Discussion

Discussion of "Delaminations by Cleavage Cracking in Duplex Stainless Steels at Sub-zero Temperatures"*

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The Swedish authors Pilhagen and Sandstrom[1] present a fascinating account of a duplex stainless steel, 22Cr-5.7Ni-3.2Mo, which, when tested at sub-zero temperatures, exhibited delaminations on the fracture surfaces of impact specimens, and cleavage fracture ahead of the crack tip in interrupted crack opening displacement (COD) tests.

Delaminations, cleavage fractures and facets, are all symptomatic of pre-cracked material. This is to be expected in a high Cr steel for which the oxide on the surface of the melt will be a dry, solid oxide rich in Cr. When mixed into the liquid metal by such turbulent actions as stirring or pouring, the surface oxide folds in, being entrained into the liquid, dry-side to dry-side, and so forming an unbonded interface between the opposed oxide films now suspended in the liquid. The unbonded interface is of course a highly effective crack. Thousands or millions of such cracks are generated by a turbulent pour of the liquid metal, but which are not easily observed because they are typically only nanometers thick, even though they may be μm, mm, or cm in diameter.

A normal duplex stainless steel will be expected therefore to have a dense population of such double oxide films, known as bifilms, which will be effective cracks. When first entrained into the liquid by turbulence of the surface, the bifilms are raveled and compacted by the bulk turbulence inside the liquid. However, during solidification, with encouragement from gases which diffuse into the central air gap, or because of dendrite pushing which flattens bifilms, the bifilms evolve from relatively harmless tangled and convoluted forms, straightening to become planar cracks resembling engineering cracks generated by stress. In this way they create the familiar features on fracture surfaces such as facets and apparently cleaved crystal surfaces.[2]

The expected population of cracks can not only account for the various flat forms of fracture surface, and the fractures observed ahead of the COD crack front as observed by the authors, but also explains the laminated form of their hot rolled steel which is seen to consist of horizontal layers of austenite and ferrite grains. The existence of oxide bifilms at grain boundaries will effectively pin the boundaries, suppressing easy recrystallization, so retaining the existence of boundaries during deformation by rolling, necessarily leading to a grain structure consisting of flattened grains, which would appear to be a highly energetically unfavorable aspect ratio for grains, and otherwise difficult to explain.

It is not necessary to entrain oxide bifilms during casting. Techniques are now available for the casting of metals without turbulence, and which are highly successful in delivering metals which are highly resistant to cracking, and therefore display impressive ductility, toughness, and fatigue resistance.[3] Corrosion properties are also enhanced, and such on-going mysteries as stress corrosion cracking and hydrogen embrittlement might also discover an important culprit or contributor.

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