ON THE OTHER PROPERTIES OF QUADRUPLE MELTED Zr-2.5Nb PRESSURE TUBES

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PURPOSE OF WORK:
Pressure tubes made from quadruple melted ingots have been shown to have excellent fracture toughness properties, but their other properties are also important. This paper summarizes comparisons carried out on the other (in- and out-reactor) properties of pressure tubes made from quadruple and double melted ingots. It shows that there is no difference in the other properties that can be attributed to the number of times the ingot was melted.

SUMMARY:
Pressure tubes used in CANDU reactors have been made from double melted Zr-2.5Nb ingots that were hot forged from approximately 600 mm diameter to produce billets that were machined into hollow billets with approximate dimensions 200 mm OD, 100 mm ID and length 600 mm. Thus, there was always at least 25% of the material from each ingot available for recycling.

Recently, pressure tubes made from material melted four times have been found to have superior fracture toughness properties compared with tubes made from ingots melted only twice (i.e., double melted, DM). This improvement in the fracture toughness arises because the quadruple melting (QM) reduced the concentration of chlorine and chloride-rich inclusions in the material. QM material is the material of choice for pressure tubes for future CANDU reactors.

There are, however, several other pressure tube properties that are of great interest as they affect the performance of the tubes. Among these are the tensile properties, the axial elongation rate in reactor, the oxidation and deuterium (D) pickup during service and the Delayed Hydride Crack growth rates (DHCV). Some of these properties could be affected by the change in ingot melting practice from the traditional DM to QM and it is of interest to determine if these properties are affected by the use of QM for ingots.

It has been found that the Zr-2.5Nb ingots contain different amounts of recycled material, from 0% to 100%. Ingots containing 100% recycled material are, in effect, QM, and it has been shown that pressure tubes made from them have excellent fracture touthness properties. Most reactor sets of pressure tubes contain some pressure tubes made from some ingots that were made up from 100% recycled material. The old Pickering Units 3 and 4 contained many such tubes.

Measurements carried out on pressure tube samples during manufacture have been reviewed and the tensile properties and corrosion resistance in the ASTM G 2 corrosion test compared for the QM and DM pressure tubes produced for some 17 units (about 8000 tubes).

The pressure tube axial elongation rates are measured during service, and the results available for five units have been reviewed to allow comparison of the rates shown by the QM and DM materials. Data from over 2000 fuel channels were available for the comparison.

During Large Scale Fuel Channel Replacement (LSFCR) in Pickering Units 3 and 4, material was set aside from many removed pressure tubes for evaluation, most from DM ingots and some from QM ingots. Many tests have been carried out in the hot cells on this DM and QM material, including the measurement of the oxide thickness, the axial DHCV and the transverse tensile properties. The results from these tests have been reviewed and the behaviour of the DM and QM materials compared. Oxide thickness data from over

900 measurements were used, together with data from 100 axial DHCV tests and 110 transverse tensile tests.

The deuterium picked up during service by the pressure tubes removed from Pickering Units 3 and 4 was also measured, but there is a possibility that some of the D may have entered the tubes from the annulus gas side. Thus the D data from these units are not considered suitable for studies of the D picked up via the inside surface of the tubes. However, several pressure tubes removed from other CANDU units have been analysed for their D concentrations and, in addition, the D concentrations in several pressure tubes in service have been measured in samples obtained from their top inside surface using Axial Scrape Tools. The D concentrations measured in these samples have been reviewed to determine if there is any effect that can be attributed to diferences in the QM and DM materials. Data from over 890 D concentrations were used in the review. Since the oxidation and D pickup rates are affected by the local temperature and the flux at the pressure tube inside surface, it was necessary for comparisons to separate oxide thickness and D pickup data into the appropriate reactor zones and into different temperature regions along the length of the fuel channels.

In most cases the comparisons were carried out between the QM material and the rest of the material. In some cases (e.g., the axial elongation rate) the data were examined to see if there was an effect arising from the different amounts (between 0 and 100%) of recycled material used in the ingots.

The review showed there was no statistically significant difference between the QM and DM materials for the different properties for which large databases were available.

There are some properties (e.g., K_{IH}, the stress intensity factor needed for DHC initiation) for which large databases do not exist, and for these properties the results from only a few tests are available. Comparison of the few measured values suggests that there is no difference attributable to the material being QM or DM.

CONCLUSION:
The review of properties (other than fracture toughness) of pressure tubes made from QM and DM ingots shows that there is no difference in the properties that can be attributed to the ingots used being melted twice (DM) or four times (QM).