Stress Relaxation Cracking in Austenitic Materials: Mechanism, Mitigation, and ASME BPVC Code Considerations

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Stress Relaxation Cracking (SRC) is a critical failure mode in high-temperature applications of austenitic materials, it can occur where high level of tensile residual stresses especially within the weld heat-affected zones (HAZ) or in cold formed area. It is particularly prevalent in austenitic stainless steels and nickel-based alloys used in the fabrication of critical components such as superheaters and reheaters in petrochemical and power generation industries. Unlike traditional forms of cracking like hot cracking or creep rupture, SRC develops during the relaxation of residual or applied stresses at elevated temperatures.

This article explores the fundamental mechanisms of SRC, compares Alloy 800H with stainless steel grades like SS347H in their susceptibility and response to SRC, and examines mitigation strategies under ASME Boiler and Pressure Vessel Code (BPVC) provisions as the main design code for pressure vessels and boilers in oil and gas industry and in nuclear applications as well.

Special Consideration

Addressing stress relaxation cracking (SRC) in equipment and weld joints requires special attention for three key reasons. First, SRC is challenging to detect during its early stages, yet once it initiates, it often progresses rapidly to failure in a brittle manner—typically rupture—early in the equipment's service life. Second, SRC predominantly occurs in thick-walled components operating at elevated temperatures, which are typically used in critical, high-risk applications. Third, the current design codes, such as the ASME Boiler and Pressure Vessel Code (BPVC), do not fully account for all the factors necessary to prevent SRC. A recent report by the U.S. Nuclear Regulatory Commission (NRC) [1] identified this as a significant gap in the ASME BPVC provisions.

Figure 1 [Ruptured Superheater steam coil, SS316H by SRC [2]]- shows the rupture of a superheated steam coil outlet header, made from 48 mm thick SS316H, caused by stress relaxation cracking (SRC) at the longitudinal seam weld. The rupture resulted in extensive damage within the convection section of the steam reformer at a methanol plant. Additionally, large fragments of debris were projected up to 100 meters across the site, impacting surrounding areas [2]

There are other names of stress relaxation cracking mechanism as indicted below [3]:

During fabrication	During service
Reheat cracking	Creep Embrittlement Cracking
Stress Relief cracking	Stress Induced Cracking
	Stress Assisted Grain Boundary Oxidation Cracking

Morphology and critical factors of SRC

SRC is intergranular and can be surface breaking or embedded depending on the state of stress and geometry. It is most frequently observed in coarse-grained sections of a weld HAZ; however, it can also occur in weld deposits.

In many cases, cracks initiate at some type of stress concentration. Once initiated, SRC cracks can enable further propagation by fatigue cracking.

There are three main factors contributing to SRC, 1)Residual stresses 2) Susceptible microstructure 3) elevated temperature in creep dominant regime [10]. Cracking happens without any gross plasticity, and most of the deformation is concentrated at grain boundaries. Alloys susceptible to SRC contain alloying elements that encourage the formation of fine intragranular precipitate particles, making the grains stronger than the grain boundaries.

Consequently, creep deformation resulting from stress relaxation concentrates at the grain boundaries and eventually causes intergranular cracking. [1]. That is why stabilized grades of austenitic stainless steel like SS347 and SS321 are more susceptible than SS304. [3]

Smaller grain sizes resist SRC better. Grain growth can be controlled by using lower solution annealing temperatures, achieving ASTM 4 or finer grains. Traditional heat treatment of austenitic alloys results in coarse grains (ASTM 5 and coarser), which improve creep resistance but also increase SRC risk after cold forming.[3]

The cracks are always located on the grain boundaries and in front of the crack's, small, isolated cavities are present. Mostly, a metallic filament is present on the cracked grain boundaries. This filament is enclosed by a chromium-rich oxide layer. In this oxide layer, the Ni and Fe contents are low. The chemical composition of the metallic filament is material dependent but always low in chromium and high in nickel (for 800 alloys) and iron (for SS alloys). Refer to figure-2 for typical crack morphology.

