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The Measurement of Basic Thermal and Mechanical Properties of HANA Cladding Tubes

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1. Introduction

Knowledge of accurate values for thermal and basic mechanical properties of nuclear fuel cladding tube is extremely important in the engineering design of nuclear reactors. Over the last decades, lots of data for those properties have been accumulated and up-dated for Zircaloy-2 and 4 and established as a material code. However, in spite of the amount of such database, the experimental methodologies determining those properties have not been released satisfactorily. This lack of information was particularly true of the advanced cladding tubes of high performance which have been adopted lately.

Recently, new cladding tubes, named "HANA claddings", was developed by a research team at Korea Atomic Research Institute and their excellent performance have been identified from the in-pile condition test as well as out-of-pile. To acquire the license of the new tubes, the basic thermal and mechanical properties are needed with the reliable methodology of the measurements. Among those properties, this paper presents the experimental data and procedures for specific heat, thermal expansion coefficient, elastic modulus and poisson ratio for the HANA cladding tubes.

2. Methods and Results

2.1 Thermal Expansion Coefficient(TEC) Measurement

Thermal expansion coefficient for the zirconium α phase was measured using a TMA2940 in the temperature range of 100 to 700^{o}C. The measurement was conducted during heating of the samples. Heating rate was 5^{o}C/min.. TEC was measured along three directions of the tubes. The samples for longitudinal and circumferential directions were cut into 10mm length. The samples for radial (or thickness) direction were specially designed to an edge shape to prevent the samples from shift during measurement. TEC for the zirconium β phase was measured using a DT 1000 during cooling from 1050 to 950^{o}C. Since in the β phase region the directional change of TEC is negligible, we measured only along longitudinal direction. Cooling speed was 10^{o}C/sec. The TEC in the region of α+β phase was calculated by connecting the thermal expansion values at 750^{o}C for α phase and 960^{o}C for β phase.

Fig. 1 shows the results of TEC in comparison with the code. One can see the excellent agreement with the code value. However, the deviation from the code line became larger for the radial direction. It comes from the relatively small initial thickness of the tubes.

2.2 Specific Heat Measurement

The specific heat of the HANA cladding materials was measured with a Perkin Elmer Pyris-1 (<500^{o}C) and Netzsch DSC 404C (>500^{o}C). The testing was performed by step calorimetry at a temperature interval of 50^{o}C. For comparison, we also tested samples using continuous calorimetry at a heating rate of 0.05K/s. The minimum amount of testing sample for a measurement was 250mg. Fig. 2 provides the data obtained. The quantitative values of specific heat were consistent with that of Ziricaloy-2. The transformation of α to β phase of HANA alloys takes place earlier than that of Zircaloy-2. This may attribute to the higher content of Nb element in HANA alloys which stabilizes β-zirconium phase. Fig. 2 also shows some abnormal change of specific heat at around 650^{o}C before the α to β phase transformation. The degree of such change is greatest for HANA-3. The reason has not been clear yet. From microstructural observation, HANA-3 was found to have some β-niobium phase. Hence, the change at 650^{o}C was considered to be related to the transformation of the β-niobium into β-zirconium phase.

2.3 Elastic Modulus and Poisson's ratio

Two different methods are available for measuring the elastic moduli: static and dynamic methods. Generally, dynamic method by a resonant frequency is known to yield higher accuracy than static method by tensile test. But, it has difficulty getting a reliable data from a complicated shape of sample. Hence, in this work for tube shape, we used static method to measure the elastic modulus and poisson's ratio. To measure the poisson's ratio, two strain gauges were attached on the tube along longitudinal and circumferential directions respectively.

Table 1 shows the result obtained. Elastic modulus of the HANA alloys is consistent with that of Zircaloy-4 obtained by the dynamic method. The average value of the Poisson's ratio for the three HANA alloys at ambient temperature was 0.376. Strain rate did not affect the Elastic modulus and Poisson's ratio noticeably.

3. Conclusion

Thermal and basic mechanical properties of the HANA cladding tubes developed by KAERI were measured and the detailed procedures for the measurements were established. The results are summarized as follows:

1. Thermal expansion coefficients were successfully obtained for α and β phase regions by adopting the heating and cooling methods respectively. Though the scattering of the data for radial direction was somewhat greater than other directions, the results were totally consistent with the code values based on zircaloy-4.
2. Specific heat of the HANA alloys were quantitatively consistent to that of Zircaloy-2, but the HANA alloys exhibited earlier transformation of α to β-zirconium phase as much as about 30°C.
3. Elastic modulus and poisson's ratio of HANA cladding tubes were successfully measured by a static method. The obtained Poisson's ratio was 0.376.

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Table 1. Elastic modulus for HANA cladding tubes (in MPa).

Tubes	HANA-2	HANA-3	HANA-4	HANA-5	HANA-6
1	99013	97122	99100	97701	97053
2	99731	98879	100473	98575	98856
average	99381	98001	99786	98138	97955

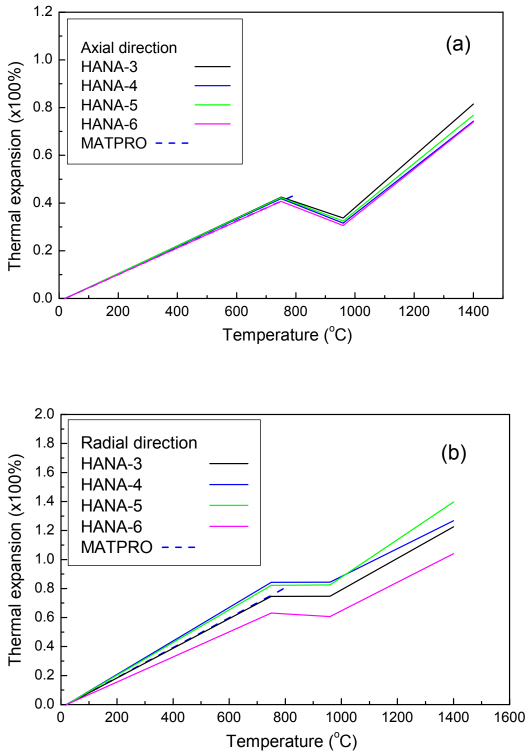

Fig. 1. Thermal expansion data for HANA cladding tubes: (a) axial direction and (b) radial direction.

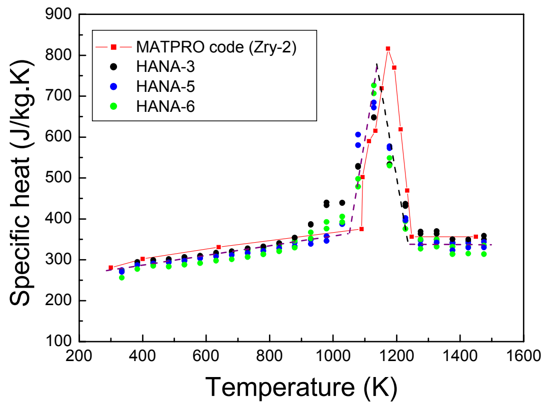

Fig. 2. Specific heat data for HANA cladding tubes.