Acoustic Emission Monitoring of Crack Initiation and Propagation During a Thermal Fatigue Test

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Abstract

In a nuclear reactor, some nozzles and pipings are submitted to thermal shocks. To study the behaviour of two types of thermal screens and to evaluate the possibilities of NDE techniques for on-line monitoring and periodic inspections, special specimens were subjected to thermal cyclic tests. 2000 cycles (280°C - 60°C) were performed. After each trial of 500 cycles, a specimen was removed for destructive examination. Continuous monitoring was carried out by Acoustic Emission (AE) measurements. An increase of AE activity was correlated with crack initiation and linear location plots show preferential sites of emission after initiation. AE capabilities for on-line monitoring are discussed.

1. Introduction

In the primary circuit of a PWR reactor, some sleeves are placed inside nozzles to reduce fast thermal stress variation which can induce cracking, particularly in the welds joining nozzles and pipings.

In French PWR, two types of thermal sleeves are used. Preliminary experiments showed that, with those two types, cracks can initiate in the weld joining the sleeve and the piping and in some cases, can propagate through the piping.

A good estimation of crack behaviour is not possible with the available computation codes; so, in 1983 new experiments were decided in order to improve the computation models, to compare the two technologies and to evaluate the NDT methods usable for on-line monitoring and periodic inspection.

In this paper, these experiments are described, and results of continuous Acoustic Emission (AE) monitoring are presented. Finally, capabilities of this technique for on-line monitoring are discussed and future works are presented.

2. Experimental conditions

2.1. Test specimens

Two types of sleeves had to be tested. The first one is attached by a continuous circumferential weld and the other one is fixed by two small tongues.

Test specimens include a sleeve of each type (fig.1) and are designed to simulate the behaviour of a nozzle-piping connection under a fast temperature change in the fluid.

2.2. Instrumentation

Twenty thermocouples were inserted in one specimen at various positions and depths. Temperature measurements were collected by a computerized data acquisition system and they were used to improve thermal computations [1].

Another test specimen was AE monitored. Room-temperature transducers, resonant at 590 kHz, were coupled to the specimen with welded wave-guides. Two different AE systems were used (fig.2).

The first one continuously measures the cumulative number of bursts, peak amplitude and RMS voltage, for each sleeve. A linear discriminating module eliminates spurious noise, mainly originated from flanges. After 500 cycles, these parameters were directly collected by a computer, which allows automatic scaling and drawing of their time evolution.

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The second one is a location and characterization system used for periodic monitoring of the two sleeves (About 15 cycles were monitored at each time).

2.3. Experimental set-up and procedures

Experiments were performed in the two loops GB 1 and GB 2 of EDF Centre des Renardières. Maximum circulating conditions in these loops are 163 bars pressure, 280°C temperature and 350 m³/h flow rate.

For thermal cycling, these loops are adjusted to the maximum and minimum temperatures of the cycle (GB 1 at 60°C and GB 2 at 280°C) and they are alternatively connected with a circuit which includes the test specimens.

Under these conditions, actual characteristics of thermal shocks were (fig.3):

- pressure 163 bars
- flow-rate 36 m³/h
- temperature 280°C - 60°C
- shock duration ≤ 5 seconds
- total cycle length 1 h 20 min

Four trials of 300 cycles were performed. Four specimens, each one including a sleeve of each type were tested. After 500 cycles and 2000 cycles, one specimen was removed for destructive examination.

3. Results of AE measurements

3.1. Continuous monitoring

AE on-line monitoring aimed at:
- detecting crack initiation and monitoring crack growth by analysing the evolution of the number and amplitude of bursts during shocks.
- detecting the eventual separation of a sleeve from the piping by observing the evolution of RMS voltage between shocks.

No evolution of RMS voltage between shocks was observed, which means no loss of sensitivity of AE system and presumably no separation of a sleeve.

An increase of AE activity during hot shocks was noted at about 700 cycles (fig.4a) on the continuously welded sleeve. On the other sleeve, no significant evolution was noted up to 1560 cycles when an increase of activity appeared during hot and cold shocks (fig.4b).

It was also observed that maximum RMS voltage during shocks has always the same evolution during a trial of 300 cycles. In the case of cold shocks this parameter reaches maximum after about 100 cycles and in the case of hot shocks it increases smoothly.

3.2. Source location

Three monitorings with AE source location system were performed.

No preferential AE source was pointed out during the first monitoring (from 687 th to 689 th cycles), whatever the sleeve and the type of shock (fig.5a).

The second monitoring (from 1501 st to 1517 th cycles) revealed a very active zone on the continuously welded sleeve, mainly during hot shocks (fig.5b).

The last monitoring (from 1959 th to 1968 th cycles) confirmed the previous emissive zone, but in that case it emitted during all shocks. An active zone was also observed on the other sleeve during hot shocks (fig.5c).

4. Discussion

Destructive examinations were performed by EDF-département matériaux Les Renardières, on two specimens. The first one was removed after 1000 cycles and the second one after 2000 cycles.

The crack initiation estimated from computation results (between 160 and 885 cycles according to various assumptions) and from fracture analysis (between 130 and 740 cycles depending on assumed crack growth rate) is coherent with the increase of AE activity observed at 700 cycles on the continuously welded sleeve.

So it appears that a continuous measurement of simple AE measurement could indicate crack initiation at a very early stage (at 1000 cycles, mean depth of crack was 300 μm). However this type of measurement is very sensitive to spurious noise and to experimental conditions and therefore
seems not applicable to in-service monitoring. Crack diagnostic could not be as reliable as requested. On the contrary, AE source location plots have clearly changed when a crack has been initiated. This type of analysis is not so susceptible to environmental conditions and the appearance of source clusterings in a weld could indicate a crack is growing. This result could be obtained by periodically applied short monitoring. After a crack has been detected, a continuous monitoring could be applied to evaluate the evolution of the source activity. However, before considering such an application, other experiments are necessary to confirm previous results and to improve location accuracy.

5. Conclusions

In accordance with other works [2] our experimental results indicate that AE monitoring can detect thermal shock cracking at a very early stage. Location technique seems suitable to monitor functioning structures. However other experiments are necessary to establish the feasibility of this technique and to optimize the adjustments of AE measurements.

A trial of 1000 cycles will be applied on the same specimen in the next months and signal propagation study in the specimen will be carried out.

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Fig. 1 - Characteristics of test specimens

Fig. 2 - Block diagram of A.E. instrumentation
Fig. 3 - Typical records of temperature evolution during thermal shocks

Fig. 4 - Continuous A.F. monitoring - typical records
Fig. 5 - Summary of location results