocation movement. Additionally, dislocation movement would be hindered by the small dispersed oxides or precipitates in the crystal. This creates a strong barrier to the plastic deformation of the material. Thus, material strength is improved but the ductility is decreased.

For the MDBT method, test results of irradiated and unirradiated specimens show that experimental data are reproducible (Table 2). The test results indicate the relative standard deviation is, in general, less than 3% for the yield strength and the ultimate tensile strength, but it is much larger for the uniform elongation. Although the level of neutron irradiation damage is not high, about 8.6×10^{-3} dpa, the changes of strength and ductility resulting from irradiation were detectable by the MDBT method. This shows that the MDBT method is sensitive to mechanical properties and their changes. Mechanical properties of materials can be approximately estimated using the MDBT method.

Table 3
Mechanical property changes after irradiation determined by the MDBT method

	σ_Y (MPa)	σ_b (MPa)	δ_u (%)
Unirrad.	839	900	5.2
Irrad.	885	938	4.6
Change	+46	+38	−0.6
Relative change	+5.5%	+4.2%	−12%

4. Summary and conclusion

After 1.73×10^{19} n/cm^2 neutron irradiation at 290°C, the yield strength and the ultimate tensile strength of irradiated specimens increased by 5.5% and 4.2%, respectively, and the uniform elongation decreased by 12%. After irradiation, the ODS alloy was found to have higher yield strength and lower ductility.

For the MDBT method, in general, the standard deviation is less than 3% for strength, but it is much larger for uniform elongation. Within an error range, it is possible to approximately estimate mechanical properties of materials using the MDBT method.

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