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STRAIN MEASUREMENTS DURING PRESSURIZED THERMAL SHOCK EXPERIMENT

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ABSTRACT

For the life extension of nuclear power plants, the residual life of most of their components must be evaluated along all their operating time. Concerning the reactor pressure vessel, the pressurized thermal shock (PTS) is a very important event to be considered. For better understanding the effects of this kind of event, tests are made. The approach described here consisted of building a simplified in-scale physical model of the reactor pressure vessel, submitting it to the actual operating temperature and pressure conditions and provoking a thermal shock by means of cold water flow in its external surface.

To conduct such test, The Nuclear Technology Development Center (CDTN) has been conducting several studies related to PTS and has also built a laboratory that has made possible the simulation of the PTS loading conditions.

Several cracks were produced in the external surface of the reactor pressure vessel model. Strain gages were fixed by means of electrical discharge welding over the cracks regions in both external and internal surfaces. The temperature was monitored in 10 points across the vessel wall. The internal pressure was manually controlled and monitored using a pressure transducer.

Two PTS experiments were conducted and this paper presents the strain measurement procedures applied to the reactor pressure vessel model, during the PTS, using strain gages experimental methodology.

Keywords: Strain gages, thermal shock, life extension, reactor pressure vessel.

1. INTRODUCTION

A reactor pressure vessel (RPV), which contains the nuclear fuel, keeps the coolant in the liquid state at high temperatures and high-pressures during normal operation conditions. Thus, it is designed, constructed and inspected according to rigid standards and the assurance of its structural integrity along its lifetime is very important (Bass et al, 1999; Mishima et al, 1994).

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Since the PTS transient occurred at Rancho Seco Nuclear Power Plant in 1978 (Stalkopf, 1994), this kind of event has been considered as an important safety issue in Pressurized Water Reactors (PWRs). A PTS involves a transient, in which an injection of cooled water inside the RPV causes a thermal shock in the vessel wall, while the pressure is kept constant or it suffers a sudden drop, and then, the system is pressurized again. The thermal stresses due to the fast cooling in the vessel wall combined with the stresses due to system pressure result in high tensile stresses that rise to its maximum value in the internal vessel wall.

A test was planned to evaluate the structural behavior of a cracked pressure vessel model, under PTS conditions. The test itself shall be a controlled event, in which the pressure vessel model is heated up to a temperature around 300 °C and, under an internal pressure around 15 MPa (PWR normal operating conditions), is suddenly cooled down by an injection of 10 m3 of water with the temperature of 8 °C.

The cooling water, at 8 °C, flows down by gravity from two reservoirs positioned at a height of 5 meters above the pressure vessel model. The piping connecting the reservoirs has an internal diameter of 250 mm. To increase the speed of the water injected in the pressure vessel model, the piping diameter of 250 mm is reduced to 70 mm, forcing the water to flow in a narrow area between the pressure vessel model external surface and a deflection shell that involves it. So, differently from an actual RPV, the vessel model receives the thermal shock in its external surface.

The internal pressure and the temperatures in the pressure vessel model wall are monitored and recorded during the event using dedicated equipment for transient data acquisition. The measured data were used for comparisons with finite element results.

From the above brief description of the test, this work has the following objectives:

- The evaluation of the strain gages installation behavior, submerged in water, when submitted to pressure and high temperatures.
- The measurement of the pressure vessel deformations near the cracked regions.
- The monitoring of possible crack growths using typical strain gages.

2. METHODOLOGY

2.1 Construction of the pressure vessel model

The pressure vessel model was built from a piece of SAE 8620 steel, in the forge brute state, with diameter of 500 mm and length of 1300 mm. In Figure 1, it is shown the obtained model after machining the piece resulting in an external diameter of 495 mm, height of 1100 mm (including the vessel head) and wall thickness of 85 mm. The dimensions and the material used in the model construction were defined in Barroso (1996). Two opposite flanges were welded in the model at the height of 760 mm to be the paths of the electrical cables connected to the internal strain gages and thermo-couples.

