Can Operating Conditions affect CANDU® Pressure Tube Resistivity?

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Introduction

- Pressure tube (PT)– Calandria tube (CT) gap in CANDU® reactor fuel channels is monitored using eddy current based gap probe, as shown in Figure 1. Contact between the normally concentric tubes from sagging could result in compromised integrity of PT due to hydride blister formation [1].

- Material resistivity is an important parameter in eddy current based inspection [2-3].

- Currently, calibration for gap measurement is performed on a non- heat treated and non- irradiated PT, and PT resistivity is assumed to reflect that of in-reactor conditions [3-4].

- A material's resistivity depends on its microstructure. Changes in microstructure by irradiation, heat treatment, hydrogen ingress and deformation can lead to changes in resistivity [5-7].

- The fuel channel has both axial and circumferential temperature gradients, which contribute to microstructure variations in the channel, as shown in Figure 2. Temperature gradients cause non- uniform heat treatment to occur, which could lead to non- uniform changes in resistivity [1].

- Understanding the relationship between PT resistivity and material properties of the PT could improve assurance of PT integrity, leading to Plant Life Extension opportunities and Enhanced Functionality of the Gap probe, which is sensitive to in- channel resistivity [2-4].

- Of the multiple in-reactor mechanisms that could impact PT resistivity this study looked at the effect of heat treatment on the resistivity of Zr-2.5%Nb.

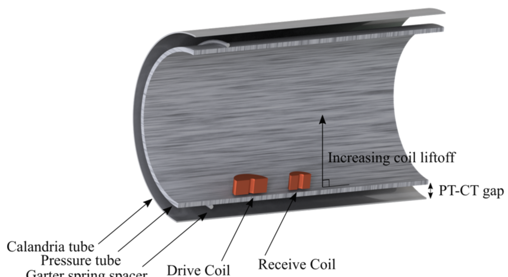

Figure 1. A half- section of a fuel channel with an inner PT and outer CT with a drive and receive coil, similar to that found on the Gap probe.

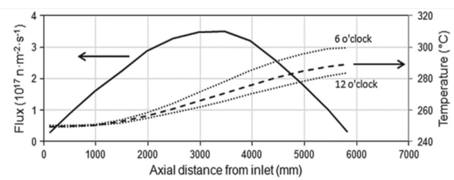

Figure 2. Flux and coolant temperature profiles along length of typical fuel channel. Note axial and circumferential variations. Figure from [1].

Experimental Methods

- Experimental process is outlined in process flow diagram (see Figure 3).

- Sectioned PT samples were held for varying periods of time at 400 °C and 450 °C under anaerobic furnace conditions, in order to decompose the beta- Zr and produce omega- Zr. Higher temperatures than those seen in-reactor were chosen to accelerate the phase transformations [8].

- Times and temperatures for heat treatment of samples were selected from Ref. [8] so omega- phase growth behaviour in samples could be related to Ref. [8] results, see Figure 4.

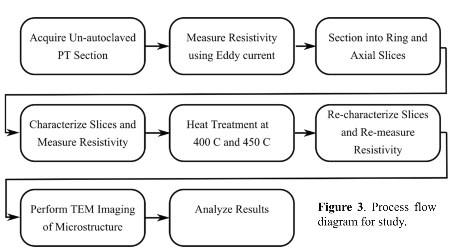

Figure 3. Process flow diagram for study.

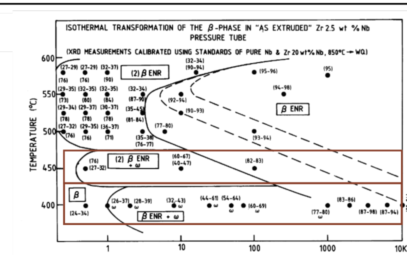

Figure 4. TTT- diagram for a Zr–2.5 wt%Nb pressure tube. The numbers in brackets refer to Nb concentration in beta-phase. Figure from [8].

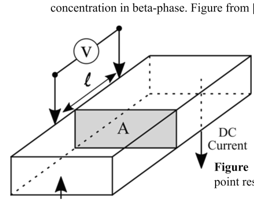

Figure 5. Basic setup for four-point resistivity measurement.

Results

- The magnitude of the resistivity was observed to decrease by up to 10% with time in the furnace, suggesting that an increase in omega- phase results in a decrease in resistivity, as shown in Figure 4 and 7.

- As a consequence, these results have implications for increasing the uncertainty in gap measurement [3-4].

- Change in resistivity due to pressure tube specimens held at temperature is associated here with changes in the microstructure during in- reactor operation over time [1].

- TEM imaging shows growth of omega- phase, consistent with the trend seen in Figure 4 [8].

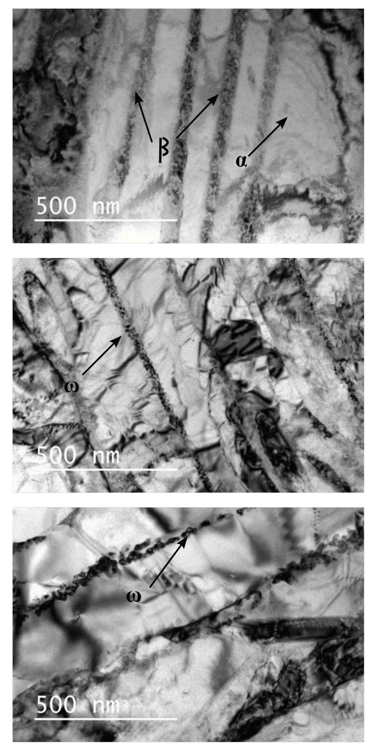

Figure 5. TEM imaging of omega- phase growth from no heat treatment (top) to 100-hr (middle) to 1000-hr (bottom) at 400 C. Follows similar trend seen in Figure 4 [8].

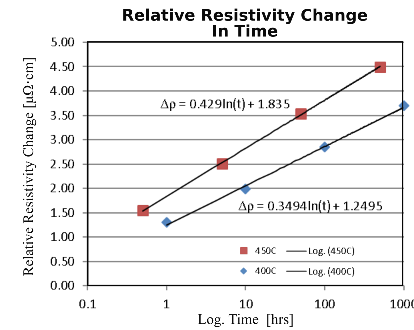

Figure 7. Relative Resistivity Change as a function of duration of heat treatment. The two temperatures follow a linear trend in semi- log space.

Conclusion

- Relative resistivity changes with heat treatment in Zr-2.5% Nb; up to 10% observed in study, as shown in Figure 7.

- R&D interest in improved assurance of PT integrity, Plant Life Extension opportunities and Enhanced Functionality of the Gap probe, which is sensitive to in-reactor PT resistivity.

- Identifying and quantifying additional mechanisms for resistivity changes in PT and CT is planned for future studies.

References

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Acknowledgements

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