

Application of Important Temperature Time History Recording at Reactor Vessel Head Penetration Multi-welding Process

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ABSTRACT

Thermocouple sensors were used for measuring and recording temperature time history of weld interpass temperature during multi-welding process on pressure vessel head penetration, which is cooling by water flow in the centre of tube. A test specimen with a flat hollow cylinder which simulates the upper head of reactor pressure vessel and a tube stand for CRDM guide tube was manufactured. These areas are mainly thermal affected area. A cooling system with 2 L/min cooling flow rate from bottom to top was established. During the interval between two weld beads, dimension of weld bead was measured and start and finish time were recorded. When finish the weld process, the specimen was cut and welds bead profile was displayed by chemical method. Then the specimen can be used for residual weld stress measurement.

INTRODUCTION

The J groove weld of reactor pressure vessel (RPV) upper head and control rod drive mechanism (CRDM) tube is part of pressure boundary of primary loop in nuclear island. While in service, the stresses and displacement due to normal loadings could be redistributed and become weld residual stress could reduce the capacity of environmental effected fatigue, fast fracture, stress corrosion crack, etc. So pay more attention to weld residual stress is important. Usually there are two methods researching the distribution of residual stress and its peak value. One is FEM simulation and the other is measurement. Due to high cost and long duration for inner weld residual stress detect, the measure technology is not applied as wide as FEM simulation.

The simulation of multi pass weld is affected by the heat form and distribution, heating and cooling speed, phase change and so on. The residual stress numerical simulation of multi pass welding is much more complex. The precision of input parameters of the numerical simulation is very important, and poor precision parameters even can generate opposite result compare with the actual distribution of residual stress. This project generate a J groove weld component of reactor vessel upper head and recording the process of manufacturing, such as currency, voltage, begin and end position, weld speed, interpass temperature, cooling water temperature, flow rate, inner and outer temperature of RPV and CRDM tube.

SPECIMEN AND MEASUREMENT SOLUTION DESIGN

Measurements are intended to: 1) By measuring temperature in welding process of J-Groove structure on reactor pressure vessel upper head, verification of weld residual stress FEM simulation on J-Groove structure could be performed, and could help to improve the model of numerical simulation. 2) By measuring the inner surface of pipes welding temperature history, heat transfer coefficient by cooling water fluid inside the tube could be estimated.

SPECIMEN DESIGN

The parameters of specimens will be manufactured same as real product, such as geometry, materials, welding and cooling process etc. While manufacturing, the sensor fix positions on surface of RPV head, inner and outer surface of tube are reserved

CPR1000 reactor totally has 61 J-Groove weld structures. In order to decline the complexity of manufacture, the centre location of J-Groove weld structure was chosen. Specimen structure is mainly composed of upper head of RPV, isolation layers, CRDM tube and J-Groove weld structure. Main dimensional geometry was shown in Figure1, and the material was shown in table 1.

Table 1: Materials of specimen

Components	Material
Upper head of RPV	16MND5
CRDM tube	Alloy 690
Weld zone	ERNiCrFe-7
Isolation layer	ENiCrFe-7

