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Material Development for Spallation Target at JAERI

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1. Introduction

The development of spallation target system for the Neutron Science Project is proceeding at Japan Atomic Energy Research Institute (JAERI). The materials subjected to pulsed pressure waves, intensive radiation damage, corrosion/erosion and mechanical strength are to be evaluated in order to assess the applicability of the target assembly[1].

- Thermal shock tests have been performed to evaluate the integrity of the container. In the ASTE (AGS Spallation Target Experiment) collaboration programme pressure wave has been measured.

- Radiation damage and irradiation data at high dose have been accumulated at HFIR through JAERI/ORNL collaboration for fusion project[2]. Furthermore a high dose, high He/dpa and high H/dpa will be necessary in order to know the effect of irradiation on the mechanical properties of the container material under spallation condition. SINQ in PSI will provide the useful irradiation data for the candidate materials. JAERI will participate post-irradiation tests.

Other irradiation tests have been done by using triple beams at TIARA (Takasaki Ion Accelerator for Advanced Radiation Application)[3] in JAERI.

- The factors of the corrosion/erosion for materials in the mercury environment have not been clear and only allows engineering works tentatively as a case study. Mechanical tests; tensile, fatigue and fracture toughness tests, are to be conducted under the mercury environment.

2. Stress wave in the solid disk

The thermal shock test has been done in order to know the stress waves in the solid. Fig.1 illustrates the test apparatus. The test equipment consists of the laser source, specimen disk, a dynamic strain amplifier and a wave memory. The laser source is ruby at a wave length of 694.3nm. The maximum energy emitted from this source is 1.0 J per pulse and the pulse duration is about 50ns. The beam profile is roughly rectangular distribution with a circle projectile at the beam diameter of 10mm. The one surface of disk specimen will be heated up and the dynamic response of the specimen will be measured by means of strain gage and/or the laser Doppler probe at the back surface of the disk.

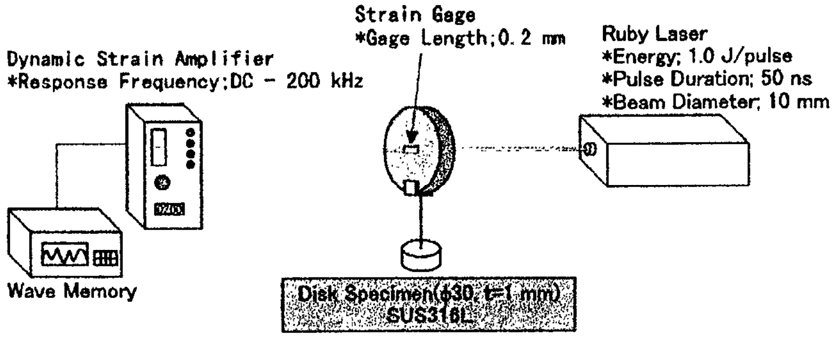

Fig. 1 Schematic drawing of test apparatus.

Fig. 2 shows the results of stress wave measurement for the type 316L stainless steel. After 2 μs from the laser exposure the maximum strain was induced to the centre of the disk. The calculation was done by using the structural analyses code ABAQUS under the input condition: the absorption ratio of the ruby laser to the material is 40 %, the heat deposition depth is 50 μm. The calculation results possibly follow the experimental results. Fig.3 shows the calculation of the thermal conduction to the depth direction in unsteady state. The maximum temperature is estimated to be 50.5°C at a time of 50 ns and then the temperature change is quite small until 20 μs in the figure.

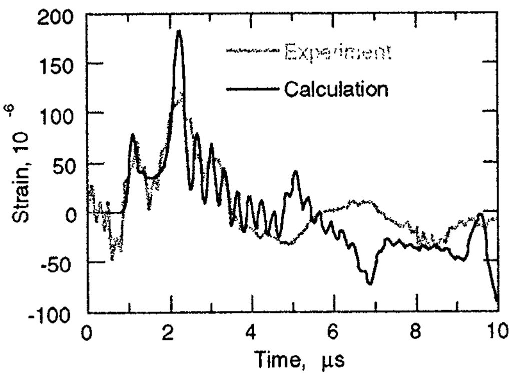

Fig.2 Thermal shock wave induced by the laser beam.

