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Journal of Nuclear Materials 343 (2005) 184–190
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Mechanical properties and microstructure of $AlMg_3$ irradiated in SINQ Target-3

Y. Dai *, D. Hamaguchi

Spallation Neutron Source Division, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Abstract

An aluminum alloy $AlMg_3$ has been used as the material for safety-hulls of SINQ targets. In the present work, the mechanical properties and microstructure of the material from the beam window of the safety-hull of SINQ Target-3 has been investigated. The tensile test results indicate that both yield stress and ultimate tensile strength increased significantly after irradiation. Meanwhile, for the specimens from the beam centre area irradiated to about 3.6 dpa, their ductility reduced substantially. However, these specimens broke in a ductile fracture mode. TEM observations show that the irradiation induced high-density dislocation loops and helium bubbles. The bubbles locate preferentially at dislocations and grain boundaries. The bubbles at grain boundaries are much larger than those in grain interior. The presence of high-density bubbles may enhance both irradiation hardening and embrittlement effects.

1. Introduction

Due to their high thermal conductivity, low absorption of thermal neutrons, and more important, excellent radiation damage resistance, aluminum–magnesium alloys are widely engaged in nuclear applications. In the Swiss Spallation Neutron Source (SINQ), an aluminum–magnesium alloy, $AlMg_3$ (close to Al-5454), has been used for the safety-hulls of the targets, which receive intensive irradiation damage induced by high energy protons and spallation neutrons, particularly at the proton beam entrance window [1]. Up-to-date four targets have been successfully operated in SINQ during the last seven years. For a safe operation of SINQ targets, it is of essential importance to investigate the changes in the mechanical properties and microstructure of this material after irradiation. Meanwhile, for developing new spallation sources where Al-alloys are considered as tentative beam window materials, it needs urgently the basic understanding of the behavior of these alloys in spallation radiation environments. Therefore, tensile tests and transmission electron microscopy (TEM) investigations have been performed on the safety-hull of Target-3 irradiated in 1998 and 1999. The microstructure of the material in both irradiated and unirradiated conditions has been studied and reported in detail elsewhere [2]. In the present paper, the results of the microstructure will be briefly described and the irradiation induced changes of mechanical properties will be reported and discussed based on the results of the microstructure study.

2. Experimental

The composition of the $AlMg_3$ alloy is in wt%: 2.72Mg, 0.3Si, 0.25Fe, 0.35Mn and balanced by Al.

* Corresponding author. Tel.: +41 56 310 4171; fax: +41 56 310 4529.
E-mail address: yong.dai@psi.ch (Y. Dai).

0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2004.11.021

The original material was in form of cylinders of about 230 mm in diameter and about 150 mm long. The heat treatment was not given by the producer. However, the microstructure and the yield stress of the as-received material indicate that it should be in an annealed condition. From the cylinders, hemisphere walls of the windows were milled. As illustrated schematically in Fig. 1, the safety-hull is a double walled container of about 200 mm in diameter and about 2 m long from the bottom of the beam entrance window to the upper flange. The thickness of the walls is 4 mm in the straight part, and changes gradually from 4 mm to 2 mm at the bottom of the beam window. There is a gap of 2–3 mm (depending on the position) between the two walls. Cooling water (D_2O) of about 40 °C runs through the gap and inside to cool the hull and the target block during irradiation. The outer surface of the outer wall faces to vacuum. However, the irradiation temperature of the outer wall is only a few degrees higher than that of the inner wall with a maximum value less than 60 °C [3].

SINQ Target-3 received a total proton charge of 6.8 A h and with a peak fluence of about $3.2 \times 10^{25}\ m^{-2}$ at the beam window of the safety-hull. The energy of the proton beam was about 570 MeV. The irradiation dose, helium and hydrogen concentrations at the peak fluence position are about 3.6 dpa, 1125 appm He and 1900 appm H, respectively [4,5]. After irradiation, discs of 40 mm in diameter were cut from the centre and edge areas of the beam footprint (Fig. 2) for post-irradiation examinations.

In order to determine the profile of the proton beam, γ-mapping was performed on the discs. Fig. 3 shows an example of the results of the disc from the centre area of the window. It can be seen that the proton beam has an elliptical profile. However, it is impossible to deduce the complete profile of the proton beam from the γ-mapping results because the size of the discs is too small. Hence, the proton fluence was still calculated from the known proton beam geometry [4].

After γ-mapping, tensile specimens with a size of 20 × 5 mm and a gauge area of 7 × 2.5 mm were cut from the discs. The tensile specimens were polished on both sides to remove the curvature, which resulted in a final thickness of about 1.4 mm. Four specimens were cut from each disc, see Fig. 4. From each of the two discs in the beam central area, two specimens were cut symmetrically to the long axis of the beam profile.

Tensile tests were performed at room temperature on a 2 kN MTS mechanical testing machine. Five irradiated specimens of doses 0.7, 2.7, 3.2 and 3.6 dpa were tested. For comparison, a few specimens were prepared in the

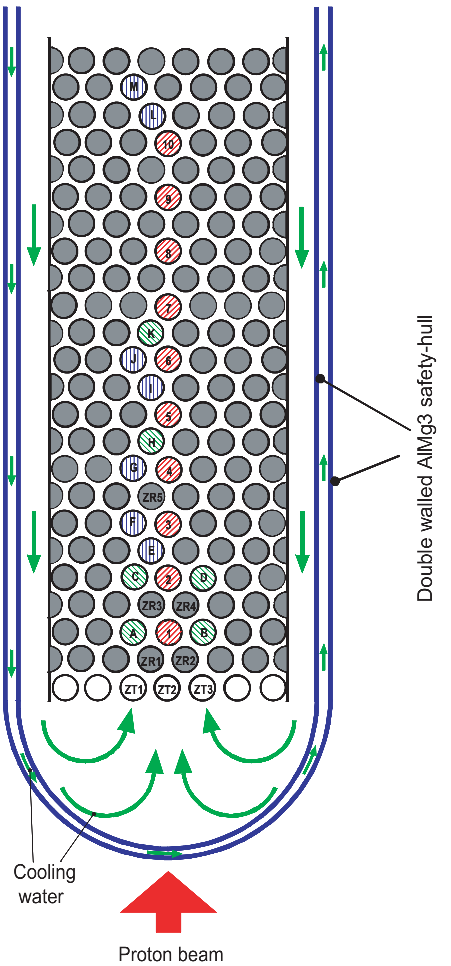

Fig. 1. A schematic sketch showing the lower part of SINQ Target-3.

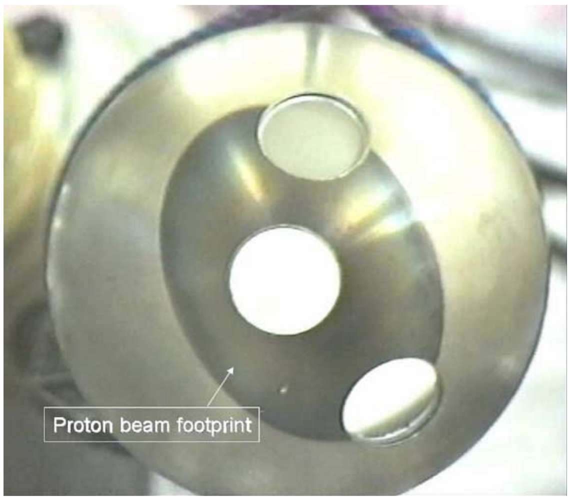

Fig. 2. A picture showing the beam window of the safety-hull of SINQ Target-3 after cutting discs (40 mm in diameter) at three positions.