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Fatigue properties and characterization of tungsten heavy alloys IT180 & D176

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ABSTRACT

Fatigue properties of tungsten heavy alloys IT180 (W-3.5Ni-1.5wt.%Cu) and D176 (W-5Ni-2.5wt.%Fe) have been determined using constant amplitude, stress-controlled high cycle fatigue tests at room temperature. The results show that the endurance limits for the IT180 and D176 alloys are about 210 and 425 MPa respectively. The fatigue strength coefficients for the two alloys have been determined as 1048 and 3000 MPa and the corresponding strength exponents are −0.11 and −0.13 respectively. Strain-controlled fatigue tests were also performed to observe the response of the materials and determine the cyclic stress–strain curves of the alloys using the multiple step method. Cyclic hardening was observed in both alloys and the cyclic strain hardening exponent for the D176 alloy had a value of 0.08. The fatigue response of the material is strongly affected by surface roughness, residual porosity, pore size and its distribution. Microstructures and the fracture surfaces of the samples were characterized by scanning electron microscopy and energy dispersive spectroscopy.

1. Introduction

European Spallation Source (ESS) is a joint European project to build a large-scale research facility to produce neutrons for materials characterization through scattering experiments. In the spallation process, neutrons are produced by bombarding a target with high-energy protons. Currently the ESS is in the pre-construction phase and a decision has been taken to use tungsten as the target material after investigating other potential target materials including tungsten heavy alloys. High power targets have to withstand a large average beam power varying in space and time which induces a combined load of high radiation damage and large temperature gradients, leading to cyclic thermal stresses in the target material. This study deals with the determination of fatigue properties of some tungsten heavy alloys at room temperature.

2. Materials and methods

In the present work, mechanical properties (tensile and fatigue) of two different tungsten heavy alloys, IT180 (W-3.5Ni-1.5wt.%Cu) and D176 (W-5Ni-2.5wt.%Fe) have been determined at room temperature, after microstructural characterization of the alloys. These powder metallurgical products were supplied by Plansee and were presumably liquid-phase sintered. For purposes of testing, 13 specimens of IT180 and 10 specimens of D176 were used in this study. The specimen geometry is shown in Fig. 1.

The specimens presented considerable surface roughness in the as-received condition and were ground using silicon carbide papers in the sequence 320, 500, 1000 and 4000 particles per square inch, followed by polishing with 3 μm and 1 μm diamond suspensions. The average specimen diameter after the polishing treatment was 4.99 ± 0.01 mm. The specimens were stored in a desiccator prior to testing.

The mechanical testing was performed at room temperature in a MTS Ramen machine controlled by a Digital Electronic system (Instron). Tensile testing was performed at a constant displacement rate of 0.05 mm/s. At a frequency of 30 Hz, stress controlled fatigue testing under fully reversed loading conditions (i.e. stress ratio $R_\sigma = -1$) was carried out to obtain median Wöhler S–N curves and design curves within the relatively high cycle fatigue region $10^4 < N < 10^6$, with N denoting the number of cycles to failure. The curves were obtained using applied statistical methods suggested in the ASTM standard practice E739 [1]. IT180 specimens were tested in the stress interval 200 to 300 MPa, while the D176 specimens were subjected to stresses in the interval 300 to 550 MPa. A minimum of two tests were performed at each stress level.

Strain controlled fatigue testing was also performed to obtain the cyclic stress–strain curves and determine the degree of hardening of the materials. The curves were obtained by testing a solitary specimen of each alloy using the Multiple Step Test method (MST) [2,3] at a strain ratio (R_ε) of −1 and a constant displacement rate of 0.05 mm/s. This was obtained by varying the frequency in each block of successively increasing constant total strain amplitude. For the IT180 alloy, the strain amplitudes used were 0.1 and 0.2%. For the D176 alloy, an amplitude sequence between 0.2 and 1%, in steps of 0.1%, was used.

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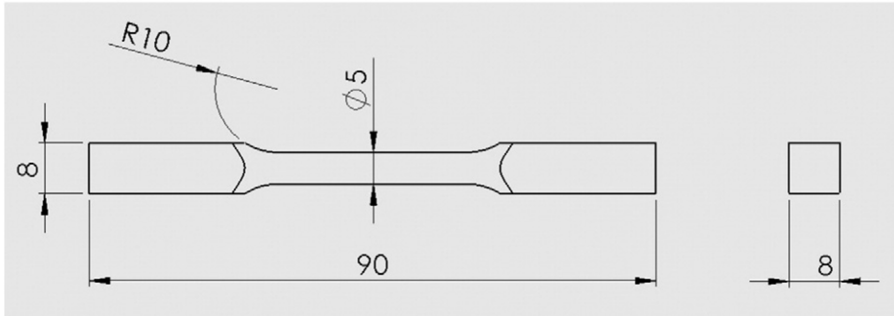

Fig. 1. Specimen geometry (dimensions in mm).

