Case N-XXX, Rev 10g (17-2049) – 0204/1420/2020

Flaw Evaluation Procedure for Cast Austenitic Stainless Steel Piping and Adjacent Fittings
Section XI, Division 1

Inquiry:
For evaluation of circumferential surface flaws in CF3, CF8, and CF8M cast austenitic stainless steel (CASS) piping and fittings adjacent to girth welds, what method for predicting failure mode may be used as an alternative to C-4210, and what Z-factor may be used as an alternative to C-6330?

Proposed Reply:
It is the opinion of the Committee that the following method may be used for predicting failure mode as an alternative to C-4210, and for predicting the Z-factor as an alternative to C-6330, for circumferential surface flaws detected in CF3, CF8, and CF8M cast austenitic stainless steel (CASS) piping and fittings adjacent to girth welds.

1 Scope
(a) The provisions of this Case apply to circumferential surface flaws in CASS piping and fittings fabricated from CF3, CF8 and CF8M materials, for a distance of \( \sqrt{R_t} \) from the centerline of the weld into the fitting. A flaw is considered to be in a weld if it falls within the region defined in C-1100, with the following additional provision. For a flaw in these CASS products, the flaw is evaluated as if it is in the weld metal only if it is between the fusion lines, otherwise the flaw is evaluated as if it is in the base metal. If the flaw location is not precisely known, the higher Z-factor for the base metal or weld metal shall be used.

Figure 1  Weld material–base material interface definition for flaw location

![Weld material–base material interface definition for flaw location](image)
(b) The provisions of this Case shall be applied to operating temperatures of 500°F (260°C) to 625°F (330°C). If a thermal transient below these temperatures occurs at the flaw location, the appropriate toughness (\(J\)) at the minimum transient temperature shall be used along with the applied stresses at that thermal transient.

(c) The provisions of this Case shall be applied to CASS that has an elemental composition parameter \(\xi\) (see Equation (1)) between 2.5 and 5.5.

Figure 2  Flow chart illustrating use of analysis procedures in this Case relative to Appendix C procedures for circumferential surface flaws
NOTE:
(1) Exact flaw location in weld or base metal cannot be determined.

2  Applicability

(a) CASS pipe and fitting material subjected to long-term high-temperature service can experience a toughness reduction due to thermal aging. Toughness of thermally-aged CASS materials may be characterized by a statistically based parameter combining the elements from the CASS composition using a parameter $\xi$, see Equation 1. This Case is applicable to the CASS materials CF8M, CF8, and CF3 that are fully-saturated, partial-aged, or have no thermal embrittlement. For CF8M, long-term fully-saturated conditions occur at approximately 15 years of hot-leg operation.
(b) This procedure is applicable only to circumferential surface flaws. If the circumferential surface flaw location can be clearly defined to be in the weld metal (fusion line to fusion line in accordance with Figure 1), the circumferential surface flaw evaluation procedures for the weld metal in Appendix C shall be used. If the circumferential surface flaw location can be clearly defined to be in the applicable CASS base metal of either side of the weld (from the fusion line and outward into the base metal as shown in Figure 1), the CASS base metal properties of that flaw location shall be used in accordance with Part 3 of this Case for determination of the Z-factors. If the flaw location cannot be clearly defined to be either in the weld or adjacent CASS base metal, the flaw shall be evaluated at both the weld location and the CASS base metal location in accordance with Article C-6300. The higher of the Z-factors for the weld from C-6330 and from Part 3 of this Case shall be used.

(c) If the calculated Z-factor for the CASS base metal at the end-of-the-evaluation period is less than or equal to 1.05, plastic collapse (limit-load) is the controlling failure mode. If the calculated Z-factor for CASS base metal at the end-of-the-evaluation period is greater than 1.05, the failure mode is characterized by elastic‐plastic fracture mechanics (EPFM) and Z factors of this Case shall be used with C-6300. This procedure replaces the screening criterion in C-4210.

(d) The EPFM and limit-load failure modes are applicable to the CASS for the temperature range of 500°F to 625°F (260°C to 330°C). Equations (2a) and (2b) are not applicable outside of this temperature range. At lower temperatures, the toughness could be lower, and the user shall determine the toughness for those operating conditions, and shall be used in Equation (3).

3 Procedure
(a) The sequence for determining the failure mode that is used in lieu of the screening criteria in C-4210, and the analysis method, are illustrated in the flow chart in Figure 2 and are described below.

(b) The following procedure shall be used to calculate the Z-factors for the applicable CASS using the composition-specific properties of the fully-saturated thermally-aged CASS. These values may be used for partially-aged or unaged CASS. If there is a transient temperature below 500°F, a \( J_1 \) value shall be determined by the user. If the chemical composition of the CASS is not known, \( \xi = 2.5 \) shall be used.

(c) For CASS pipe and fittings, the Z-factor is a function of the \( \xi \) value and pipe diameter. The \( \xi \) value is calculated using the chemical composition from the material certification sheet for the pipe or fitting where the flaw is located (see Equation 1). This analysis is applicable to CASS material with \( 2.5 < \xi < 5.5 \). The following equations shall be used to calculate the Z-factors.
\[ \xi = (11.25 \cdot 2.185\text{Si} - 0.224\text{Cr} - 0.515\text{Mo} + 19.432\text{N}) \]  

**US Customary Units**

\[ J_i = 5.025(e^{\xi} - 3.32), \text{in.-lb/in.}^2 \]  

**SI Units**

\[ J_i = 0.88(e^{\xi} - 3.32), \text{kJ/m}^2 \]

For US Customary units or SI units,

\[ Z = \left(\frac{\pi}{2}\right)/(\text{arc cos}[\exp(\text{-}29\cdot\text{DPZP})]) \]

\[ \text{DPZP} = \left(\frac{2E J_i}{\pi^2 \sigma_f^2 D}\right) \]  

## 4 Acceptance Criteria

The acceptance criteria of C-2600 shall be used.

## 5 Definitions

- **Cr**: Chromium, wt.%
- **D**: Pipe mean diameter, in. (mm)
- **DPZP**: Dimensionless Plastic-Zone Parameter
- **E**: Elastic modulus, psi (MPa)
- **J_i**: Fracture toughness at start of ductile tearing (J at 0.2mm or 0.0078 inch in unloading compliance tests), in.-lb/in.² (kJ/m²)
- **Mo**: Molybdenum, wt.%
- **N**: Nitrogen, wt.% (if undetermined use 0.04 wt.%)
- **R**: Mean pipe radius, in. (mm)
- **Si**: Silicon, wt.%
- **S_y**: Code-specified yield strength at operating temperature, psi (MPa)
- **S_u**: Code-specified ultimate strength at operating temperature, psi (MPa)
- **t**: Thickness adjacent to girth weld bevel, in. (mm)
- **Z**: Z-factor load multiplier as defined in Equation 3
- **\sigma_f**: Material flow stress that is the average of yield strength and ultimate tensile strength at operating temperature or \((S_y + S_u)/2\); if known, the aged strength values for the heat being evaluated may be used, psi (MPa)
- **\xi**: Statistical combined element relationship in Equation 1; if unknown use \(\xi = 2.5\)

(Note to Editor: applicable from 2004 Edition up to and including 2019 Edition.)