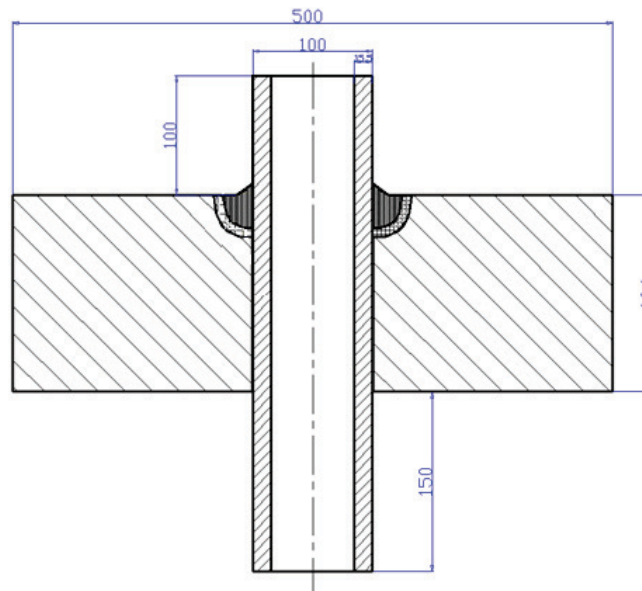


Figure 1. Main geometry of specimen

FLUID COOLING SYSTEM

During the welding process, the fluid cooling system is in service. The outline of fluid cooling system was shown in Figure 2. The fluid cooling system is composed of pump, cooling water tank, pipes and seal components. On the upper and lower surface of CRDM tube, special glue was used for sealing the tube and gaskets. Pipes are fixed with seal gasket and water tank. Pump drives the water from tank to the lower seal gasket and fulfils the CRDM tube cavity, and the water could recycle to tank with pipes from upper seal gasket. Thus forced heat transfer mechanism was established. This cooling system could sustain cooling CRDM tube well.

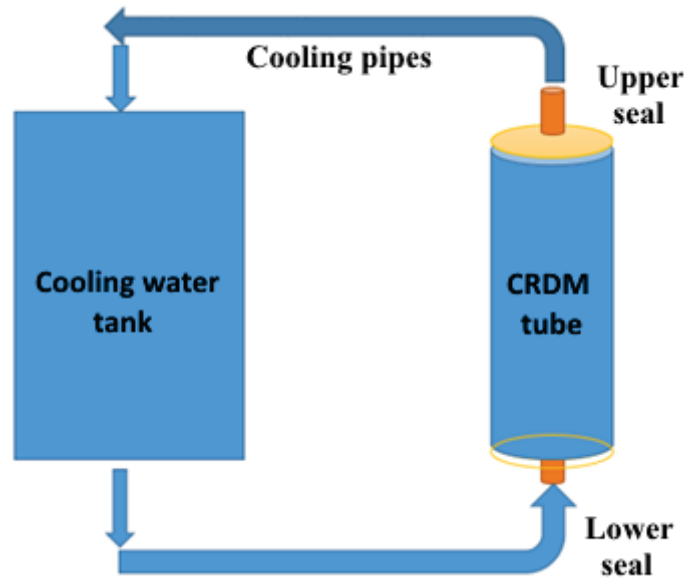


Figure 2. Fluid cooling system schematic diagram

MEASUREMENT SCHEME

Thermocouple sensors are used for recording the temperature history during welding. While welding, the heat affected zones of RPV upper head and CRDM tube were interested. These sensors are arranged on the surface and interior position mentioned above, totally 16 locations. Also the temperature at inlet and outlet interface of CRDM tube was detected.

SENSORS AND THE WIRES LAYOUT

Thermocouples are used for recording the temperature history on heat affected area and elastic zone of RPV upper head and CRDM tube surfaces. The sensors installation locations are in two section plane, one is 90°, and the other is 135°. Sensors installation locations and sensors distribution are indicated by Figure 3 and Table 2.

There are 5 sensors on the RPV upper head surface, the distance from groove edge are 5mm, 8mm, 10mm, 15mm, 30mm respectively. 4 sensors are on CRDM tube surface, and the distances from groove edge are 5mm, 8mm, 12mm and 20mm respectively. Sensors installation process is shown below. Determine heat affected zone and elastic zone by FEM simulation and drill shallow hole on the surface of RPV upper head and CRDM tube. The diameter of shallow hole is 3mm diameter and depth is 2mm. Embedded the measure end of sensor at bottom of hole, and then layout the sensor at measure location by glue.

There are 7 sensors at CRDM tube interior zones for detecting the inner wall temperature of CRDM tube. Two layout ways are used. They are shallow hole at inner surface and deep hole from outer surface to interior zones. 3 sensors are installed by shallow hole at inner surface of tube. The wires are connected to the inner surface of tube and layout from top gasket seal. The depth of shallow hole is 2mm. Waterproof treatment is performed for these sensors and wires. 4 sensors are installed by deep hole from outer surface to interior zones. The depth of hole is 14mm and the diameter is 3mm. The distance from lower weld

edge are 5mm, 8mm, and 8mm, 12mm from upper weld edge respectively. Fix the thermocouple at bottom of the hole and lay out the wire by notch at outer surface of tube.

