Development & Fabrication of D9 Pressurised Capsule and Material Irradiation Capsule

EXECUTIVE SUMMARY

Pressurised capsules made of D9 alloy have been developed to determine the in-reactor creep performance of indigenously developed D9 alloy. Two numbers of non-instrumented irradiation capsules for irradiation of specimens of alloy D9 and type 316 stainless steel (FBTR quality) in FBTR have been fabricated to generate baseline irradiation performance data on these materials at low temperature and low fluence irradiation conditions. D9 is the alloy selected for PFBR fuel cladding and wrapper tube and Type 316 SS (FBTR quality) has been used in the fabrication of reactor vessel and other block pile components in FBTR.

OUTLINE

D9 alloy
D9 alloy is modified type 316 stainless steel with controlled additions of titanium and silicon. It has also reduced chromium content and increased nickel content. Its swelling resistance to neutron irradiation, and irradiation creep behavior are better than those of type 316 stainless steel.

Development of D9 pressurised capsule
D9 tube of 6.6 mm outer diameter and 0.45 mm wall thickness is closed by welding at one end and fitted with special end plug at the other end, which enables filling of gas at the desired pressure into the tube using a pressurising system. After pressurising, the gas entry path is sealed with a soft gasket and welding is carried out to close the special end plug with a cap. The diameter of the special end plug has been designed to accommodate all features within the diameter of 6.6 mm. The length of the pressurised capsule is about 74 mm. Capsule with an internal pressure of 6.5 MPa has been successfully developed (Fig. 1).

Design and Fabrication of Material Irradiation Capsule
Two numbers of non-instrumented irradiation capsules for irradiation of specimens of alloy D9 (Fig. 2) (pressurised capsules, tensile and swelling specimens) in FBTR have been fabricated. The aim of the experiment is to generate baseline irradiation performance data on the indigenously developed D9 alloy, and type 316 SS (FBTR quality) at low temperature and low fluence irradiation conditions. D9 is the alloy selected for PFBR fuel cladding and wrapper tube and Type 316 SS (FBTR quality) is with more stringent composition specifications than the corresponding ASTM grade and has been used in the fabrication of reactor vessel and other block pile components in FBTR.

D9 pressurised capsules have been fabricated and arranged in five partitions in an irradiation capsule along with D9 disk specimens. These pressurised capsules were fabricated from indigenously developed D9 alloy clad tube of outer diameter 6.6 mm and 0.45 mm wall thickness. A gas mixture of 97% argon and 3% helium was used for the pressurisation. The hoop stresses that will be developed in the pressurised capsules at the irradiation temperature are 30, 60 and 90 MPa respectively. The second irradiation capsule contains small size flat tensile specimens and disk specimens of both D9 alloy and type 316 SS (FBTR Quality), and D9 tubular tensile specimens. Holes have been drilled on the wall of irradiation capsules to allow the reactor sodium to enter and surround the specimens during irradiation. The irradiation temperature of specimens will be the same as temperature of sodium (346 to 350 deg. C). The irradiation capsules are assembled in two special steel subassemblies and will be loaded in the 4th ring of FBTR for irradiation. After irradiation, the irradiation capsules will be taken to Radio metallurgy Laboratory and post irradiation examination will be conducted.
EFFECT OF RADIATION ON MATERIALS

Creep is time dependent deformation of materials under stress and temperature. Normally, this strain occurs at elevated temperatures and is known as thermal creep. Irradiation creep is the additional deformation due to presence of neutron flux. Thermal creep occurs above about one third of absolute melting temperature whereas irradiation creep is found in materials even at low temperatures. Irradiation induced swelling and creep are important phenomena that affect the design, operation and performance of core structural materials of Fast Breeder Reactors (Fig. 3).

There are many methods by which irradiation creep experiments are carried out. Use of pressurised capsules is one such important method to determine irradiation creep particularly in non-instrumented irradiation experiments.

The pressurised capsule is made of the same material for which the irradiation creep data is required. It is in the form of a gas filled tube with both ends sealed. A pressurising gas such as argon is filled in the pressurised capsule at high pressure. The filling pressure of pressurised capsule at room temperature is chosen in such a way that the target stresses are attained at the desired temperature of irradiation in the reactor.

The material specimens including pressurised capsules are kept in irradiation capsules, which are in turn locked in special steel subassemblies. These special subassemblies are loaded in Fast Breeder Test Reactor for irradiation.

Due to intense neutron flux and high temperature that prevails in a nuclear reactor, there will be degradation in the mechanical properties of materials such as ductility, impact strength and in-reactor creep strength. The impingement of neutrons on the structural material in the reactor causes extensive displacement of lattice atoms from their normal position and a variety of defect structures get produced. Subsequently, there is gradual degradation in performance of materials. For instance, the material hardens, its ductility reduces, its creep rate increases, and its volume increases due to appearance of voids. These changes can be determined by carrying out irradiation experiments in a reactor under controlled experimental conditions and testing the irradiated samples in hot cells.

GENERAL EXPLANATION RELATED TO THE DESCRIPTION

Fig. 3: Typical core plan of FBTR in which the special subassemblies with irradiation capsules containing pressurised capsules & other specimens are loaded in the 4th ring during 14th irradiation campaign.

Brief Description of Theoretical Background

Pressurised capsule is designed as a thin wall cylinder subjected to high pressure. The pressure of gas filled at room temperature is determined from the mass of the gas and using gas laws. Pressure developed at high temperature is also determined using gas laws. It is aimed to obtain the steady state creep rate of the material, which can be used in design calculations. Maximum temperature of pressurised capsules in the irradiation capsule in case of sodium flow blockage in the special subassembly has been calculated to verify the stress that will be developed in the pressurised capsule in that condition and the stress is found to be within safe limit.

Achievement

Development of pressurised capsule of 6.6 mm diameter with high pressure is a challenging task and it has been successfully carried out. The proposal for irradiation in FBTR has been approved by statutory safety committees.

Publications Arising Out of This Study and Related Work


Further inquiries:
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