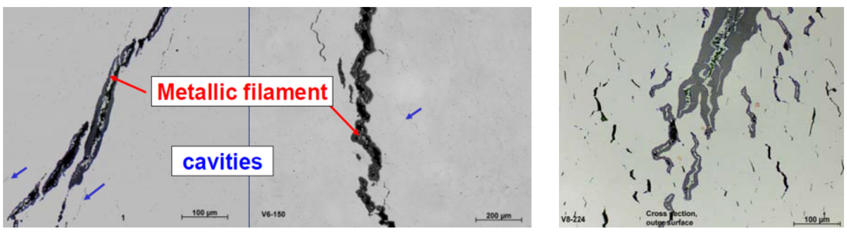

Figure-2, Typical SRC morphology showing metallic filaments enclosed by rich oxide layer [11]

Review of applicable standards and guidelines

Although SRC is well addressed and known damage mechanism, up to date there is lack of coverage of the special guidelines in the applicable codes in such a way that equipment can be designed in compliance with the design code while still prone to SRC and immature brittle failures. In this section, the most common standards and guidelines will be discussed.

ASME BPVC SEC II Part D [4]

In non-mandatory Appendix A " Issues associated with materials used in ASME code construction, paragraph A-206 addresses SRC that can occur in cold- or warm-worked austenitic materials when precipitation of temper-resistant particles occurs at defect sites introduced during mechanical working. When the material is exposed to intermediate temperatures (510°C to 760°C) during heat treatment or service, strain localizes at the grain boundaries, leading to rapid intergranular creep cracking.

The code highlights that this phenomenon has led to through-wall failures in pressure parts made from susceptible heats of materials like 347H and 310HCbN, even during heat-up for solution annealing. To reduce the risk, ASME has introduced rules in PG-19 (Section I) and UHA-44 (Section VIII, Division 1), specifically aimed at mitigating SRC risks during design and fabrication.

This inclusion confirms that SRC is recognized and partially addressed within the ASME Code framework, though additional design-specific considerations may still be necessary.

ASME BPVC SEC VIII Div.1 [5]

In Nonmandatory Appendix UHA-A, paragraph UHA-A-4 acknowledges that stress relaxation cracking (SRC) may develop in P-No. 8 materials, not only in cold-formed areas but also in weld zones where high residual tensile stresses are present. To minimize this risk, the code advises applying post-weld heat treatment (PWHT) in accordance with Table UHA-44, unless specific criteria are met—such as when the design temperature is below 1000°F (540°C) or the welding is limited to low-risk configurations (e.g., circumferential welds or fillet welds with a thickness of 13 mm or less, or specific fin welding scenarios under tightly defined limits). This reflects the code's recognition of SRC and its efforts to provide guidelines for mitigating it during design and fabrication.

It's important to highlight that Table UHA-44 recommends solution annealing as the heat treatment method for relieving stress in cold-formed parts that exceed allowable fiber elongation. For example, the minimum recommended heat treatment temperature for SS347H is 1095 °C.

Meanwhile, in the mandatory portion of the code, Table UHA-32-3 outlines PWHT requirements for P-No. 8 materials and states that PWHT is neither required nor prohibited, effectively deferring the decision to the user, guided by non-mandatory Appendix UHA-A.

This creates a grey area in the code, possibly since PWHT itself can introduce SRC under certain conditions, in addition to increasing the risk of sensitization

By contrast, the treatment of Alloy 800 series materials (UNS N08800, N08810, N08811) is more explicit. Paragraph UNF-56(d) mandates PWHT at 885 °C when the design temperature exceeds 540 °C, providing a clear preventive measure against in-service SRC. Notably, design software tools typically account for such conditional requirements, whereas manual design calculations might overlook them—posing a risk of noncompliance or design oversight.

ASME BPVC SEC I [6]

ASME Section I presents similar guidance to that of Section VIII, Division 1 regarding post-weld heat treatment (PWHT) for P-No. 8 materials. According to Table PW-39-8, PWHT is neither mandated nor prohibited. However, Note (b) in the same table suggests that PWHT may be advisable to mitigate the risk of stress relaxation cracking (SRC), particularly for thick sections operating at elevated temperatures, aligning with the recommendations in ASME Section II, Part D, Nonmandatory Appendix A. Ultimately, as in Section VIII, the decision is left to the user's discretion, based on the specific service conditions and fabrication details.

