Irradiation Examination Plan for Thermal Conductivity of Inconel-690 TT

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1. Introduction

The KAERI(Korea Atomic Energy Research Institute) is developing new type of nuclear reactor which has many features of small power and system integrated modular type. That is named SMART (System integrated Modular Advance Reactor)[1]. SMART has substantially enhanced its safety with an integral layout of its major components, such as the reactor core, steam generator, coolant pump, and pressurizer which are integrated within a single pressure vessel. The reasons are to eliminate the possibility of a large break loss of coolant accidents fundamentally, to improve the natural circulation capability, and to better accommodate and thus enhance a resistance to a wide range of transients and accidents. SMART can serve dual purposes for a seawater desalination and electricity generation. Thus SMART can supply energy and water simultaneously to large industrial areas or isolated areas such as islands.

Alloy 690 was selected as the candidate material for the heat exchanger tube of the steam generator of SMART [2]. The SMART R&D is now facing the stage of so-called 'engineering verification and approval of standard design' toward application to DEMO reactors.

Therefore, the material performance under the relevant environment is required to be evaluated. The important materials performance issues are mechanical properties i.e. (fracture toughness, tensile and hardness) and thermal properties for which the engineering database is necessary to design a steam generator. However, the neutron irradiation characteristics of the alloy are barely known. Therefore, an irradiation test plan of the Alloy 690 materials to obtain the neutron irradiation characteristics of thermal properties for Inconel-690 TT using HANARO irradiation capsules is discussed in this study.

2. Thermal Properties

For engineering verification and approval of standard design toward application to DEMO reactors, The thermal properties of heat exchange tube are examined in order to evaluate for impact of neutron irradiation effects. The most important thermal property is thermal conductivity of heat exchange tube located in steam generator. The thermal conductivity is derived from Fourier thermal conduction law in equation (1).

$$\overrightarrow{q(r,t)} = -k\nabla T(r,t) \qquad (1)$$

where $\overrightarrow{q(r,t)}$: heat flux vector
k : thermal conductivity
T : temperature scalar function

The relation of thermal conductivity and others properties is derived by Fourier thermal conduction equation like below equation (2)

$$\frac{k}{C\cdot\rho}\nabla\cdot grad(T) = \frac{\partial T}{\partial t} \qquad (2)$$

$$\nabla\cdot grad(T) = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

where α: thermal diffusivity

Therefore, the relation of thermal conductivity and others is $k = \alpha\cdot\rho\cdot C_p$ where k is thermal conductivity , ρ is density of material and C_p is heat capacity under uniform pressure.

3. Examination Plan for Thermal Conductivity

3.1. Irradiation plan for thermal conductivity

The fast neutron fluence of the specimens was required to be $1x10^{19}$ n/cm^2, $1x10^{20}$ n/cm^2, and $1x10^{21}$ n/cm^2 (E>1.0 MeV), considering the lifetime neutron fluence of the SMART steam generator. To obtain these neutron fluences, 3 different irradiation capsules [3] will be irradiated in the OR5 and CT test holes of HANARO

3.2. Specimen preparation

Necessary conditions of irradiated specimen are low radiation activity and well for remote handling by manipulator. In the case of thermal diffusivity measurement for Inconel 690 TT, optimum specimen thickness is 2 mm thick. But considering radiation activity and radiation shielding, we have determined the specimen thickness is 1 mm and 9 mm diameter disk type specimen. The specimen is sampled three kinds of heat treated materials i.e. (heat A, heat B, heat C) and machining direction by longitudinal and radial. Specimen sampling materials are shown in fig 1.

Fig 1. Sampled Materials for thermal property

Specimen sampling methods are shown in Fig 2. And Specimen shape and dimensions for thermal diffusivity and density measurement are shown in fig 3.

