DUCTILE-BRITTLE TRANSITION TEMPERATURE SHIFT CONTROLLED BY GRAIN BOUNDARY DECOHESION AND THERMALLY ACTIVATED ENERGY AND HYDROGEN GB EMBRITTLEMENT

Jun Kameda, Retired, USA
jun.kameda@gmail.com
Martin L. Jok, independent consultant

Keywords: ductile-brittle transition temperature, grain boundary segregation and embrittlement, effects of hardness and strain rate, hydrogen embrittlement

Classical structural problems of temper embrittlement are evaluated in terms of changes in the ductile-brittle transition temperature (DBTT). Experimentally, DBTT is not only strongly dependent on the effects of the type and amount of segregated solute X_{gb}^{s} at grain boundary (GB) but also on the hardness of the steel and strain rate.

Recent first-principles calculations provide the decohesion of the GB based on the concentration of different elements on the GB. The decohesion, $2\gamma_{int}$, is difference between the energy of the fracture surfaces and the energy of the GB ($2\gamma_{int} = 2\gamma_{fs} - \gamma_{gb}$) The calculations show that the decohesion is linearly related to the concentration of metalloids on the GB. The calculations show that the embrittling potency (Δe_p) of the different metalloids, Sb, Sn, and P, are ranked as follows: $\Delta e_p^{Sb} > \Delta e_p^{Sn} > \Delta e_p^{P}$.

This study reanalyzes earlier experimental data and attempts to correlate the effect of strain rate and hardness to DBTT on samples with GB embrittled with different concentrations of Sb, Sn and P. Charpy notched and cantilever static bending tests on 3.5 Ni – 1.7 Cr steels were performed at two different strain rates and at two different hardness.

It is found that DBTT is linearly related to X_{gb} when the strain rate and hardness are not changed. That is $DBTT = c + \alpha X_{gb}$, where c and α are constants that vary with strain rate and hardness. The constant c is function related to DBTT for cleavage fracture but the slope, α, is a function of strain rate only for the medium hardness steel, but is independent of strain rate for the hard steel.

The activation energy for the motion of dislocations that is responsible for the plasticity is estimated by relating the strain rate to activation energy and DBTT through an Arrhenius relationship. This activation energy then is correlated with the $X_{gb}$and Δe_p. The activation energy is strongly dependent on GB decohesion and high hardness sample

In addition, hydrogen GB embrittlement is linked with decohesion and analyzed in terms of micro- and macro-fracture mechanics.