Effect of Titanium on the Void Swelling Behavior in (15Ni-14Cr)-Ti modified Austenitic Steels Studied by Ion Beam Simulation

EXECUTIVE SUMMARY

One of the important property changes caused by irradiation in the reactor structural materials is void swelling, which introduces dimensional changes and thereby limits the lifetime of structural components used in a reactor. Ion simulation of void swelling in D9 alloy (Ti-modified austenitic steel) has been carried out using the heavy ion beam from the 1.7 MV Tandetron Accelerator. D9 alloy is the candidate material for clad and wrapper in the prototype fast breeder reactor (PFBR). Using heavy ion irradiation, displacement damage ~ 100 dpa can be obtained over a short period of few hours and rapid screening of alloys with regard to their irradiation behavior, specifically effect of minor alloying elements in void swelling can be carried out. The study clearly demonstrated the role of Ti concentration in the void swelling behavior of the alloy.

OUTLINE

The dimensional changes introduced by void swelling limits the lifetime of structural components used in a reactor. Therefore, resistance to void swelling is a major consideration in the choice of materials for the core components. The titanium modified steels exhibit greatly improved swelling resistance under breeder reactor conditions and consequently, have become prime candidates for structural applications. Titanium modified (15Ni, 14Cr) steel and its improved versions with phosphorous additions (designated as D9 and D9I) are envisaged for use as fuel cladding and wrapper materials in Indian Fast Breeder Reactor (FBR) programme. At IGCAR Kalpakkam there is a strong programme for the simulation of radiation effects in reactor structural materials using ion beams and modeling of radiation damage. The minor alloying elements like Ti strongly influence the void swelling resistance of austenitic steels. In the cold worked Ti modified austenitic stainless steels, the formation of fine stable precipitates of TiC termed as secondary precipitates has been reported to enhance the void swelling resistance. Fine precipitates of TiC are strong neutral sinks for vacancies and interstitials and hence act as seats for increased recombination of vacancies and interstitials. This increase in recombination reduces the swelling in these alloys. The void swelling behavior of (15Ni-14Cr)-0.25Ti and (15Ni-14Cr)-0.15Ti steels are studied using heavy ion irradiation for understanding the influence of titanium in the void swelling resistance of the alloys(Fig.1). The cold worked samples have been pre-implanted with a uniform helium concentration of 30 ppm spanning a width of about 640 nm. This was followed by a 5 MeV nickel ion irradiation to create a peak damage of ~ 100 dpa at damage rate of 7×10^{-3} dpa/s at various irradiation temperatures between 700 and 970 K. The gross swelling in the implanted range is measured by step height measurements. It is found that the peak swelling temperatures and the magnitude of swelling for the alloys are different. The swelling at the peak swelling temperature of the alloys with 0.25% of titanium and 0.15% of titanium are found to be ~4% and ~15% respectively.

In order to understand the drastically different behaviour of the two alloys with regard to void swelling, the TiC precipitate formation in these two alloys was studied by positron lifetime measurements. The un-irradiated alloys were subjected to isochronal annealing and the positron life time was measured after each annealing. These alloys show different TiC precipitate formation behavior (Fig.2). The observed variation of lifetime τ displays distinct stages viz., a monotonic decrease in τ from the initial cold worked state upto ~900 K in sample B and ~ 800 K in sample A. This is followed by a stage where there is an increase in lifetime to saturation, followed by a decrease in lifetime. The first stage corresponds to point defect recovery. This is explained by the migration of vacancies to sinks such as cold worked dislocations resulting in the annihilation of dislocations. The subsequent stage where there is an increase in lifetime τ is the result of positron trapping by the TiC precipitate-which forms during the heat treatment. The increase in average lifetime of positrons trapped in the sample A in comparison to sample B is due to the higher number density of TiC precipitates formed in the former. The difference in void swelling behavior in these two alloys with titanium variation is discussed on the basis of the role of titanium on the vacancy migration and TiC precipitate formation.

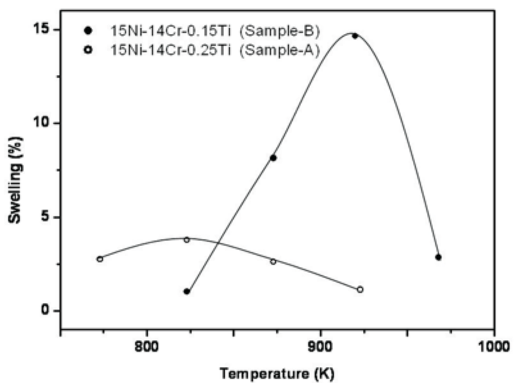

Fig. 1 : Temperature dependence of void swelling measured by surface profilometry for the D9 alloys