Table 2: Measure locations and sensor numbers

Zones	Components	Measure location	Number of sensors
1	RPV upper head	Heat affected zone and heat elastic zone	5
2	CRDM tube	Heat affected zone and heat elastic zone	4
3	CRDM tube	Tube interior zone	7

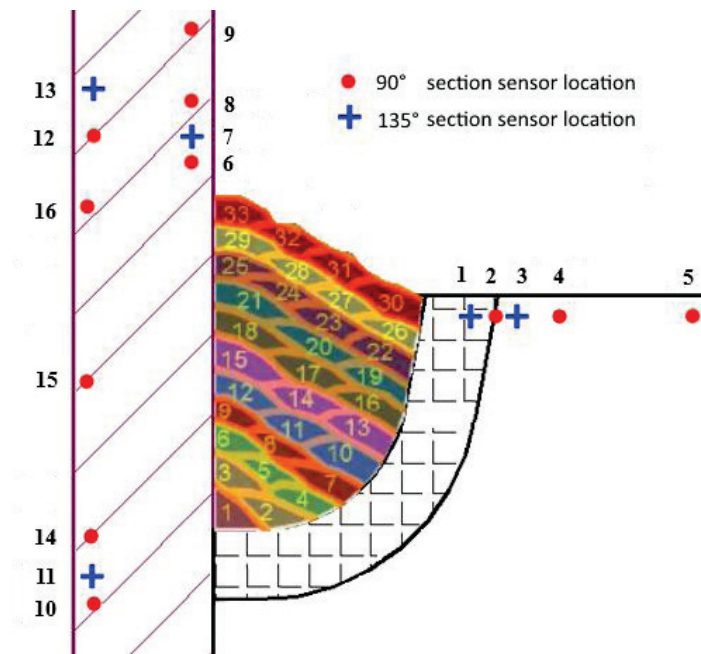


Figure 3. Sensor locations

The installation and wire layout of sensors is shown by Figure 4.



Figure 4. Sensors installation and wire layout

PROCESS OF TEMPERATURE MEASUREMENT

HIOKI-LR8400-21 temperature acquisition system is used for recording the temperature history while manufacture the specimen. The range of temperature collecting is set as 2000 Celsius degree, and the temperature precision is 0.1 Celsius degrees.

The diameter of K-shape sheathed thermocouple (Nickel-chromium-nickel Silicon thermocouple) is 0.5mm, and the precision level is 1 class. In accordance with the measure plan, 16 location of the welded structure are selected and machined for thermocouple installation. The inlet and outlet of CRDM tube gasket temperature are also detected by thermocouple. The sketch of temperature acquisition equipment is shown in Figure 5.

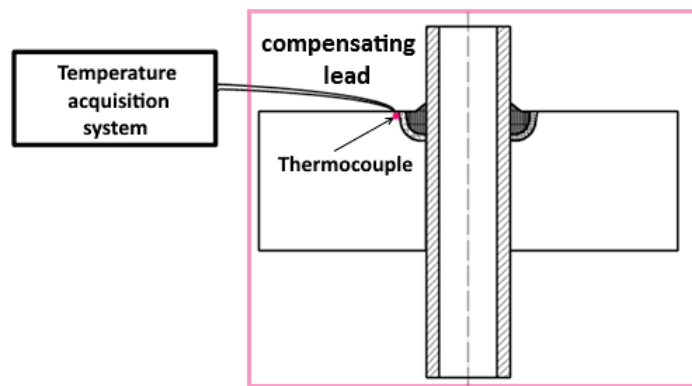


Figure 5. The sketch of temperature acquisition equipment

First stage of welding is shield metal welding. There are 11 layers and totally 33 beads. Each bead used 2 or 3 weld rods. PT detection is applied at first layer, every 3 layers, and the last layer. Before TIG welding, a surface polish and PT on weld surface is performed. TIG weld has 3 layers and totally 20 beads. The diagram of weld layers and its process is shown by Figure 6.