API RP 571 [7]

API RP 571 SRC as a damage mechanism discussed in Paragraph 3.54. It identifies susceptible materials including austenitic stainless steels (304H, 316H, 321, 347) and nickel-based alloys (Alloy 800H, 800HT, 617). SRC typically occurs in the 500–750°C range and is influenced by grain size, material composition, weld strength, residual stresses, section thickness, and fabrication conditions. Large grain sizes and high residual stresses, especially in thick sections, increase SRC risk. The RP also notes that stress relief or stabilization heat treatments can sometimes worsen SRC.

API TR 942A [8]

This API technical report addresses material selection, fabrication, and repair concerns for hydrogen and syngas reformer furnace outlet pigtails and manifolds. It highlights SRC as a major failure mode in these components when exposed to fabrication and operating temperatures between 500°C and 750°C. Additionally, the report includes a case history of SRC occurred in pigtail fabricated from alloy800HT see Figure-3.

Figure-3, SRC of alloy 800HT inlet pigtail [8]

API TR 942B [9]

This report examines Stress Relaxation Cracking (SRC) in austenitic alloys used in high-temperature refinery services, detailing its causes, susceptibility, and prevention.

- Report ranked the alloy Susceptibility as : 800HT > 347 SS > 800H > 321 SS > 304 SS > 316 SS (higher susceptibility in alloys with fine intergranular precipitates).
- Grain Size & Cold Deformation: Finer grains (ASTM 3.5+) resist SRC; ≥2% cold deformation increases risk, mitigated by 980°C stabilization heat treatment.
- Mitigation Strategies:
- Welding: Minimize restraint, avoid stress concentrations, and use low heat input techniques.
- Heat Treatment: PWHT (843°C to 899°C) or multistep treatment (stress relief → solution annealing → stabilizing at 593°C).
- Material Considerations: Limit Bismuth (Bi≤0.002%) in Type 308 FCAW weld metal for temperatures >538°C.

API TR 942B recommends the application of PWHT for some austenitic SS grades and at temperature quite different than the advisable by ASME BPVC. For example, the recommended PWHT temperature for SS 347 is 900 C (1hr / 25 mm, 3 hrs. minimum), followed by still air cool.

Case Histories:

The following are **two case histories** for two of the most vulnerable materials to SRC: alloy 800H and stainless steel grade347H

CASE-1:
Cracking of Alloy 800H Reformer Riser [12]

A failure occurred in a steam reformer riser where a cast HP Micro Alloy riser tube was welded to an alloy 800H transition piece. While the first incident in 2010 was caused by thermal shock from a water leak, further inspections revealed multiple cracks in the heat-affected zones (HAZ) of the 800H welds—not linked to water damage. This prompted a detailed investigation.

The cracking showed classic signs of Stress Relaxation Cracking (SRC), including:

- Intergranular cracks in the HAZ
- Voids and grain boundary oxidation
- Nickel-rich metallic filaments with chromium-depleted zones
- Cracking in areas with hardness near 200 HV
- Occurrence within 1–2 years of service at around 600°C

The design had been modified in 2006, moving the weld joint location closer to a cooler area near a water jacket. This location likely created the ideal conditions for SRC: high residual stress, coarse grains, and operating temperatures within the critical 500–750°C range.

The solution was to perform post-weld heat treatment (PWHT) at 885°C, which relieved stress and reduced hardness. After this treatment, no further cracking was observed, confirming that SRC was the root cause. Which is the recommended heat treatment condition in ASME BPVC sec VIII div.1 para UNF-56 as explained earlier in the article, and this is an example for how such requirements can be missed.