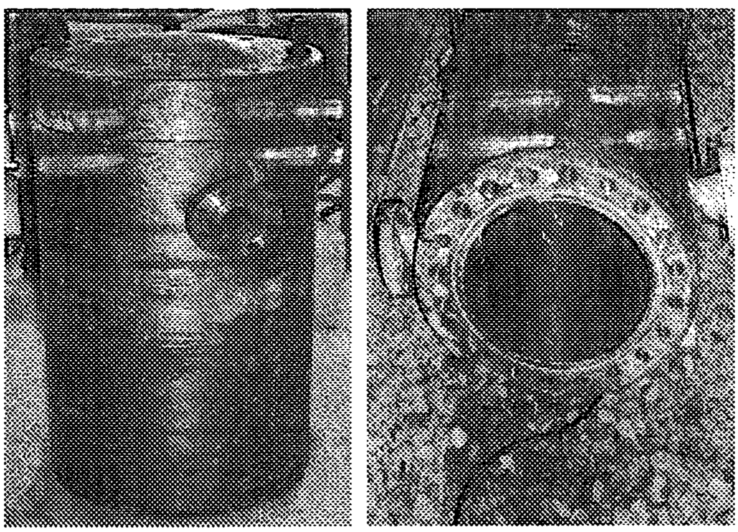


Figure 1 - The pressure vessel model.

2.2 Arrangement of cracks in the pressure vessel model wall

Five axial cracks were built in the pressure vessel model wall. The tips where the cracks start were machined 400 mm from the model top, equally spaced in the circumferential direction. Figure 2 shows the crack locations in the model wall.

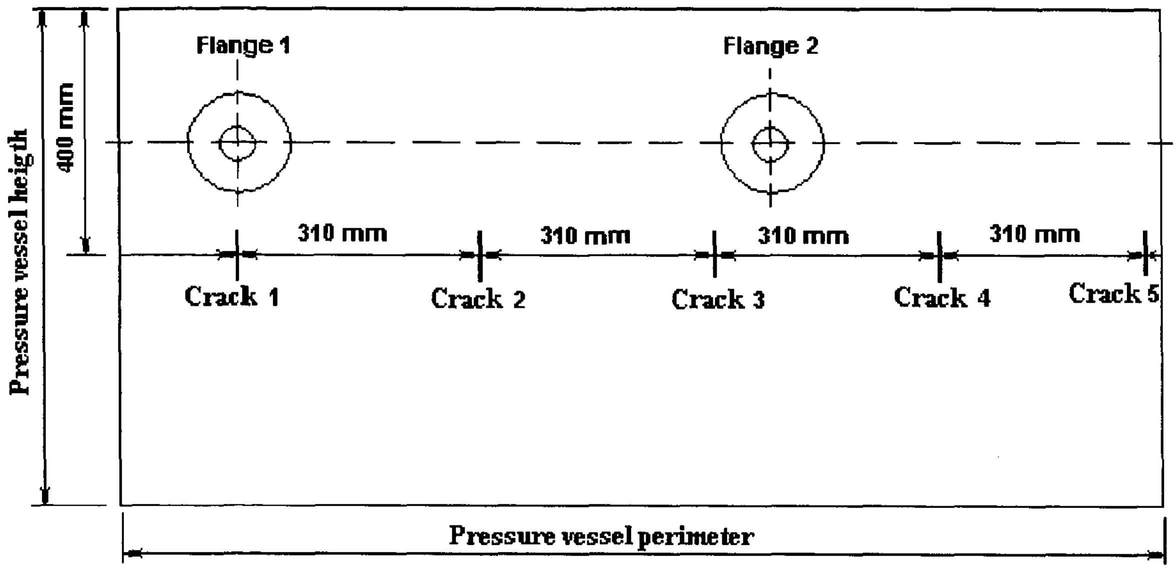


Figure 2 - Cracks locations in the pressure vessel model wall.

2.3 Instrumentation of the pressure vessel model

The pressure vessel model was instrumented to register the temperatures and the circumferential and axial strains in previously chosen positions, which were:

- The internal strain gages were glued 400 mm below the model top, exactly at the same height of the cracks centers.
- The circumferential external strain gages were positioned over the cracks and the axial external strain gages at cracks sides.

The internal pressure was measured during the whole event using pressure transducer specially designed for such purpose. The temperatures were monitored with ten thermo-couples radially distributed inside the model wall. The pressure vessel model was heated up by internal electric resistances, which were controlled by electric controller.

