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Development of a Simulation Technique and an Examination of a Mechanism for the Swelling of a Steam Generator Tube

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1. Introduction

Since 1983, in-service inspections of the bundle of steam generators have shown a swelling of some tubes in France [1]. At the end of 1996, this type of degradation affected 106 tubes in 14 steam generators from 11 units among the 54 EDF nuclear power plants.

Non destructive examinations of Inconel 600 steam generators tubes located the swelled zone of the tube just above the top of the tube sheet (TTS). The position of the swelled tubes was mainly at the periphery of the bundle. In more than 50% of cases, some loose parts have been found near the tubes.

In order to characterize this new kind of degradation and try to understand the mechanisms of a tube swelling, some tubes were pulled out and metallurgical examinations were performed at the EDF Irradiated Material Laboratory. Fig. 1 shows a photo of the most swelled tube.

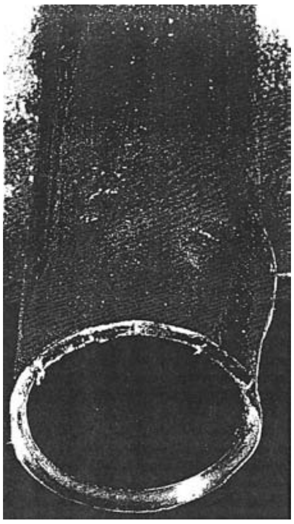

Figure 1. Picture of a swelled tube[1].

The laboratory examination clearly showed a high strain hardening on the outer surface of the swelled tube zone. Thus, the most probable cause of a swelling was suspected to be the presence of secondary side loose parts, impacting the external tube surfaces. A R&D program was developed in order to explain the appearance of this phenomenon and to evaluate its effect on the integrity of tubes [2].

Preliminary calculation with the CASTEM 2000 EF code showed that a phenomenon of hammering with low energy can lead to swelling by progressive deformation, then a simulation test program was performed using the bench PIVER. These tests validated the hypothesis that swelling can be a consequence of hammering with low energy.

Also, from the inspections of steam generator tubes in domestic nuclear power plants, deformation in the shape of a bulge was recently confirmed just above the TTS. This phenomenon is supposed to be similar to the new type of degradation observed in EDF steam generators and thus research is needed for the root cause analysis of the steam generator tube swelling in domestic nuclear power plants.

In this study, simulation technique for swelling of steam generator tube was developed and mechanism of swelling was investigated.

2. Experimental

For the simulation experiment of a swelling, a swelling simulation apparatus was manufactured. It consists of a tube fixing unit, an impactor (as a component for simulation of a loose part hammering) which can move along x, y, z-axes and a pressure control/maintaining device. A steel sphere with a size of 20 mm in diameter is attached to the top of the impactor which is driven by electrical motors. The movement of the impact system is controlled by an automatic device which works to read in programs. Inconel 600 MA (19.05 mm in diameter, 1.09 mm in thickness, 600 mm in length) and 690 TT (18.90 mm in diameter, 1.03 mm in thickness, 600 mm in length) tubes are surrounded and held vertically by a cylindrical sleeve. A schematic diagram of a swelling simulation apparatus is shown in Fig. 2.

At the conditions of impact energy of about 70 mJ, impact frequency of 1 Hz and internal hydraulic pressure of 1015 psi in tubes, swelling simulation tests were performed within a square shaped impact area of the tube outer surface. After a complete set of impacts for each specimen, the diameter of the maximum swelled zone was measured by digital vernier calipers

3. Results and Discussion

Fig. 3 shows the change in the diameter of a maximum swelled zone with the accumulated number of impacts for an Inconel 600 MA tube with a hydraulic pressure at 1015 psi. After 300,000 impacts, the magnitude of the increase in a diameter for a swelled zone is about 720 μm. It was saturated after 250,000 impacts and the change in a diameter as a function of the number of impacts showed a logarithmic form. From this result, it is demonstrated that the swelling of steam generator tube results from a loose part impact with a low energy.

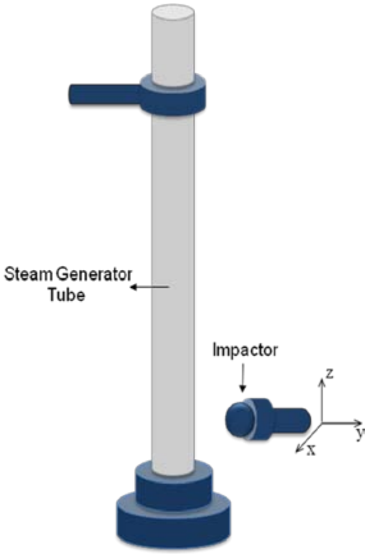

Figure 2. A schematic diagram of the swelling simulation apparatus.