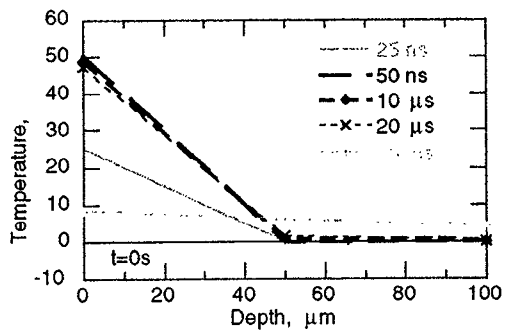

Fig.3 Thermal conduction to the depth direction of the disk.

3. Radiation damage

The radiation damage of the materials will be evaluated as shown in Fig.4. The irradiation data of fission reactors were accumulated in order to get irradiation data. The data were also obtained from JAERI and ORNL collaboration for International Thermonuclear Experimental Reactor(ITER). The irradiation parameters under spallation for 316 austenitic stainless steel. is characterized by He production, H production and irradiation temperatures. These values are higher than irradiation parameter of fission condition except irradiation temperature. High dose and He/dpa and H/dpa irradiation data must be obtained for the spallation environment. HFIR (High Flux Isotope Reactor) irradiation are planed for high dose data. HFIR is a mixed spectrum fission reactor at ORNL.

TIARA test facilities as shown in Fig.5 is used to obtain high He/dpa and H/dpa data. TIARA, Takasaki Ion Accelerator for Advanced Radiation Application, has a triple ion beam facility. Moreover, JAERI participates an International collaboration, SINQ. Swiss neutron spallation source, irradiation program, to obtain spallation irradiation data of the structural materials. SINQ collaboration program is proceeding for accumulating the irradiation data. Irradiation of Phase 1 by SINQ will be started July 1998. JAERI will intend to participate post-irradiation tests. Table 1 shows an irradiation matrix of Phase 1. Main materials are 316 austenitic stainless steel, ferritic/martensitic stainless steel and Al alloys. Specimen for these test are irradiated at SINQ and then post-irradiation tests will be conducted at PSI.

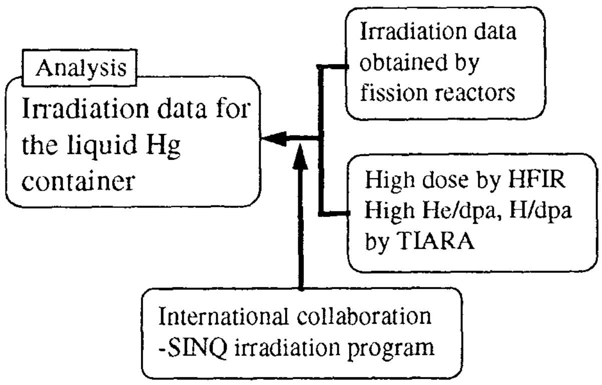

Fig.4 Materials evaluation for radiation damage.

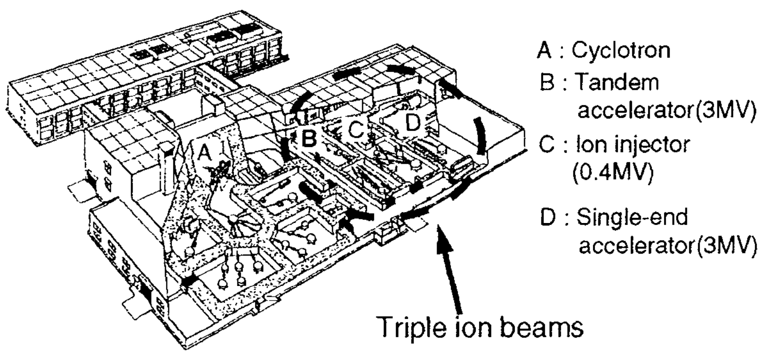

Fig.5 Takasaki Ion Accelerator for Advanced Radiation Application(TIARA)

Table 1 Irradiation matrix of Phase 1 by SINQ international collaboration.

