The 𝑐2 fracture parameter is defined as a function of the diffusible hydrogen

content̄ 𝑐 𝐿 to make the criterion depend on the hydrogen concentration. Experimental tests of hydrogen-charged specimens are needed to define the functional dependence of 𝑐2 with̄ 𝑐 𝐿, so the MC criterion reads as

|  |  |  |
| --- | --- | --- |
|  |  | (220) |

The equation developed by this thesis defines the parameter as follows

|  |  |  |
| --- | --- | --- |
|  |  | (221) |

where:

* ​ – The intrinsic cohesive strength in the absence of hydrogen.
* – A scaling factor that quantifies the sensitivity of cohesive strength to H concentration.
* ​ – The local H concentration.
* – An exponent that controls the non-linearity of the degradation effect. Typical values range from 1 to 3.

Unfortunately, the fitting is not good with high RMSE of 200 MPa, so it is possible that the stress-based MC criterion is not suitable for CP1000 steel. In brief,

ANNEX E: FEM formulation of Abaqus’s C3D8 element for structural deformation field

B-bar method in C3D8 element

The ideal solution for elements which suffer from incompressibility constraints is to break up the stiffness matrix into two parts, one dilatational and one deviatoric. It is the dilatational part which produces the overstiff response. This part can then be integrated using a lower order integration rule. This method is called selective integration method.

The element stiffness is given as

The element internal force vector is given as

where *nnode* is the number of element nodes. For C3D8 elements, nnode is 8. The strain displacement matrix for each node is

Where is the shape function associated with node *knode* at the current IP *kinpt*, and, are the Cartesian coordinate.

Numerically, the stiffness matrix, AMATRX in UEL subroutine, is defined as

In this case, for all IP

The right hand side, RHS in UEL subroutine, is defined as

Let  denote the volumetric (dilatational) part of

The deviatoric part of is then defined by

The Bbar method is defined as

Now we only need to define

Where the values in the matrix are

Where is defined as follows

Same calculation is for y and z direction

Numerically, the stiffness matrix, AMATRX in UEL subroutine, is defined as

In this case, for all IP

The right hand side, RHS in UEL subroutine, is defined as