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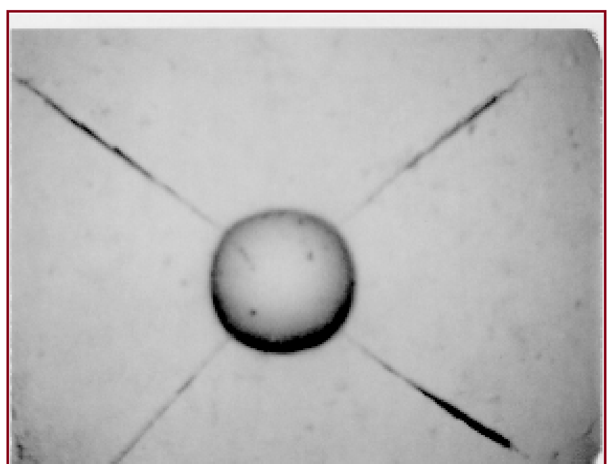
How can the ABI test determine the fracture toughness of ferritic steels?

Answer: It is agreed that an ABI test does not produce fracture in a metallic test sample (because of the plastic constraint and the ductility of the test material) and that there is no fatigue crack requirement for the ABI test (which makes it nondestructively attractive). However, there are four reasons for the success of this technique to determine fracture toughness of ferritic steels in the transition region. They are:
(1) the attainment of a high degree of stress-triaxiality (stress concentration similar to that ahead of a crack-tip) because of the plastic constraint provided by the test material surrounding the spherical indentation;
(2) the increase of the value of maximum stress (110% of the mean pressure in the material beneath the ball indenter) with increasing indentation depth until reaching or exceeding (at some low test temperatures) the critical fracture stress of the material;
(3) the fracture of ferritic steels at low temperatures in the transition region is controlled by the critical fracture stress of the material, and
(4) the critical fracture stress as a function of test temperature is calculated using Tetelman's equation and fracture toughness and yield strength results of PVS base metal and weld specimens tested at ORNL.

At a critical indentation depth (when the maximum stress underneath the ball indenter equals the critical fracture stress), the deformation energy (integration of the area under the indentation mean pressure versus indentation depth up to the critical indentation depth, in the same units as the J-integral) represents the temperature dependent part of the fracture toughness of the test material. A temperature-independent value of 30 MPa.m$^{0.5}$ is added to the ABI-determined fracture toughness value, similar to the equation of the fracture toughness master curve of ASTM Standard E1921-97. The fact that during an ABI test all the requirements to calculate the initiation fracture toughness are achieved at a critical deformation energy depth allows the determination of fracture toughness without any crack propagation (the latter is prevented by the high plastic constraint of the test material surrounding the spherical indentation). Hence, only fracture toughness initiation, and no tearing modulus, can be determined from the ABI test.

We produced cracks in two perpendicular directions in a single sodium chloride crystal using a 1.57-mm diameter ball indenter (see photograph below) which is proof that: 1) in addition to compressive stress underneath the indenter, ball indentation also creates tensile stress around the free surface edge, and 2) the maximum stress underneath the ball indenter reached the fracture stress of the single crystal.



In the non-standardized bulge test (sometimes called small punch test) a very thin sheet of metal is clamped in a die and a punch with a large spherical end is pushed against one surface of the thin sheet until the sheet is fractured on the opposite/tensile side. However, fracture toughness

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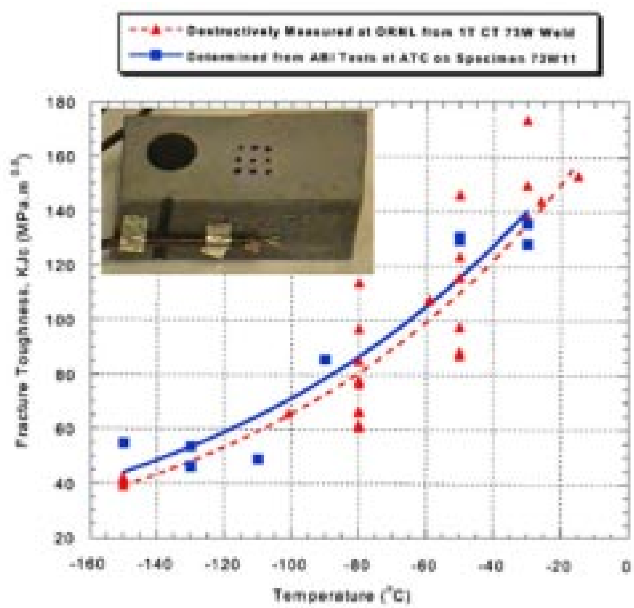
continued from the other side

cannot be calculated from the plane stress bulge test. In the bulge test, fracture occurs even though the specimen does not contain any fatigue crack prior to the test.

In an ABI test, the maximum stress underneath the indenter increases with depth but fracture does not occur because of the plastic constraint of the material surrounding indentation (the specimen or the structure thickness must be ten times the maximum indentation depth to avoid back surface effects and to obtain valid ABI test results). Furthermore, in a destructive J_{Ic} fracture toughness test, although we propagate/extend the fatigue crack, we extrapolate the power-law-fit of the J-integral versus crack extension curve to intersect a line parallel to the blunting line (0.2 mm offset line) where the intersection point determines the J_{Ic} initiation fracture toughness. This procedure is required since it is very difficult to stop loading the sample at the appropriate deformation energy level associated with the onset of crack extension from the pre-existing fatigue crack of the destructive fracture toughness specimen. This means that the fracture toughness value determined from the destructive test is actually a deformation energy up to the point of initial crack extension. Hence, the capability to determine fracture toughness from the ABI test without having to machine and fatigue crack a specimen is a truly innovative method.

Furthermore, the current and challenging need for numerous industrial applications is to obtain fracture toughness of ferritic steel structures without cutting boat samples to machine miniature fracture specimens. Miniature specimens often produce invalid fracture toughness values because of the violation of the geometry requirements for plane strain. For example, many pipelines and vessels are not manufactured in the large thickness required to obtain valid fracture toughness test results and often the owner of such components will not allow the cutting of a boat sample regardless of its size. Moreover, ABI tests produce valid fracture toughness values all of the time while the current ASTM destructive methods may never produce valid test results.

Another great advantage of the ABI test method is its applicability to small welds and heat-affected-zones where the current ASTM standard test techniques might not be feasible.



Fracture Toughness (KJc) Values Determined From Nondestructive ABI Measurements Are in Excellent Agreement with Destructive Values From One-Inch Thick Compact Tension Specimens

Reference:

Haggag, F. M., "Nondestructive and Localized Measurements of Stress-Strain Curves and Fracture Toughness of Ferritic Steels at Various Temperatures Using Innovative Stress-Strain Microprobe™ Technology," Report DOE/ER/82115-2, October 1999.