In order to get an idea about the porosities in the samples, densities of the alloy specimens were determined using the Archimedes principle. An attempt was also made to characterize the distribution of porosity along the axial direction in the specimens using recommended procedures [4,5]. This was done with a view to relate crack initiation sites to porosity content in the specimens.

The microstructures of the alloys were examined using optical and Scanning Electron Microscopy (SEM). The phase compositions were determined using Energy Dispersive Spectroscopy (EDS).

3. Results and discussion

3.1. Mechanical properties

3.1.1. Tensile testing

Each alloy (one specimen) was tested in tension according to ASTM practice E8 [6] and the stress–strain curves obtained are shown in Figs. 2 and 3. Data on the yield strength ($R_{p0.2}$), ultimate tensile strength (R_m), fracture strain (ε_f) and the Young's modulus (E) are summarized in Table 1. For purposes of comparison, data provided by Plansee are also included in the table. The differences observed between the results obtained in the present study and those provided by Plansee could be due to variations in porosity levels and the extent of cold work in the specimens tested. It is also seen that the yield strengths as well as the Young's moduli do not vary much between the alloys. Unlike the elastic properties, there are significant differences in the ultimate tensile strengths and ductilities of the two alloys. This is primarily due to the higher amount of tungsten contained in IT180.

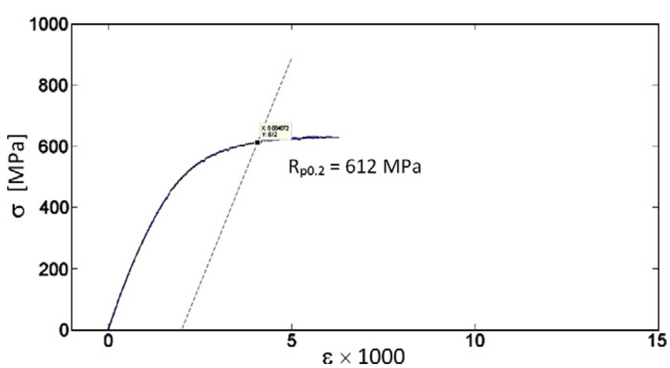

Fig. 2. Stress–strain diagram for IT180 alloy.

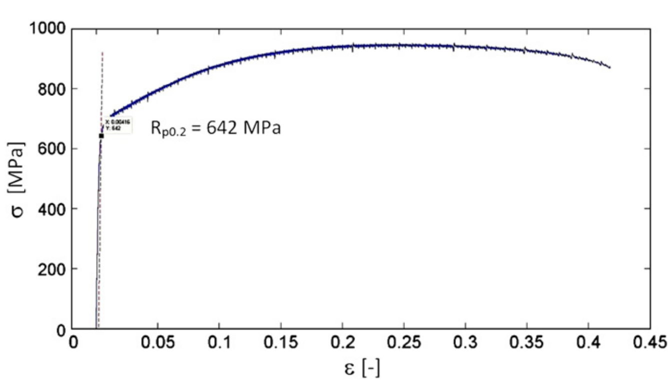

Fig. 3. Stress–strain diagram for D176 alloy.

3.1.2. Stress-controlled fatigue experiments

Fatigue experiments were carried out under stress control using 11 specimens of IT180 and 8 specimens of D176. In these experiments, the procedure recommended by ASTM practice E466 [7] was followed. The first test was carried out at a stress level of 50% of the ultimate tensile strength and the following stress levels were chosen either higher or lower than this value depending on whether the specimen had failed or not. As the focus in the present study was on a fatigue life in the interval 10^4 to 10^6 cycles, a specimen enduring 2×10^6 cycles was considered a run-out and the test was interrupted. For other stress levels at which the specimens failed, a minimum of two tests were performed.

Table 1
Tensile properties of IT180 and D176 alloys.

Mechanical property	IT180		D176	
	Present work	Plansee	Present work	Plansee
$R_{p0.2}$ [MPa]	612	610	642	620
R_m [MPa]	631	685	945	880
ε_f [%]	0.6	3	42	20
E [GPa]	308	360	309	360

Table 2
Stress-controlled fatigue data for IT180 alloy.

Specimen #	σ_a [MPa]	d [mm]	N [cycles]
3	300	4.99	33,831
4	300	4.99	40,177
5	200	4.98	[a]6×10^6
6	200	4.98	2×10^6
7	250	4.98	139,854
8	225	4,98	336,042
9	210	4.99	312,378
10	210	4.99	2×10^6
11	210	4.99	1.63×10^6
12	250	5.00	329,748
13	225	5.00	424,545

[a] Experiment was continued up to this limit (only for #5).