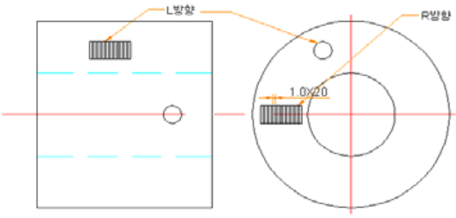

Fig 2. Sampling Method by Direction

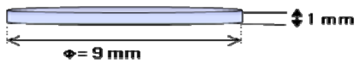

Fig 3. Specimen Shape and Dimensions

3.3. Thermal diffusivity examination

Thermal diffusivity examination for heat exchange tube will be performed by laser flash method proposed by Parker in 1961. This method is widely used in merit of rapid , accurate and use small specimen. The apparatus of examination is LFA-427 Laser Flash supplied by NETZSCH**.** Diffusivity measurement system is shown in Fig 4.

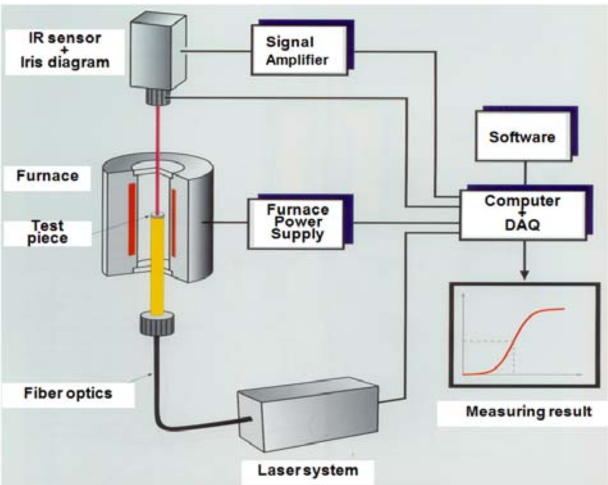

Fig 4. Schematic Diagram of LFA 427

Because heat exchange tube's operating temperature is about 250 ℃, test temperature condition is performed from room temperature to 250 ℃ by increasing 50 ℃ and from 250 ℃ to 350 ℃ by increasing 20 ℃. The test is performed longitudinal and radial sampled specimen for each heat treated material and five sample is repeated for each direction sample. In addition, in order to determine reference value and optimum test condition, un-irradiated materials is also examined by same manner of irradiated materials. As mention above irradiation plan, three times of neutron irradiation are performed so that thermal properties examination is done by three times using same examination conditions.

3.5. Density measurement

Density measurement will be done same manner of thermal diffusivity examination in sampling method and specimen. Measurement will be done first and thermal diffusivity examination will be done later. The test method is Archimedian's immersion method. To reduce radiation dose and facilitate experiment, we will use commercial density measurement kit using micro balance. The apparatus model is Mettler Toledo XS 50DUV.

3.6. Heat capacity measurement simulating neutron irradiation effect

We don't have appropriate measuring system of irradiated materials for heat capacity. In order to evaluate effect of neutron irradiation, we will use simulating method by making dislocation in materials. In general, high energy neutron bombardment in material bring about lattice defects i.e. void, pore and dislocation. Dominant factor impact to heat capacity is mainly dislocation in material. Therefore, simulation of neutron irradiation is devised by material rolling method. Material rolling reduction rate will be about 2% and size is 10 mm width, 30 mm length and 3 mm thickness. The rolled and un-rolled specimen are performed heat capacity measurement in same temperature condition mentioned in thermal diffusivity measurement plan.

3.3. Determination of thermal conductivity

Thermal conductivity is determined in the relation $k = \alpha \cdot \rho \cdot C_p$ varying test temperature.

4. Conclusion

To obtain the thermal properties change caused by neutron irradiation for the heat exchanger tube of the SMART steam generator, Thermal diffusivity, density and heat capacity test plan are provided for irradiated material. The thermal conductivity of irradiated material will be determined by resulting relation and evaluated by thermal diffusivity density and heat capacity.

REFERENCES

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