Studies of Behavior Melting Temperature Characteristics for Multi Thermocouple In-Core Instrument Assembly

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1. Introduction

Bottom-up type in-core instruments (ICIs) are used for the pressurized water reactors of OPR-1000, APR-1400 in order to measure neutron flux and temperature in the reactor. It is a well-known technique and a proven design using years in the nuclear field. ICI consists of one pair of K-type thermocouple, five self-powered neutron detectors (SPNDs) and one back ground detector. K-type thermocouple's purpose is to measure the core exit temperature (CET) in the reactor. The CET is a very important factor for operating nuclear power plants and it is 327℃ when generally operating the reactor in the nuclear power plant(NPP) in case of OPR-1000. If the CET will exceed 650℃, Operators in the main control room should be considered to be an accident situation in accordance with a severe accident management guidance(SAMG). The Multi Thermocouple ICI is a new designed ICI assuming severe accident conditions. It consists of four more thermocouples than the existing design, so it has five K-type thermocouples besides the thermocouple measuring CET is located in the same elevation as the ICI. Each thermocouple is able to be located in the desired location as required. The Multi Thermocouple ICI helps to measure the temperature distribution of the entire reactor. In addition, it will measure certain point of melted core because of the in-vessel debris of nuclear fuel when an accident occurs more seriously. In this paper, to simulate a circumstance such as a nuclear reactor severe accident was examined.[1]

2. Test Methods and Results

In this section represents behavior melting temperature characteristics of k-type thermocouples of Multi Thermocouple ICI Assembly through the test of electric Induction furnace.

2.1 Test Overview

Generally, In case of a nuclear severe accident condition such as Fukushima accident, the temperature of the core is expected to reach over 2000℃ for an instant. With the result in over 2000℃, the core will be melted-down by the loss of coolant, since the fuel is exposed from top of the core, thus the end of the ICI will be begun to be melted which is located in CET Thermocouple. The ICI Assembly consisting of Inconel 600 has the melting points from 1354℃ to 1413℃. And typically the k-type thermocouple has EMF versus temperature data until 1372℃ in the reference table. The purpose of this experiment is to confirm the voltage and temperature characteristics of the response when the Multi Thermocouple ICI is inserted into the electrical Induction furnace which simulates the melting debris of nuclear fuel.[2]

2.2 Test Method

Two samples of Multi Thermocouple ICI were manufactured as shown in Figure 1. They were exactly produced as same as the actual production. Only difference is the length and intervals. They were about three meters long for convenience of tests. Each thermocouple was located with 20 centimeter spacing from the end. The latter part was connected to an extension cable to obtain EMF signal data.

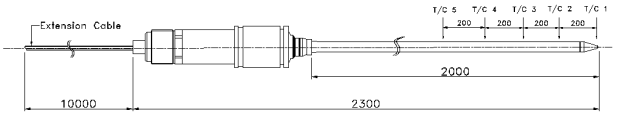

Fig. 1. Test Sample of Multi Thermocouple ICI

Fig. 2 shows two test samples used for the test and the electrical Induction furnace. The temperature of furnace was maintained at 1610℃ during the melting test.

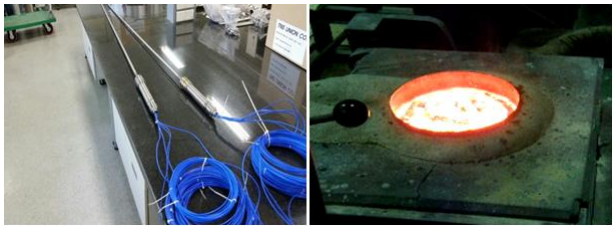

Fig. 2. Test Samples and Electrical Induction Furnace

The test was performed in two methods. For the sample no.1, temperature and voltage data of four thermocouples were acquired by data acquisition of Agilent 34970A while it was inserted into the furnace at a constant rate by 1 cm per second. For the sample no.2, temperature and voltage data of five thermocouples were also acquired with same method while it was

inserted into the furnace, however this time it was inserted and stopped and repeated. In case of the sample no.2, when the signal of one junction of the thermocouple was turned off, it was very slowly inserted until next thermocouple junction in the furnace. Fig. 3 shows the schematic method of the test.

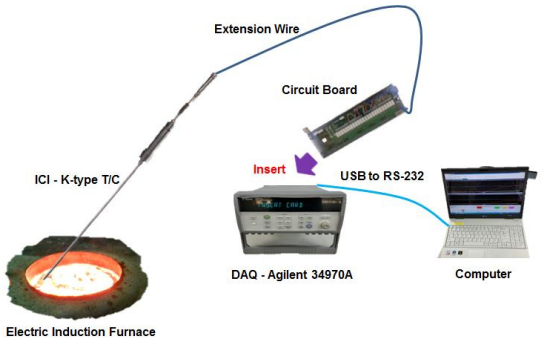

Fig. 3. The Diagram of Test Method

Fig. 4 shows appearance that the test sample was inserted into the furnace and temperature that the data acquisition program measured corresponding to the time. Four graphs in the picture show the four temperature values of each thermocouple respectively.