2.4 Strain measurements

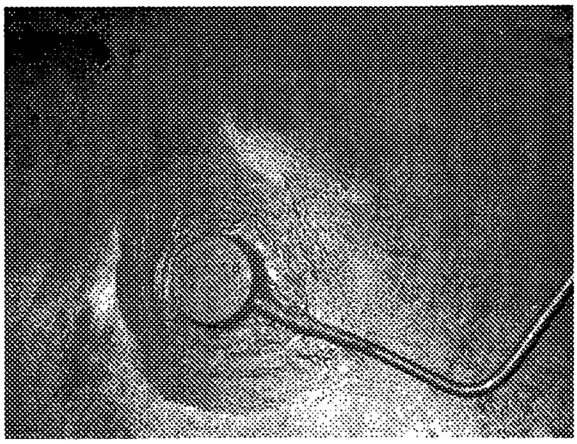
One of the objectives of this work was the evaluation of the strain gages installation behavior. To reduce the cost of the installation, one has chosen to use non capsulated strain gages and to develop specific protections, in order to avoid encapsulated strain gages for high temperature.

To evaluate the strain gages behavior some tests were conducted over the heat up to and the cool down from 300 °C. One has concluded that the strain gages could be used in the test temperature if they were protected superficially by ceramic glue commonly used in strain gage installations.

To measure the cracks growths and also the strains in the model wall, it was used circumferential strain gages installed over the cracks.

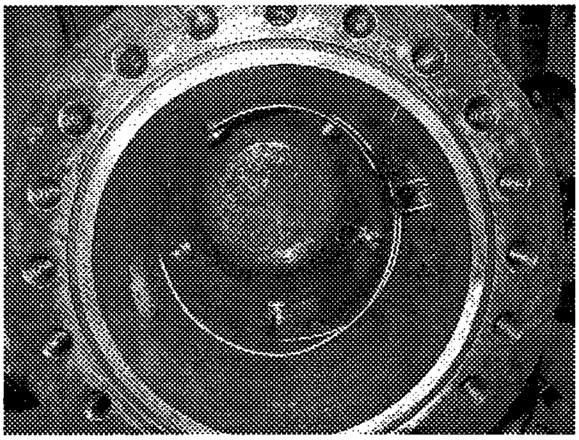
Twenty two strain gages were installed in the model. Six of them were internal, being one strain gage for each crack in the circumferential direction and one strain gage in the axial direction. These strain gages were protected by a stainless steel cover and silicone rubber for high temperature because they were under the internal pressure and immerged in the water. The electric cables were protected by 6 mm diameter stainless tubes. Figure 3 shows a strain gage inside the stainless steel cover protected by silicone rubber. Figure 4 shows a general view and details of the strain gage installation inside the model.

Strain gage inside the stainless steel cover

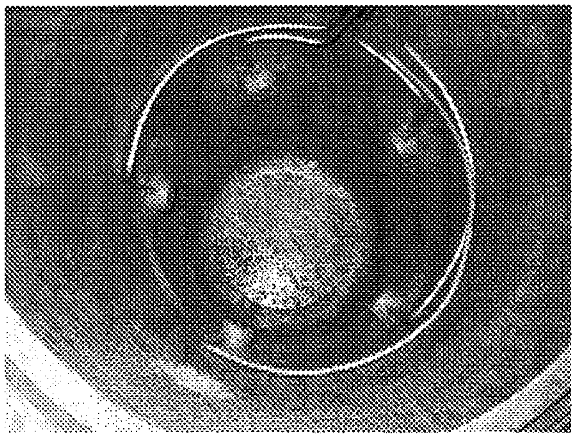


Installation protected by silicone rubber

Figure 3 - Strain gage installation details inside the model.



