# QUANTITATIVE PREDICTION OF ENVIRONMENTALLY ASSISTED CRACKING

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Environmentally-assisted cracking (i.e. stress corrosion and corrosion fatigue) has presented a significant structural integrity problem in various industries including marine, petrochemical, aerospace and power generation. This may be attributed to various factors including inadequate databases for relevant engineering-based design criteria, and the complex interactions between the various material, stress and environmental conditions found in operating plant. Such shortcomings and complications lead to an inability to proactively manage the situation and, thereby, avoid a considerable financial penalty.

This situation is offset by the increase in quantitative understanding of the mechanisms of cracking over the last 20 years and this has allowed the development of a mechanistically based prediction methodology for the relevant degradation modes. Provided this methodology is qualified via adequate agreement between predictions and experimental and plant observations, it may be used to evaluate the existing engineering-based design and disposition criteria and to support proactive, cost-effective, life-management decisions.

This paper reviews the role that such developments have had in mitigating the problem of stress corrosion and corrosion fatigue of structural alloys in boiling water reactors (BWRs). These reactors have experienced cracking problems in, for instance, piping, pressure vessels and attachments, and in irradiated core internals.

Based on thermodynamic and kinetic reasoning, the slip oxidation model has been adopted as a working hypothesis for environmentally assisted cracking of ductile austenitic (i.e. stainless steels and nickel base alloys) in the oxygenated water environment in these particular designs of light water reactors. The model has been quantified by taking into account the oxidation kinetics at the localized alloy composition/environment at an embryo crack tip, and how these change as the protective oxide is ruptured at various frequencies associated with the details of the stressing system. The model has been qualified by comparison with laboratory and reactor data. For instance, Figure 1, it is apparent that the predicted dependence of crack propagation rate in sensitized type 304 stainless steel on the calculated crack tip strain rate is in fact observed; thereby underscoring the quantitative interrelation between stress corrosion, strain assisted cracking and corrosion fatigue, and the interdependencies between the material, straining and environmental conditions. Under constant stress conditions the dependency of intergranular cracking susceptibility on corrosion potential (Figure 2), anionic activity and stress intensity can be high, depending on the system definition. Thus the specification, control and effectiveness of life management actions (water chemistry control, stress modification, alternate alloys, etc.) depend critically on the specifics of the system definition.

These mechanisms-based developments and their use are outlined in a logical progression from the cracking of unirradiated stainless steels to the effect of irradiation on this cracking susceptibility to the cracking of nickel basealloys.

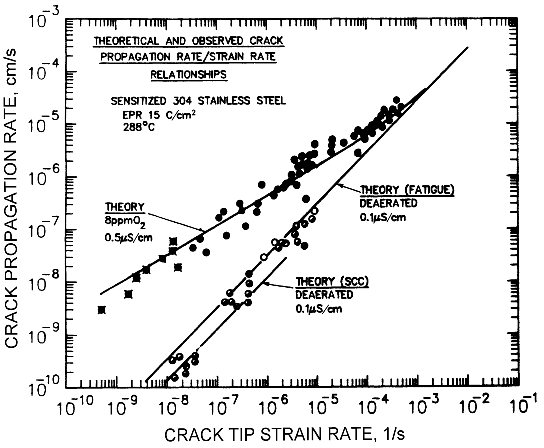

Figure 1 Observed data and theoretical crack propagation rate / crack tip strain rate relationships for sensitized type 304 stainless steel in aerated and deaerated water at 288$^0$C. Note the fact that the crack tip strain rate has been changed via different degrees of constant stress, cyclic loading and monotonically increasing strain, and that the dependency of propagation rate on strain rate is a function of the environmental condition. These complex materials, environment and straining interactions abound in these nuclear systems.

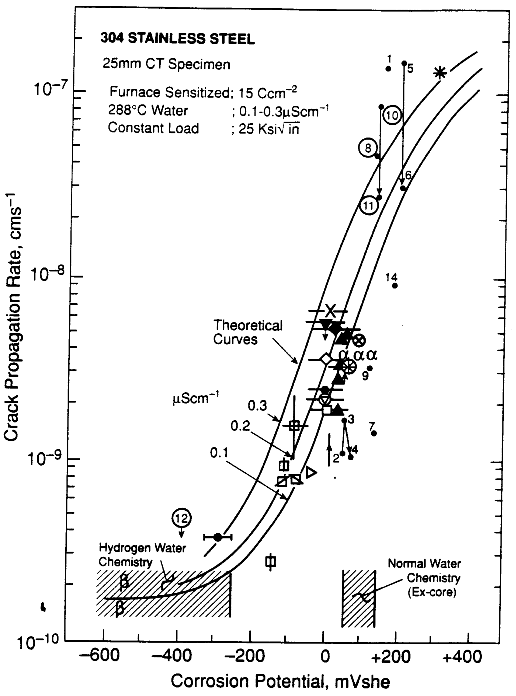

Figure 2. Observed data and predicted relationships between the crack propagation rate and corrosion potential for sensitized type 304 stainless steel in 288$^o$C water under constant load. Water conductivity in range 0.1 to 0.3 μS/cm. These predicted and observed relationships are the basis for mitigation actions based on environmental control.