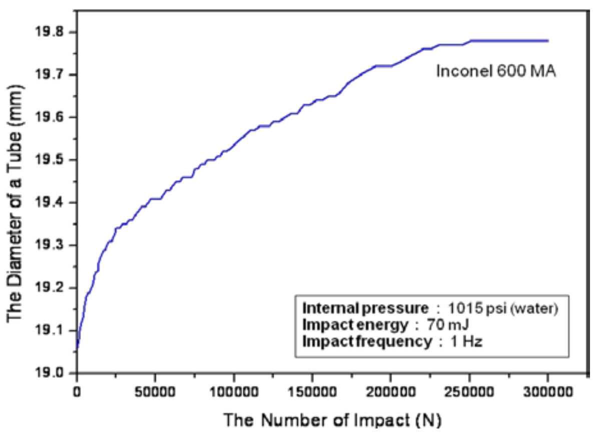

Figure 3. The change in the diameter of a maximum swelled zone for an Inconel 600 MA tube as a function of the number of impact.

Also, an experiment under the same condition was performed for an Inconel 690 TT tube. Fig. 4 shows the comparison of diameters of maximum swelled zones for Inconel 600 MA and 690 TT tubes. In the case of the Inconel 600 MA tube, the magnitude of the increase in a diameter of the swelled zone is about 290 ㎛ after 220,000 impacts. It is considered that the difference in the results of each experiment may due to the mechanical properties of the tubes.

In order to investigate the effect of the pressure media in tubes on a swelling, the swelling simulation experiment was conducted with an Inconel 600 MA tube pressurized with Ar gas at 1015 psi. As shown in Fig. 5, the increase of the diameter for the tube pressurized with Ar gas was a little smaller than that for the tube pressurized with water. However, it is considered that the effect of the pressure media on a swelling may be minor.

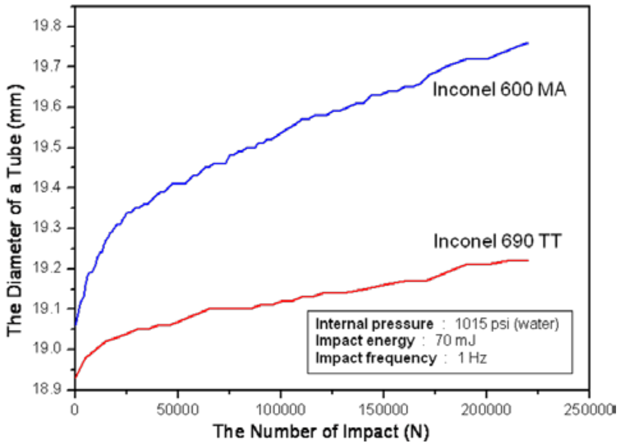

Figure 4. Comparison of the diameters of maximum swelled zones for Inconel 600 MA and 690 TT tubes as a function of the number of impact.

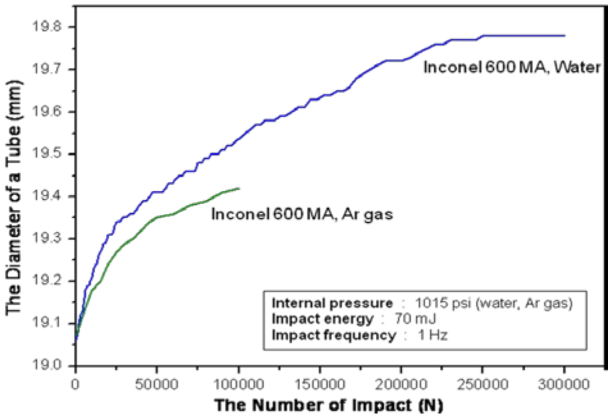

Figure 5. Effect of media in tubes on swelling of Inconel 600 MA tubes

4. Conclusion

• The swelling of a steam generator tube results from a loose part impact with a low energy, and is affected by the mechanical properties of tubes.
• It is considered that the effect of the pressure media on a swelling may be minor.
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