General view of the internal installation



Detail of the internal installation

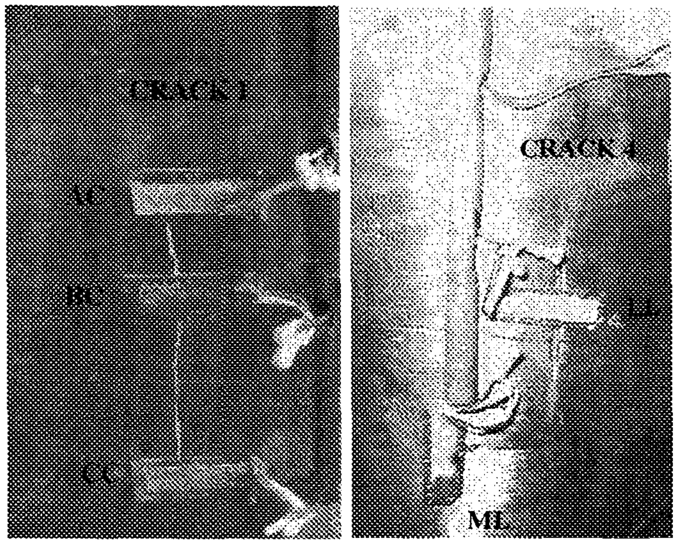
Figure 4 - View of the strain gage installation inside the model.

The external strain gage installation was done using three strain gages for each crack. Thus, one strain gage is installed in each end and one in the center of each crack. The electric cables were also protected by 6 mm diameter stainless tubes and by silicone rubber of silicon for high temperatures. Figure 5-a shows an external strain gage installation over a crack. It can be noticed three strain gages welded in the circumferential direction (perpendicular to the crack). The crack profile is enhanced in white color by magnetic particles. Figure 5-b shows a strain gage welded in circumferential direction and two strain gages in axial direction (parallel to the crack).

2.4.1 Strain gage identification

The internal strain gages glued in the circumferential direction were identified by the letters Ci followed by the number of the corresponding crack. The internal strain gages glued in the axial direction were identified by the letters Li followed by the number of the corresponding crack.

The external strain gages were identified by characters followed by the character C for the circumferential direction and by the character L for the axial direction. (see Figure 5).



(a) (b)

Figure 5 - External strain gage installation.

3. RESULTS

Table 1 shows the strains in the external and internal surfaces of the model wall obtained by formula (thick cylinder under internal pressure) for the pressure of 15 MPa.

Table 1 - Strains in the model wall for pressure of 15 MPa.

Strain gage location	Circumferential strain (μm/m)	Axial strain (μm/m)
External	93	23
Internal	185	23

Figures 6, 7 and 8 show the strains calculated by formula and measured by the strain gages during hydrostatic test at room temperature. It can be noticed that it is not presented the measured values for all installed strain gages. This is due the fact that some sensors had problems during installation by water flood through protective silicone rubber coat, even at room temperature.

It is also observed that there is a large difference between the calculated values and the measured values, mainly in the strain gages in the crack centers. This fact occurs due to the crack influence that opens as tension circumferential stresses increase, causing large strains in the sensors. In the crack ends, it can be notice that the dispersion between calculated and measured values is large but smaller than the previous one.

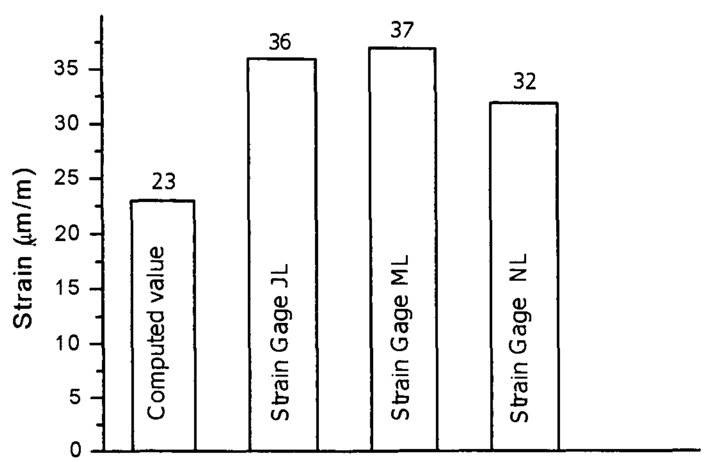


Figure 6 - Calculated strains and measured strains in external axial strain gages.