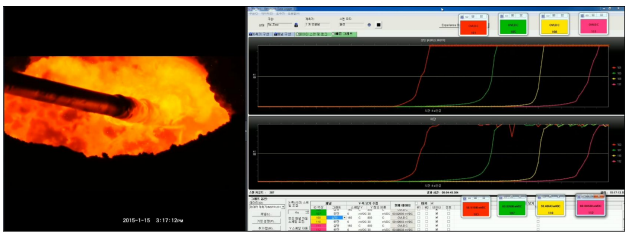

Fig. 4. Insertion Test and Data Acquisition

2.3 Test Results

In the first test of sample no.1, the scale of temperature was set from 0℃ to 1600℃ in the data acquisition program. Fig. 5 shows the test result of sample no. 1. Once each thermocouple junction was melted, it was directed to the infinite value of EMF in the program.

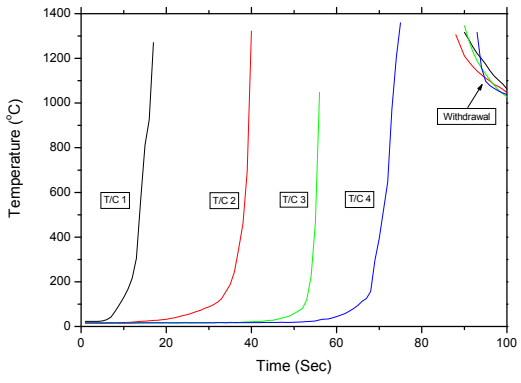

Fig. 5. Test Result of Sample No. 1

The reason for directing the four thermocouples at approximately the same temperature at the withdrawal point is that all junctions of the four thermocouples were re-made at a single point by melting. The test data of last temperature and maximum temperature are shown in Table I.

Table. I. Temperature data of Sample No. 1

T/C No.	Last Temp. (℃)	Maximum Temp. (℃)
1	1270.34	1316.23
2	1321.93	1305.93
3	1047.58	1346.24
4	1358.87	1316.55

In the test of sample no.2, the sample was inserted very slowly into the furnace. So the values of EMF between last temperature and withdrawal temperature were severely hunted. Fig. 6 shows the test result of sample no. 2.

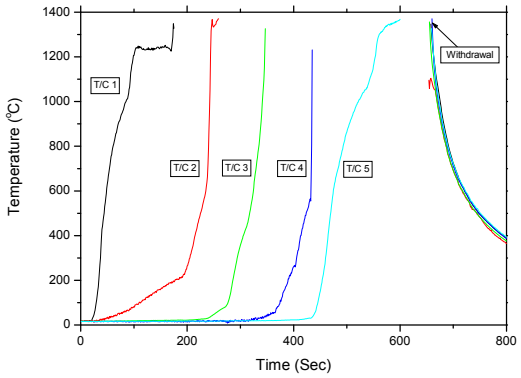

Fig. 6. Test Result of Sample No. 2

Table II shows the test data of last temperature and maximum temperature of sample no. 2. Removing the value of the hunting data, Maximum temperature is similar to the maximum value 1372℃ of the ITS-90 EMF table.[3]

Table. II. Temperature data of Sample No. 2

T/C No.	Last Temp. (℃)	Maximum Temp. (℃)
1	1327.85	1347.10
2	1370.44	1370.44
3	1326.28	1356.62
4	1231.43	1370.37
5	1367.82	1326.73

3. Conclusions

In this study, the K-type thermocouples of Multi Thermocouple ICI was confirmed experimentally to be able to measure up to 1370℃ before the thermocouples have been melted. And after the thermocouples were melted by debris, it was able to be monitored that the signal of EMF directed the infinite value of voltage. Therefore through the results of the test, it can be

assumed that if any EMF data among the Multi Thermocouple ICI will direct the infinite value, the reactor core will be damaged as to the position of installed that thermocouple. Also, It is able to know that if the temperature data of the thermocouple will be decreased below 1300℃ by properly controlled after a severe accident, it can be confirmed to re-make a new thermocouple junction at a withdrawal point. In that case, the operators of nuclear power plant can make sure that the severe accident mitigation action is effective. In this study, it is confirmed that the Multi Thermocouple ICI can be importantly applied as a detector to be monitored from entry to mitigation during the nuclear reactor severe accident.

4. Future Work

In the future, it will be necessary to do the study of the simulation or test that the temperature of coolant increase until all evaporated just before melting ICI. And also, it will be necessary to do the additional study of behavior of perpendicular melting characteristics of the Multi Thermocouple ICI to shape as to be an actual installation.

ACKNOWLEDGMENT

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