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Modelling Phase Transformations in Zircaloy-4 Fuel Cladding under Transient Heating Rates

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Abstract : Zirconium alloys exhibit solid-state phase transformations under thermal loading. These can lead to a significant evolution of the microstructure and associated mechanical properties of materials used in nuclear fuel cladding structures. Therefore, the ability to capture effects of phase transformation on the material constitutive behavior is of interest during conditions of severe transient thermal loading. Whilst typical Avrami, or Johnson-Mehl-Avrami-Kolmogorov (JMAK), type models for phase transformations have been shown to have a good correlation with the behavior of Zircaloy-4 under constant heating rates, the effects of variable and fast heating rates are not fully explored. The present study utilises the results of in-situ high energy synchrotron X-ray diffraction (SXRD) measurements in order to validate the phase transformation models for Zircaloy-4 under fast variable heating rates. These models are used to assess the performance of fuel cladding structures under loss of coolant accident (LOCA) scenarios. The results indicate that simple Avrami type models can provide a reasonable indication of the phase distribution in experimental test specimens under variable fast thermal loading. However, the accuracy of these models deteriorates under the faster heating regimes, i.e., $100 Cs^{-1}$. The studies highlight areas for improvement of simple Avrami type models, such as the inclusion of temperature rate dependence of the JMAK n-exponent.

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