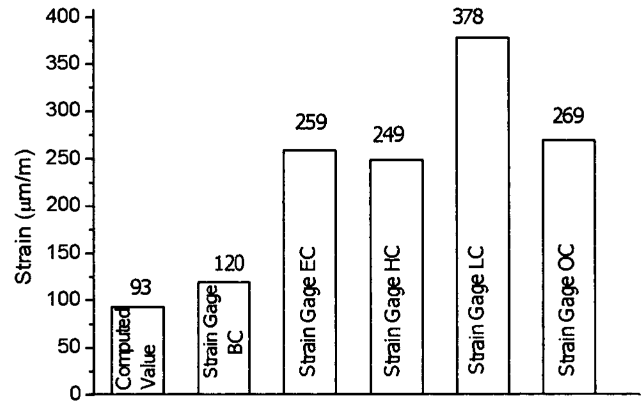


Figure 7 - Calculated strains and measured strains in external circumferential strain gages in the crack centers.

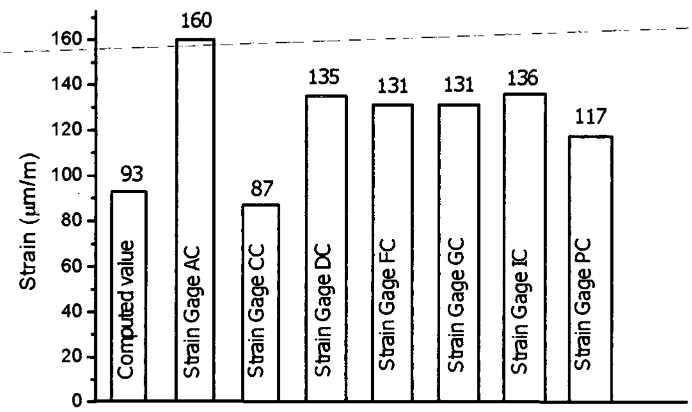


Figure 8 - Calculated strains and measured strains in external circumferential strain gages in the crack ends.

Figure 9 shows the strain gages behavior during the hydrostatic test The external strain gages measured values follow the pressure variation profile with good agreement. For internal strain gages, only three of them work during the test and the measured values do not agree with the pressure variation profile, reinforcing the idea that there were problems in the internal strain gages insulation caused by the environment (water).

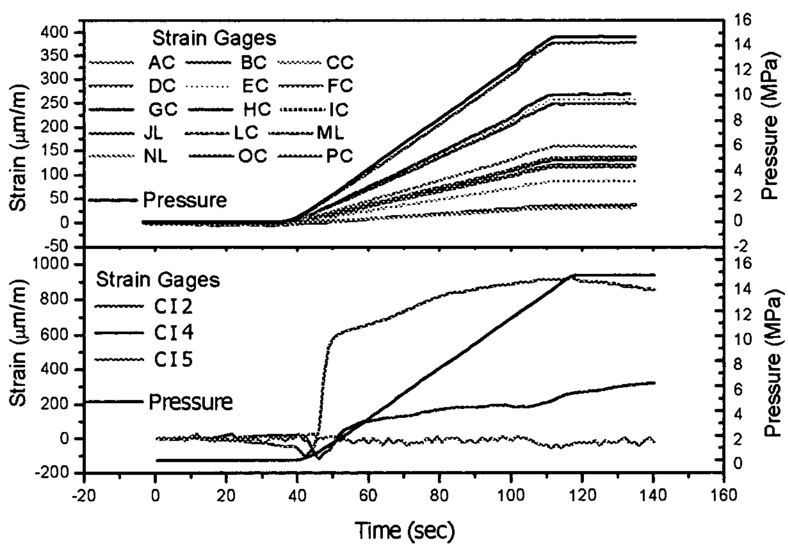


Figure 9 - Measured strains during hydrostatic test.

Figure 10 shows the measured strains during heat up and pressurization of the model. It can be noticed that the strain gages behavior is almost the same during the whole test.