This clearly illustrates how SRC can silently damage high-temp. components and the critical role of heat treatment in preventing it—even in austenitic alloys like 800H, which were once thought to be immune

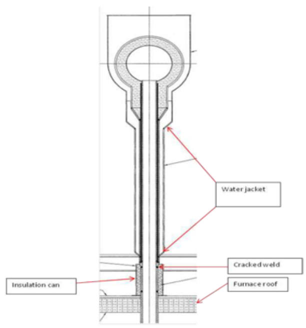

Figure 4-a Top section of the modified riser design illustrating the location of subsequent failures [12]

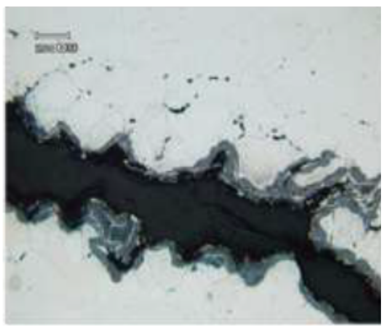

Figure 4-b Cracking of the alloy 800H transition cone with typical morphology of SRC [12]

CASE-2:

Cracking of SS 347H pipe at inlet of Steam Reformer [13]

Inlet piping of steam reformer fabricated from SS 347H failed at welded support pad. Cracking occurred in less than 16 months. The failures were observed in welded reinforcing pads and branch connections of inlet pipes. Notably, no Post-Weld Heat Treatment (PWHT) had been applied.

Key features of SRC observed included:

- Intergranular cracks originating at grain boundaries.
- Nickel-rich metallic filaments surrounded by chromium-rich oxide layers.
- Cavities and signs of localized embrittlement.
- Hardness >200 HV at crack locations with no visible plastic deformation.

Corrective actions included:

- Replacing welded supports with clamp-type supports to reduce restraint.
- Applying PWHT at 875–930°C to relieve residual stress and reduce hardness.
- Improving insulation to prevent sensitization and external corrosion.

This case history reinforces the importance of considering SRC in 347H, even when codes do not mandate PWHT, especially for thick sections, critical welds, or high-stress configurations in high-temperature environments.

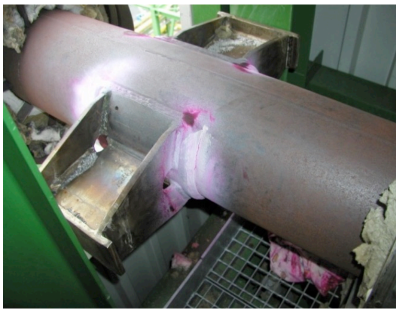

Figure 5-a Cracked pads of horizontal guides [13]

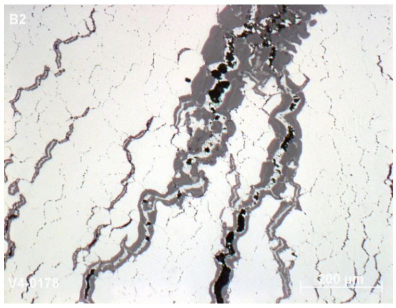

Figure 4-b Cracking of SS 347H pad with typical morphology of SRC [13]

Conclusion:

Stress Relaxation Cracking (SRC) is a critical yet often overlooked failure mechanism in austenitic stainless steels and nickel-based alloys used in high-temperature environments. While industry codes such as ASME BPVC and API standards address SRC, it remains a complex challenge influenced by residual stress, material microstructure, and operating conditions. The case studies discussed—particularly those involving SS347H and Alloy 800H—highlight that SRC can still occur even when materials are used within code limits, revealing the gap between compliance and true reliability.

To mitigate the risk of SRC, engineers must focus on minimizing cold work and residual stresses, applying appropriate post-weld heat treatment (PWHT), carefully managing grain size, and identifying high-risk configurations like thick sections and welded supports. While ASME codes acknowledge SRC, their guidance—especially on PWHT—is often non-mandatory or loosely defined, leaving engineers and designers responsible for making informed decisions. Ultimately, preventing SRC requires a combination of deeper technical understanding, proactive design strategies, and greater industry awareness. By prioritizing these factors, we can enhance the long-term integrity and reliability of high-temperature pressure equipment, reducing the likelihood of premature failures.

References:

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