Fracture Toughness Tests

Toughness is a term that refers to a material’s ability to resist cracking through plastic deformation when a load is applied. Fracture toughness tests provide designers and engineers a rational means with which to estimate the effects of new designs, materials, or fabrication practices on the performance of structures and their resistance to cracking. Fracture mechanics analyses are typically performed to determine the conditions under which a stationary crack will propagate or a running crack will arrest. In service, the stored elastic strain energy in the structure is the driving force for crack propagation. In fracture toughness tests, the testing machine produces the energy.

Toughness tests can be grouped into three categories based on their use: crack propagation resistance, nil-ductility transition (NDT) temperature evaluation, and quality control.

Charpy V-Notch Test

The Charpy V-notch (CVN) impact test has gained worldwide acceptance and is employed for steel specification and quality assurance. The test does not provide fracture toughness directly, but it is often used to specify minimum acceptance criteria for the manufacturing of base and filler metals and to qualify welding procedures.

The CVN specimen is shown in Fig. 1. It is not precracked, but has a standard 45-degree radius notch. The correct notch tip radius is critical in ensuring consistent results.

The specimen is cooled (or heated) to a specified test temperature. It is then placed in the test machine and broken within five seconds. The testing machine uses a heavy pendulum to break the specimen. The angle of the pendulum upswing after breaking the specimen is calibrated to measure the energy absorbed by the fracture. Normally three specimens are broken with the minimum and average values reported. Specifications for most metals typically require a minimum energy absorption at a particular temperature.

In addition to absorbed energy, the percentage of shear fracture area can be measured. This is evaluated by observing the fracture surface of the specimen and estimating the relative amount of shear fracture, which looks rough or torn, to that brittle fracture (cleavage), which appears flat and faceted.

Lateral expansion is also used to indicate the relative amount of ductile tearing during fracture. Lateral expansion is reported in mils as the increase in width of the broken specimen over the unbroken specimen’s width. For a brittle specimen, the width of the break will be very close to the width of the unbroken section. A specimen that displays toughness will have significant tearing at the sides (shear lips), increasing the width.

Drop-Weight Nil-Ductility Temperature Test

The drop-weight nil-ductility test was created to determine the nil-ductility transition (NDT) temperature — the temperature above which a dynamic crack is arrested.

The test involves welding a brittle crack-starter bead on a test specimen and then notching the weld bead — Fig. 2. The specimen is chilled to the designated test temperature and a specific weight is dropped from a specific height to provide a potential energy of 250–1200 ft-lbf. The falling weight causes the specimen to deflect a fixed distance (restricted by stops). Upon application of the load, the specimen either breaks or fails to break. If the specimen does not break, the test temperature was above the NDT. Thus, a new test is performed at a lower temperature, generally in 10°F (5°C) increments, until the NDT is determined. A second test is then per-
formed at this temperature to confirm the result. This test is also employed as an acceptance test for steel plates and shapes. When the drop-weight test is used as an acceptance criteria, a temperature is usually specified at which a no-break performance is required.

**Dynamic Tear Test**

The dynamic tear test was developed to characterize the fracture properties of ultrahigh-strength steels, as well as aluminum and titanium alloys that do not exhibit sharp transition temperature behavior. This test is performed under impact loading, and the resulting absorbed energy at various testing temperatures can consistently define the NDT temperature.

The test specimen is prepared by machining the rectangular shape with the notch geometry—Fig. 3. The final notch tip is prepared using a 0.001-in.- (0.025-mm-) radius hardened knife edge that is pressed into the bottom of the notch to provide a distance of 1.125 in. (28.6 mm) between the notch tip and the back of the specimen.

The specimen is then cooled (or heated) to the test temperature and struck by the impact load, which is provided by a falling weight or pendulum. The dynamic tear testing machine is calibrated to provide the energy absorbed by the specimen, which is reported.

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**Fig. 2 — Standard drop-weight test specimens.**

<table>
<thead>
<tr>
<th>Dimensions, in. (mm)</th>
<th>P-1 Specimen</th>
<th>P-2 Specimen</th>
<th>P-3 Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, Thickness</td>
<td>1.0 (25)</td>
<td>0.75 (20)</td>
<td>0.62 (16)</td>
</tr>
<tr>
<td>L, Length</td>
<td>14.0 (360)</td>
<td>5.0 (125)</td>
<td>5.0 (125)</td>
</tr>
<tr>
<td>W, Width</td>
<td>3.5 (88)</td>
<td>2.0 (50)</td>
<td>2.0 (50)</td>
</tr>
<tr>
<td>DL, Deposit length</td>
<td>2.5 (64)</td>
<td>1.75 (45)</td>
<td>1.75 (45)</td>
</tr>
</tbody>
</table>

**Fig. 3 — Dynamic tear test specimen configuration.**