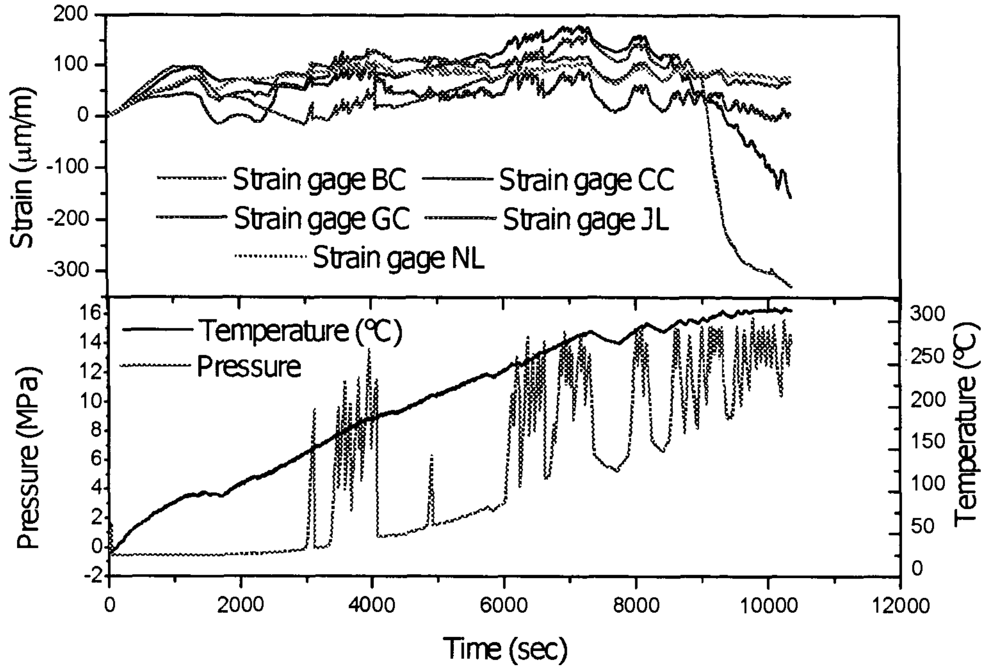


Figure 10 - Measured strains during heat up and pressurization.

Figure 11 shows the measured responses of three circumferential strain gages and of two axial strain gages during a thermal shock. It can be noticed that the axial strain gage JL showed high tensile strains while the circumferential GC strain gages presented smaller values. This values should be near each other once both are fixed in the same direction. Some strain gages showed compressive strains when it was expected tensile ones.

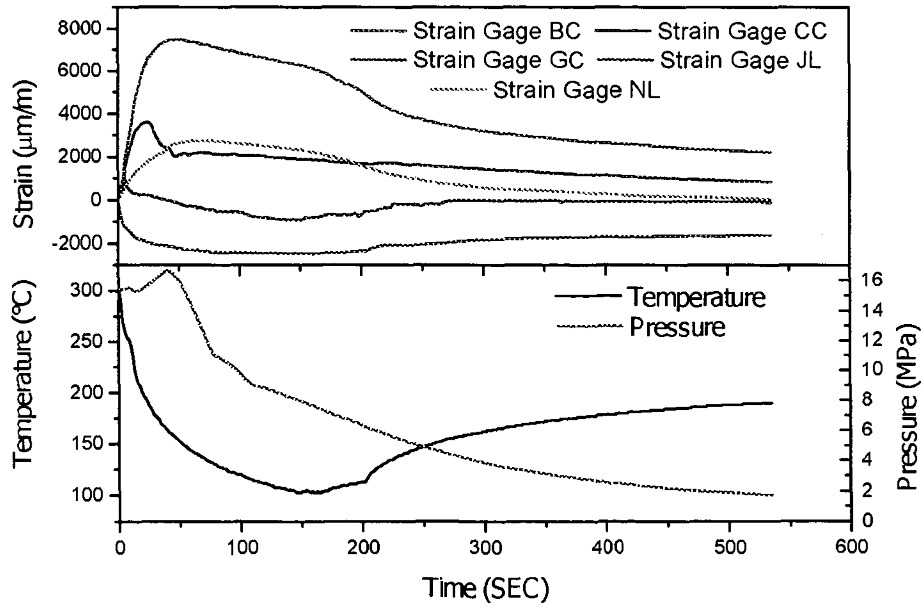


Figure 11 - Measured strains during a thermal shock.

4. CONCLUSIONS

Considering the strain gages installation to measure stresses and crack growth during a thermal shock experiment in a pressure vessel model it can be stated that:

- The used mechanical protection for the internal strain gages (stainless steel cover) showed good strength to the pressure but the silicone rubber insulation was not waterproof.
- Although more expensive, one can recommend the use of encapsulated strain gages to measure stress in submerged rigs under high temperature, with low or high pressures.
- The use of strain gages over the cracks to measure their growths is not recommended because large strains occurs due to the crack opening.
- It was not possible to detect crack growth during the thermal shock with the installed strain gages.

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