Test Type	316SA, CW, WJ	Ferritic/Martensitic	Al	Ti-Zr, W, Mo
Tensile	X	X	X	X
Bend fatigue	X	X	X	
Tesrtest	X	X		
Bend	X	X		
Charpy		X		
Small punch	X	X		X
TEM	X	X	X	X

The materials used in HFIR are type 316 austenitic stainless steels. A chemical composition of the materials is shown in Table 2. Fig.6 shows, for example, engineering stress-elongation curves of irradiated J316 stainless steel[2]. He/dpa level is almost 10 (nearly fusion environment). Irradiation and test temperature range is 60 to 400°C. Dose levels are 7 and 18 dpa. The elongation of J316 decreased with dose, the strength increased with dose. Irradiation caused reduction of ductility at all temperatures.

Table 2 Chemical composition of Type 316 austenitic stainless steels

Alloy	Fe	C	Si	Mn	P	S	Ni	Cr	Mo	Ti	B	N
JPCA	bal.	0.06	0.50	1.77	0.027	0.005	15.6	14.22	2.28	0.24	0.003	0.0039
J316	bal.	0.058	0.61	1.80	0.028	0.003	13.5	16.75	2.46	0.005	-	-
316F	bal.	0.038	0.04	0.23	0.003	0.002	14.0	16.80	2.30	-	-	0.0011
ERH	bal.	0.061	0.67	1.7	-	-	12.4	17.3	2.1	0.21	-	0.003
EC316L	bal.	0.024	0.46	1.8	-	-	12.3	17.4	2.3	-	-	0.06

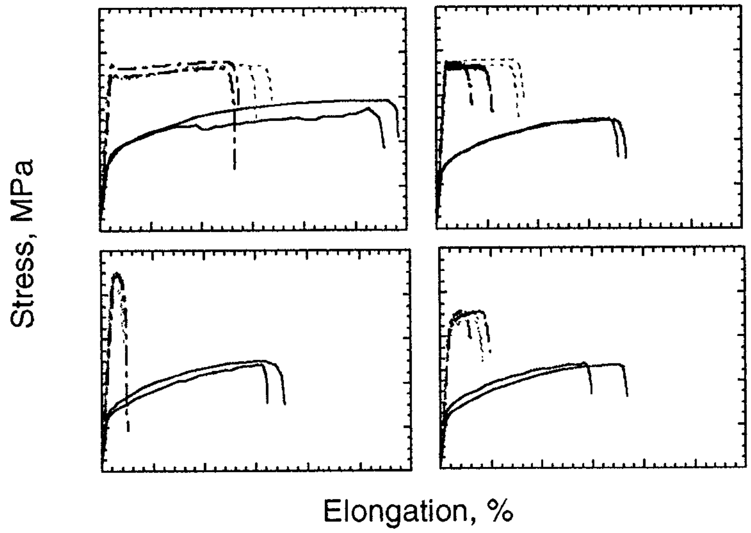

Fig.6 Engineering stress-elongation curves of J316 stainless steel at 7 and 18 dpa.

Fig.7 shows a preliminary result[3] from the TIARA facility. This figure shows load/depth-depth curves of the ion irradiated material obtained from the microhardness tests. This includes the results of the unirradiated, the ion irradiated and the ion irradiated after annealing. The materials tested were a Japan Primary Candidate Alloy (JPCA) in the solution-annealed(SA). The JPCA was modified from type 316 stainless steel to improve the swelling properties under the neutron irradiation. The specimens were in the form of TEM disks. in 3mm diameter by 0.2mm thickness. The TEM disks were irradiated in the JAERI triple ion facility(TIARA) using 12 MeV Ni ions with an irradiation rate of $1x10^{-3}$ dpa/s at a temperature of 200•. The TRIM85 code was used to compute the required ion fluences and the displacement dose as a function of depth beneath the specimen surface.