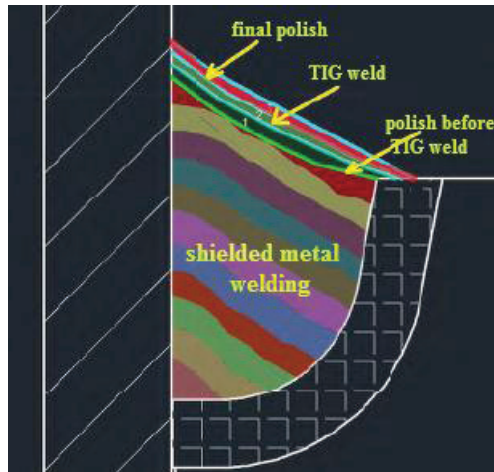


Figure 6. Weld layers

While perform the shielded metal welding, temperature history of each weld bead is recorded as a temperature file. The initial time of temperature file is 30s early than welding start and the time end recording while the temperature is below than 40 Celsius degrees. Upon complete the shielded metal welding, several thermocouples are removed in order to avoid obstruct the TIG welding process.

Also the temperature history of TIG welding process is recorded and saves as files. The initial and end time is similar with files of shielded metal welding. Table 3 shows the recording items while perform welding

Table 3: Recording items while welding

NO.	Category	Record Items	Methodology of Measurement
1	Parameters while welding	Start and end of weld	Visual inspection
		Weld duration	Record by watch
		Weld currency	Set by engineer
		Weld voltage	Obtained from machine
2	Weld bead information	Radial dimensional of weld bead	Measure by ruler
		Height of weld beads	Measure by calliper

Measurement results and analysis

In the same section but with different distance between sensor and weld edge, the temperature history of one weld bead detected by sensor 1 and 3 is shown by Figure 7. It is very clear that temperature of detected by sensor 1 is quite higher than sensor 3. The peak value is from 486 Celsius degrees to 250.4. Decline duration is 17s and cooling rate is 13.9 Celsius degrees per second.

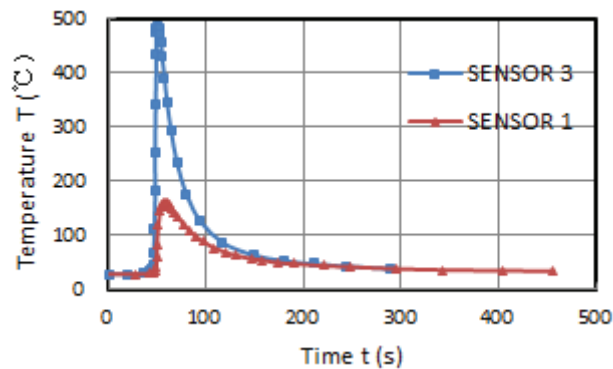


Figure 7. Comparison of temperature detected by sensor 1 and 3

When weld spot near the sensor location, the detected temperature rise to its peak value and decline quickly while weld spot away. It indicates that these temperature history detected by sensors could reflect the property of multipass welding.

Both two measuring methods of CRDM tube inner surface temperature detect plan work well. The inner surface shallow hole plan could receive more information of temperature transfer. Take sensor 15 as example, it can obtain temperature history while multipass welding and cooling tube inner cooling. Then the heat transfer coefficient could be deducted.

On the surface of RPV upper head, the peak temperature of sensor 1 (5mm away from weld edge) during welding is 480 Celsius degrees. Compare with sensor 1, the peak value of sensor 2 is 240 and sensor 3 is 100 and sensor 4 is less than 100 Celsius degrees respectively. It indicates that the austenite transformation did not occur at location 1-5. The scale of heat affected zone is less than 4mm at RPV upper head surface. Heat transfer coefficient between air and specimen also could be estimated.

While shield metal welding processing, the peak temperature of CRDM tube detected by sensor 6 is 520 Celsius degrees. This position reflects the plastic property. The peak values of sensor 7, 9 are 290 and 110 respectively. These positions reflect the elastic to plastic transition zone. With large heat capacity due to large depth of RPV upper head, weld heat could dissipate quickly while welding. So based on temperature history detecting and thermal expansion coefficient of material, elastic-plastic zones could be estimated at RPV upper head and CRDM tube.