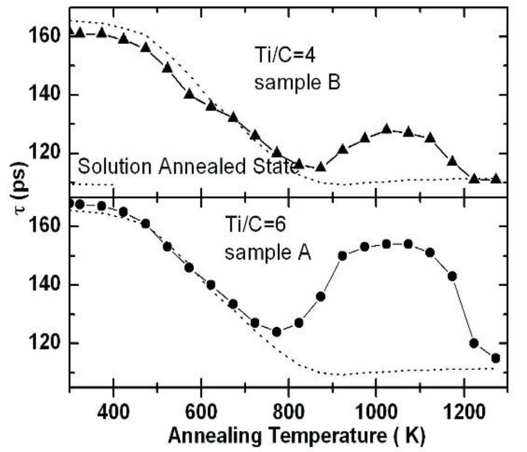

Fig. 2 : Variation of positron life time with annealing temperature for the cold - worked D9 alloys with different titanium concentration,
sample A (Ti / C = 6) and sample B (Ti / C = 4)

■ ADDITIONAL INFORMATION ABOUT VOID SWELLING

The term void swelling is used to refer to the increase in volume of metals and alloys exposed to fast neutron bombardment at elevated temperature. The fast neutron irradiation gives rise to the displacement of atoms from their regular lattice positions, giving rise to the formation of point defects. The vacant lattice positions created by the displacement of atoms are called vacancies. The vacancies are mobile at elevated temperatures and cluster to form three dimensional clusters called voids. The nucleation of voids is aided by the presence of helium atoms formed by nuclear transmutation (n,α) reactions.

■ HEAVY ION SIMULATION OF VOID SWELLING

The impact of energetic ion beams gives rise to the displacements of lattice atoms from their equilibrium positions and consequently defects are generated. Due to high differential cross section for transfer of energy to the lattice, energetic charged particles (e.g., heavy ions) displace atoms in materials with much faster rate than the fast neutrons. Figure 3 gives a comparison of the rate of displacement damage production by different projectiles. Using heavy ion irradiation, displacement damage ~ 100 dpa can be obtained over a short period of few hours. The effect of helium produced by (n,α) reactions can be simulated in accelerator experiments by pre implanting appropriate concentration of helium in the sample. Ion simulation allows rapid screening of alloys with regard to their irradiation behavior. For the development of better swelling resistant D9 alloy, one needs to optimize composition of minor alloying elements like P, Si, Ti, etc., which have a major influence on the swelling. Therefore the alloy development program is in need of a test bed where one can study the effect of minor elements on swelling of the model alloys, which are exposed to high displacement damage levels. Accelerated heavy ions, which possess an inherent advantage of producing high displacement rates, have been used for evaluating the effect of minor element on swelling and for basic studies in radiation damage Through ion simulation it is possible to optimize the composition of minor alloying elements with respect to void swelling.

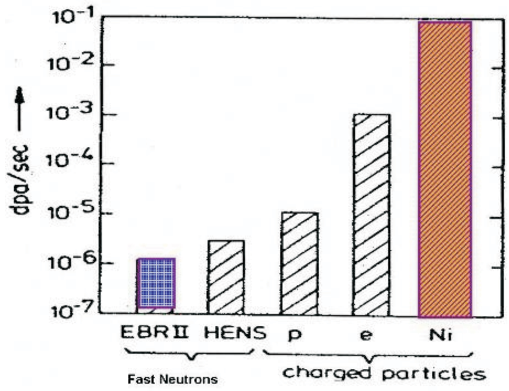

Fig. 3 : The defect production rate by different projectiles (Ion beams produce displacement damage at a much faster rate than neutrons

■ ROLE OF MINOR ALLOYING ELEMENTS IN VOID SWELLING

Minor Alloying elements like Si, Ti, P, are often added to of austenitic stainless steels to improve their swelling resistance. Some of the minor alloying additions influence the void swelling behavior through the formation of fine precipitates (TiC) which act as recombination centre for defects. The minor alloying elements also substantially modify the defect mobility.

■ ACHIEVEMENT

Accelerator irradiation has been used to probe the effect of titanium concentration in the void swelling behavior of D9 alloy. The temperature dependent void swelling in two alloys with differing Ti content has been understood in terms of TiC precipitation and the role of titanium in altering the vacancy mobility.

■ PUBLICATIONS ARISING OUT OF THIS STUDY AND RELATED WORK

Christopher David, B.K. Panigrahi, R. Rajaraman, S. Balaji, A.K. Balamurugan, K.G.M. Nair, G. Amarendra, C.S. Sundar and Baldev Raj, *J. Nucl. Mater.* (In Press)

Further inquiries:
Dr. B. K. Panigrahi and Dr. K. G. M. Nair, Materials Science Division
Metallurgy and Materials Group, IGCAR, e-mail: bkp@igcar.gov.in; kgmn@igcar.gov.in