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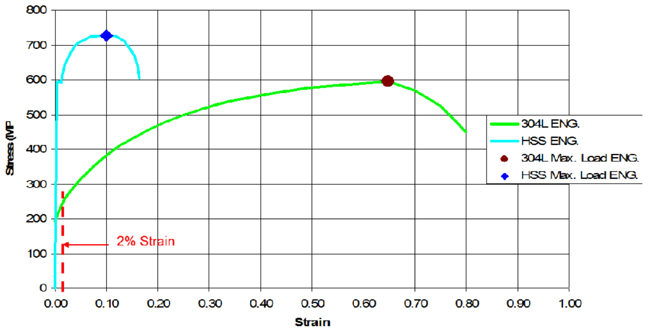

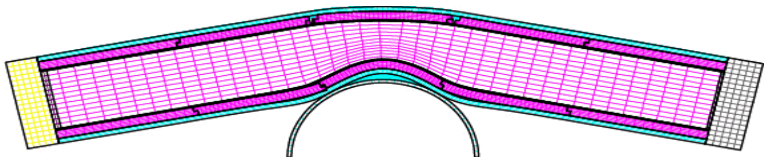

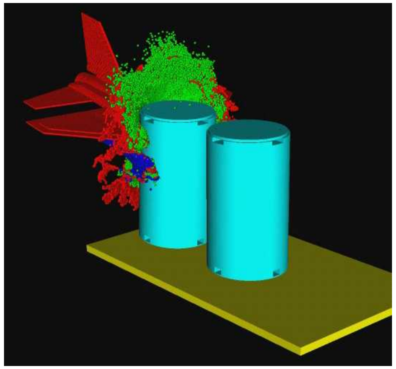

Strain Based Acceptance Criteria in Div. 3, Section III, of the ASME Boiler and Pressure Vessel Code

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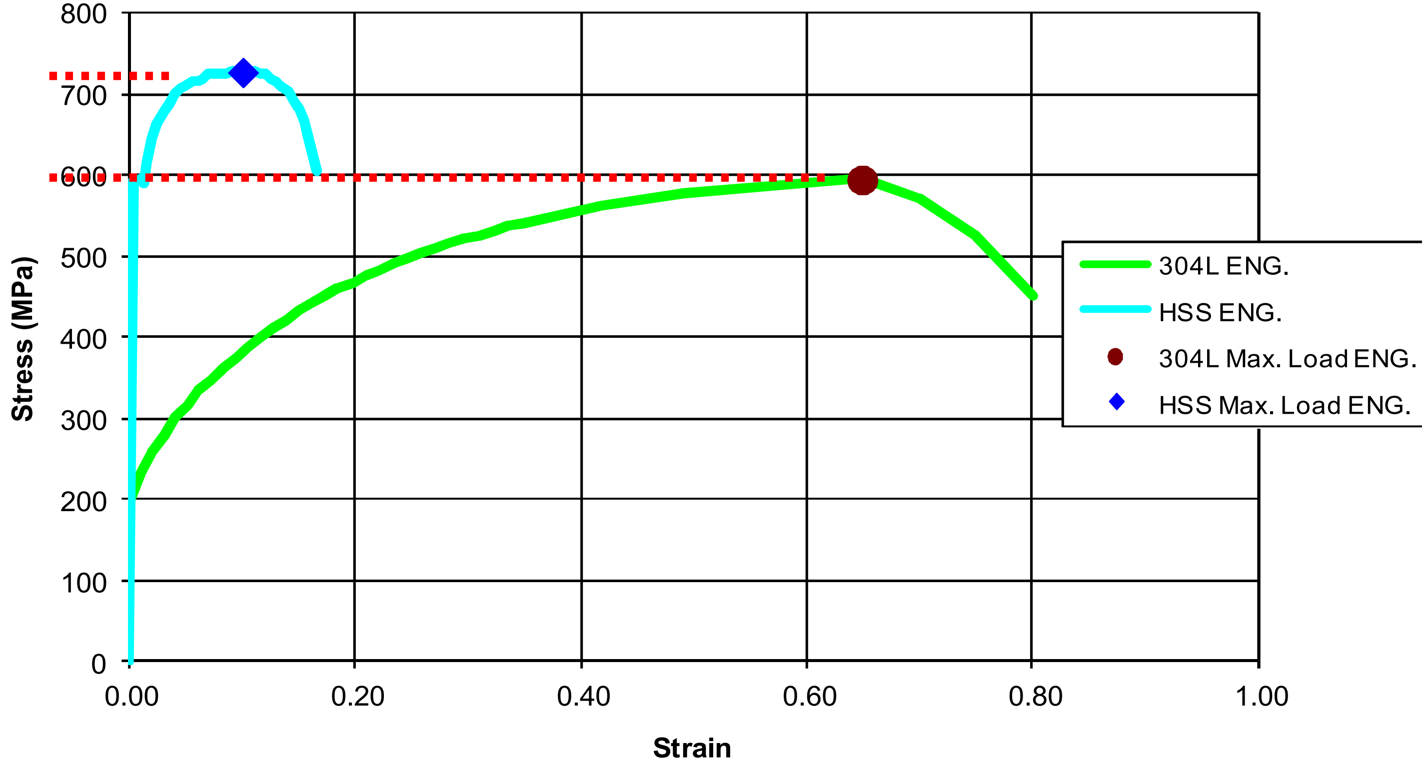
Why are strain-based criteria needed?

