Fracture toughness can be represented by three parameters, which are critical stress intensity factor (), the critical value of the integral (), and the critical crack-tip opening displacement ( or ). The common method of fracture toughness tests include plane-strain fracture toughness test (), charpy v-notch test (), and crack-tip opening displacement test ().

, which characterizes the lowest bound of brittle fracture toughness in plane-strain behavior, is hard to determine directly by test in most applications. This is because most members do not have sufficient thickness for plane-strain conditions, which requires a thick specimen thickness (t) satisfying following equation.

|  |  |
| --- | --- |
| (not relevant) | (1)[1] |

where

t= pipe wall thickness, m

= static yield strength, Mpa;

= plane strain fracture toughness,

Therefore, the direct  test result is defined to be invalid for most thin pipes.

Alternatively, test results have been studied to correlate test result for many years, which is easier and more economical to conduct. A CVN-KIc empirical relationship discovered by Barson and Rolfe (1987) is commonly used. At higher temperature in the upper shelf region, the correlation is given by

|  |  |
| --- | --- |
|  | (2)[2] |

where

= plane-strain fracture toughness,

= static yield stress at the temperature of interest, Mpa

= charpy V-notch impact value, J

The CTOD test is used for too ductile material with section that is too thin to be tested for . The “equivalent” value can be inferred from CTOD and J data obtained from test under plane strain linear elastic conditions. The relationship of three parameters are given by

|  |  |
| --- | --- |
|  | (3) |
|  | (4) |
|  | (5) |

where

=equivalent fracture toughness derived from or value,

=critical - integral value, kJ/m2

=young’s modulus at the temperature of interest, Gpa

= possion’s ratio in the elastic range, normally taken as 0.3 for steels

= conversion constant, taken as 1.4 in the absence of more reliable information (This under F.8 Nomenclature page 1019 in the pdf)

= flow stress, taken as the average of the static yield () and tensile strength (), Mpa

= critical crack-tip opening displacement (CTOD) toughness, mm

Assume that plane strain fracture toughness () derived from charpy v-notch test and CTOD test is equal, and therefore critical crack-tip opening displacement toughness () can be inferred from above equations, and results are shown in the table below.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | E  (Gpa) | (J) | ( | (kJ/m2) | (mm) | (mm) |
| Longitudinal direction | Base metal | 410 | 570 | 490 | 199 | 123 | 177 | 143 | 0.2080 | 0.5467 |
|  | New HAZ | 419 | 526 | 473 | 206 | 168 | 210 | 194 | 0.2933 | 0.7467 |
|  | Old HAZ | 420 | 509 | 465 | 205 | 149 | 197 | 173 | 0.2657 | 0.6622 |
| Circumferential direction | Base metal | 422 | 553 | 488 | 226 | 123 | 179 | 129 | 0.1893 | 0.5467 |
|  | New weld | 425 | 586 | 506 | 213 | 142 | 194 | 160 | 0.2262 | 0.6311 |
|  | Old weld | 435 | 563 | 499 | 207 | 69 | 134 | 79 | 0.1133 | 0.3067 |
|  | New HAZ | 445 | 566 | 506 | 216 | 168 | 216 | 196 | 0.2773 | 0.7467 |
|  | Old HAZ | 424 | 563 | 494 | 218 | 149 | 198 | 164 | 0.2373 | 0.6622 |
| Average |  |  |  |  |  | 146 | 197 | 162 | 0.2325 |  |

In addition, the obtained value should be checked against CVN value according to CSA Z662-1. The maximum value of should be smaller than both and , which are given by

|  |  |
| --- | --- |
|  | (6) |
|  | (7) |

where

= minimum charpy impact energy, J

= average charpy impact energy, J

Conclusion:

Taking into account all data obtained from charpy specimens from base metal, weld metal and HAZ, the average of the Charpy impact energy (CVN) is 146 Joule. Accordingly, the empirical estimated plane-strain fracture toughness () is 197 , which is a conservative result. Based on the assumption that  from CVN test is equal to equivalent from CTOD test, the critical value of the integral  is 162 kJ/m2, and the critical crack-tip opening displacement toughness or  is 0.2325mm. Any of these three parameters , , and can be used for assessing fracture toughness. However, the results obtained above are not direct indication of the fracture toughness of the material, it is simply an estimate of fracture toughness based on CVN test. Although results are conservative, they can be regarded as a good reference when direct tests are not available.

**References**

[1] Inspection, Evaluation, and Repair of Hydraulic Steel Structures, EM 1110-2-6054, page 5-5 (57 in the pdf)

[2] API 579-1 on page F-14 (138 on pdf)

[3]