The temperature history detected by sensor 1, 6 and 15 are displayed by Figure 8, 9 and 10.

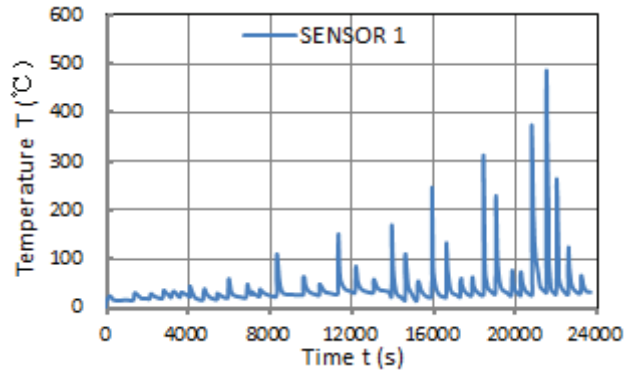


Figure 8. Temperature detected by sensor 1

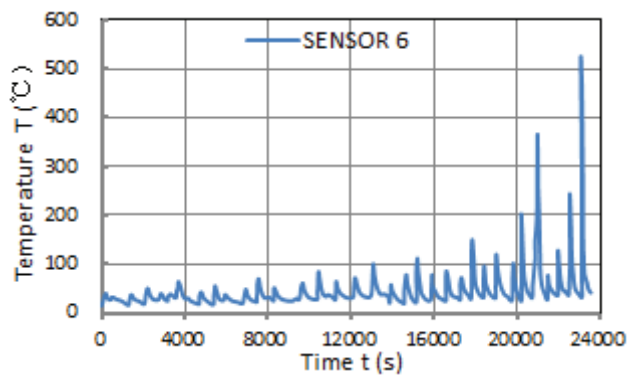


Figure 9. Temperature detected by sensor 6

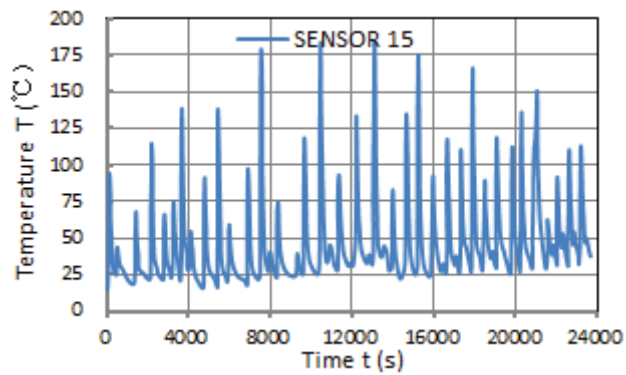


Figure 10. Temperature detected by sensor 15

Figure 11 shows the input and output temperature of CRDM tube. In welding duration, the difference between input and output temperature of CRDM tube is less than 4 Celsius degrees. The flow rate is enough while manufacturing the specimen.

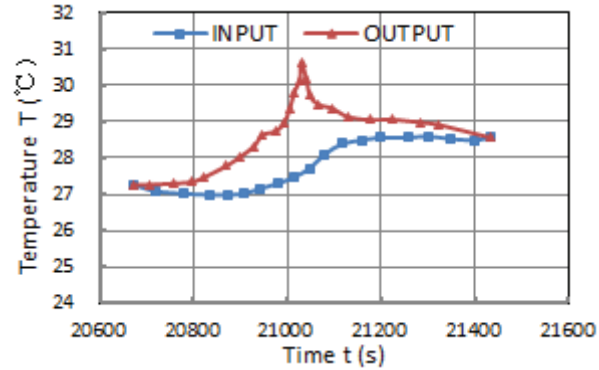


Figure 11. Comparison of input and output temperature of CRDM tube

CONCLUSION

Temperature measurements were comprehensive performed on the specimen welding process. It indicates that measurement could reflect the temperature change while welding, and heat affected zones, including elastic, elastic-plastic, plastic zones, can be estimated. The inner surface of CRDM tube temperature history data could deduct the heat transfer coefficient between fluid and tube surface. All these useful data could help weld residual stresses numerical simulation.