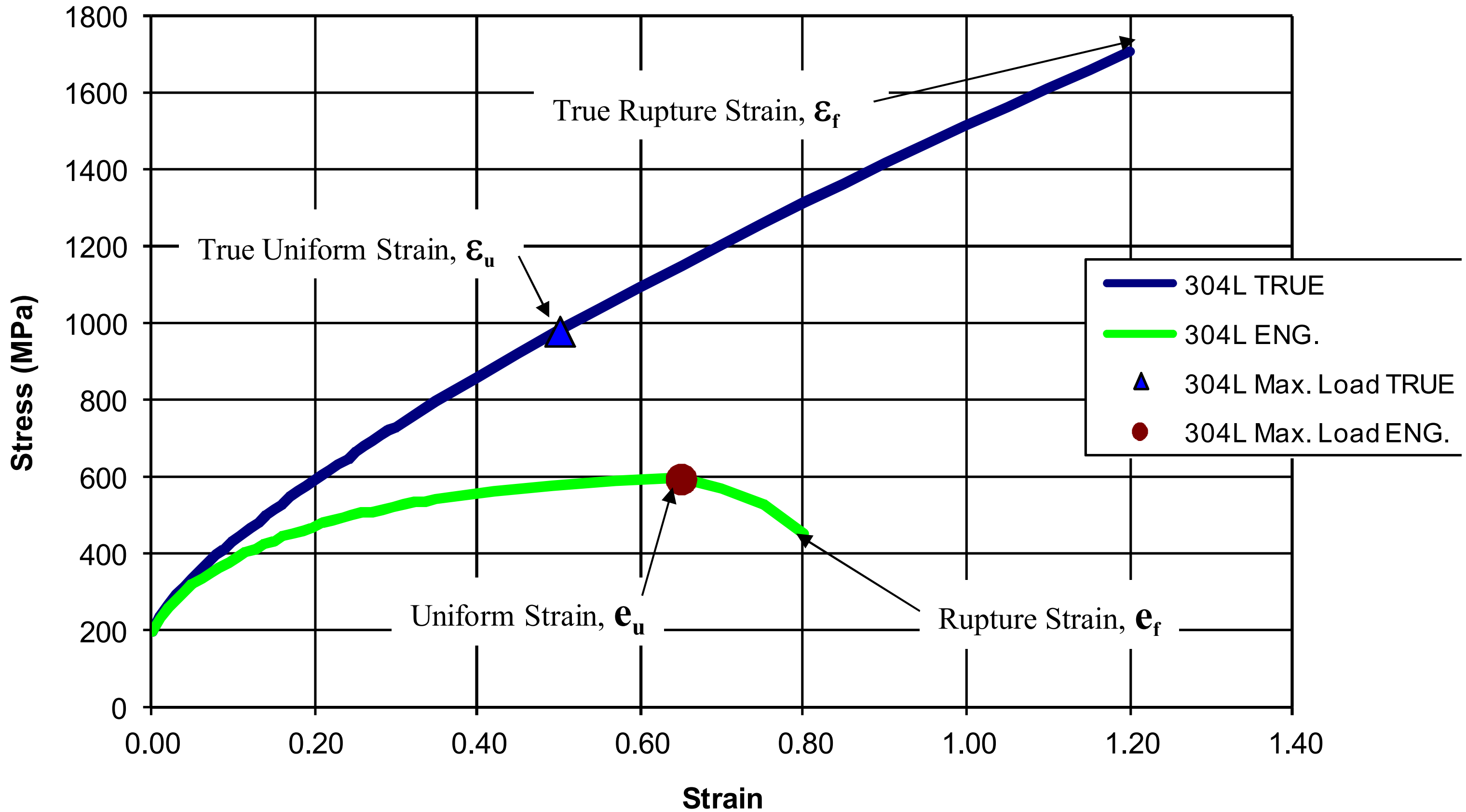
- Many of the loading conditions for transportation and storage casks are energy limited.
- Stress-based criteria push designers toward high-strength material that may be less ductile.
- A quote from Bill Cooper, founder of Appendix F.