The results of the TRIM calculation for the specified irradiation conditions are shown in Fig. 8. The solid line goes with the left axis and shows the damage in dpa as a function of depth in the specimen. The peak dose is about 30 dpa around 2μm. The dashed line goes with the right axis and shows the injected Ni ions as a function of depth. The peak (0.7 at%) occurs about 2 μm. Both the displacement dose and Ni content in the ion irradiated TEM disk are varying as shown in Fig. 8. The effect of injected Ni ions on the microhardness of the TEM disk is neglected in this experiment because Ni is one of main elements of the JPCA. After the ion irradiation, some of the TEM disks were annealed at 500• for 8 hours in a vacuum. Microhardness tests were carried out on the surface of the TEM disk at room temperature. A microhardness testing machine, DUH-200 (Shimadzu Co.), was used for the hardness testing. A load was applied with a loading speed of $2.6x10^{-3}$ N/s, held 1 second and then removed. The load was continuously monitored along with the displacement with a resolution of 20 mN(2 mgf) and 0.01 μm, respectively.

The relationship between load and depth from the surface under loading in the microhardness test was given by $L/d=A+Bd$, where d is a depth(μm) from the surface, L is the load(N) at that depth, and A and B are constant. In particular, the value of B is in direct proportion to the microhardness of the material. The initial s age in each curve is neglected because this part of the curve includes a surface effect of the specimen. In Fig.7, the slope of the unirradiated line, which corresponds to B in the equation, is about 3. The slope of the ion irradiated curve is about three times as high as that of the unirradiated curve up to a depth of 0.4 μm and then decreases to 3. It means that the microhardness of the ion irradiated is as low as that of the unirradiated over 0.4 μm depth.

The ion injected layer (about 2 μm) affects the microhardness of the ion irradiated up to 0.4 μm depth. This tendency was observed in another study using the same technique. The slope of the ion irradiated specimen decreases to 4 up to 0.8 μm depth by annealing. It is considered that the change is attributed to thermal diffusion of defects induced by ion irradiation. It is well known that a hardness can be related to a yield strength. It seems that the change in yield strength of the irradiated material can be predicted by the change in microhardness of the ion irradiated TEM disk. Moreover, the effect of helium and hydrogen on mechanical properties of the irradiated materials can be estimated using the TIARA.

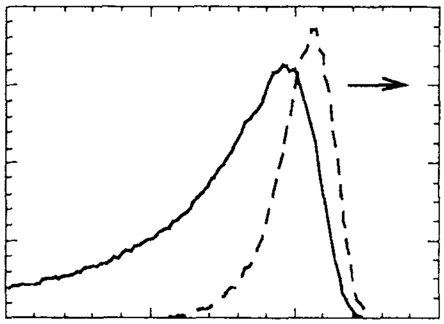

Fig.7 Load/depth-depth curves of the ion irradiated materials[3].

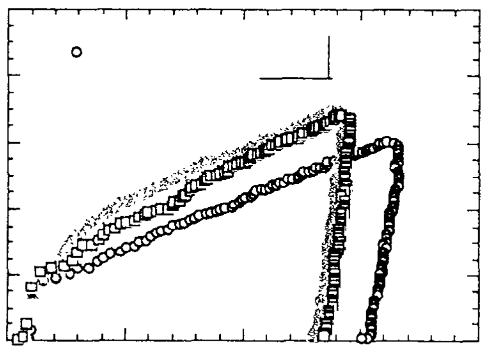

Fig.8 Displacement dose and Ni content in the ion irradiated TEM disk[3].

4. Corrosion/erosion test in mercury

Mechanical tests of the structural materials are scheduled to do in JAERI laboratories. These tests will show the effects of corrosion and/or erosion on the mechanical properties. In order to understand the combined effects of the corrosion/erosion with the irradiation effect the irradiation data under spallation environment should be obtain in the mercury target system. A real target material which is used in the target will be the best material to evaluate those dual effects. In-beam tests of the materials will show useful data under the condition of proton exposure in the mercury environment. PSI will be one of the promising test facilities for the in-beam tests in the 72MeV proton line.

5. Summary

The thermal shock test was done to assess the damage of pulsed shock wave. The stress wave was measured by strain gauge and a computing work was done in order to simulate the stress history. Radiation damage test was done at TIARA. Through the micro-hardness test of the TEM disk specimen, the effect of ion irradiation on the hardness was was investigated.

References

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