> 5.3.4.5.2 Energy-controlled conditions. It is poor practice to apply criteria developed for load-controlled conditions to energy-controlled conditions when deformations do not have to be controlled; and, as was cited earlier, it is not the intent of Appendix F to limit deformations. If the condition is energy controlled, the structural acceptance criteria should be related to structural energy absorption. The only way to achieve that objective is to present the criteria in terms of strain limits which are proportional to the usable ductility of the material under the imposed stress state.

The ASME Code Stress-Based Criteria can Lead to Poor Material Choices



Strain-Based Acceptance Criteria for Energy-Limited Accident Events



Any Strain-Based Acceptance Criteria Must Have Four Essential Components

- Strain-Based Criteria must be based on specific characteristics of a material's behavior and its stress-strain curve.
  - Uniform Strain, ε_u
  - Failure or Rupture Strain, ε_f
- Uncertainty in material properties must be accounted for by using minimum properties (mean – 2σ, or 98% EP)
- Triaxiality Factor applied to the minimum properties to account for the potential loss of ductility due to state of stress
- The numerical factors chosen to limit ε_u and ε_f in the strain-based criteria to account for uncertainty in
  - Loading
  - Quality of Construction
  - Quality of the Analysis

Proposed Applicability

- Transportation and storage containments
- Non-cyclic, energy-limited events for which Level D Service Limits have been established
  - Impacts without impact limiters or with integral impact limiters
  - Puncture events
  - Aircraft and missile impacts
  - Non-mechanistic tip-over of storage casks
- 304/304L and 316/316L materials only
- Base material and full penetration welds
- Not for regions where strain deformations are detrimental to maintaining the desired leakage rate (e.g., sealing region of a bolted closure)

Strain Determination

- Uses equivalent plastic strains calculated with FEA programs using Explicit solution methodology
  - Equivalent (true) plastic strain (ε^p_{eq}) is defined as:

$$\varepsilon_{eq} = \int_0^t \sqrt{\frac{2}{3}\, \dot{\varepsilon}^{pl} : \dot{\varepsilon}^{pl}}\, dt$$

- Accurate determination of predicted strains using ‘quality models’
- Strain rate effects and fabrication strains are addressed

Strain-Based Acceptance Criteria

- Locations away from a gross or local structural discontinuity
  - $[TF \cdot (\varepsilon^{p}_{eq})]_{avg} \leq (0.67\ \varepsilon_{uniform})$
  - $[TF \cdot (\varepsilon^{p}_{eq})]_{max} \leq [\varepsilon_{uniform} + 0.25\ (\varepsilon_{fracture} - \varepsilon_{uniform})]$
- Locations at a gross or local structural discontinuity
  - $[TF \cdot (\varepsilon^{p}_{eq})]_{avg} \leq (0.85\ \varepsilon_{uniform})$
  - $[TF \cdot (\varepsilon^{p}_{eq})]_{max} \leq [\varepsilon_{uniform} + 0.25\ (\varepsilon_{fracture} - \varepsilon_{uniform})]$

Degradation of strain limit due to state of stress

- Triaxiality factor (TF) is defined as:

$$TF = \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{\sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}}$$

- Many finite element codes use mean stress, instead of first stress invariant, as the numerator (this divides the TF by 3)
- The proposed rule does not allow for the increased ductility that occurs with compressive states of stress, and requires the TF to be always greater than or equal to one.
- The proposed rules penalize the allowable strains under bi-axial tension.

Status

- The rules for applying the strain-based limit are currently being balloted within the ASME Code Committee.
- They have been approved by the Committee for Design of Division 3 Containments.
- They have been approved by Subgroup on Component Design (BPV III) and Working Group on Design Methodology (SG-D) (BPV III)
- Still must be approved by Committee on Construction of Nuclear Facility Components (BPV III)
- Expect to be part of the 2013 version of the Code