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Integrity and Challenges

SA 387 Grade 9 Plates for Pressure Vessel

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This paper explores SA 387 Grade 9 plates, known for their excellent thermal fatigue and corrosion resistance in high-temperature, high-pressure environments. It examines their metallurgical properties, practical applications, and challenges in welding, such as hydrogen cracking and martensitic transformation. The study delves into the creep behaviour of SA 387 Grade 9, emphasizing key factors and testing methodologies. Due to the absence of allowable stress values in ASME Section VIII Division 1, ASTM A387 Grade 91 plates are proposed as alternatives. This comprehensive study is aimed for engineers to understand criticality and optimizing material selection for performance and extending the service life of high-temperature pressure vessels.

INTRODUCTION

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The study delves into the creep behaviour of SA 387 Grade 9, emphasizing key factors and testing methodologies. Due to the absence of allowable stress values in ASME Section VIII Division 1, ASTM A387 Grade 91 plates are proposed as alternatives. This comprehensive study is aimed for engineers to understand criticality and optimizing material selection for performance and extending the service life of high-temperature pressure vessels.

In the world of industrial materials, finding the right alloy for high-temperature and high-pressure applications is crucial. Chromium-Molybdenum (Cr-Mo) steels play an essential role in the petrochemical and oil/gas industries, renowned for their remarkable strength, durability, and resistance to extreme conditions. These properties make Cr-Mo steels a cornerstone in these critical sectors.

One such alloy is martensitic steel containing 9% chromium and 1% molybdenum, commonly used in the hardened and tempered condition (9Cr-1Mo Steel). In plate form, SA 387 Grade 9 stands out as a prime choice for such demanding environments.

A 387 Grade 9 plates are distinguished by their remarkable ability to resist thermal fatigue and corrosion, ensuring durability and longevity even under the most challenging operational conditions. The chromium content provides a robust defense against oxidation, while molybdenum enhances strength and toughness. This combination not only extends the service life of pressure vessels and boilers but also contributes to safety and efficiency in industrial processes.

In this paper, we will take a closer look at the key features and benefits of SA 387 Grade 9 plates. From their metallurgical properties to practical applications, you will gain a comprehensive understanding of why these plates are a preferred choice for engineers and manufacturers around the globe. Additionally, we will address the critical challenges and complexities involved in welding and manufacturing pressure vessels with SA 387 Grade 9.

MANUFACTURING ORIENTED CHALLENGES & MITIGATION

The manufacturing of pressure vessel process involves forming the plates into shells, which serve as crucial pressure components. Ensuring the integrity and performance of these shells requires meticulous attention to welding, as SA 387 GR 9 (9Cr-1Mo Steel) presents several challenges and issues that need to be addressed to ensure the integrity and performance of welded joints.

Here are some common welding issues associated with SA 387 GR 9 and ways to mitigate them:

STRESS INDUCED CRACKING:

SA 387 GR 9 is a high-strength, low-alloy steel designed for elevated temperature service. Preheating and Post Weld Heat Treatment (PWHT) are essential to reduce the risk of cracking, minimize residual stresses, and improve weld joint properties. Preheat temperatures typically range from 200°C to 350°C, and PWHT is usually performed at around 620°C to 680°C followed by slow cooling.

HYDROGEN INDUCED CRACKING

Hydrogen-induced cracking is a significant concern during welding. Proper control of hydrogen content, as well as preheating to reduce hydrogen levels and post-weld heat treatment to relieve residual stresses, can help mitigate this issue.

FORMATION OF HARD AND BRITTLE MARTENSITE IN HAZ

SA 387 GR 9 undergoes martensitic transformation upon cooling from welding temperatures. Rapid cooling rates can lead to the formation of hard and brittle martensite in the heat-affected zone (HAZ), increasing the risk of cracking. Controlled cooling rates and PWHT are necessary to temper the martensitic structure and improve toughness.

OVER-TEMPERING AND CRACKING IN MULTI-PASS WELDING:

Controlling interpass temperatures during multi-pass welding is important to prevent excessive heat input, which can lead to over-tempering of the base metal, reduced toughness, and increased susceptibility to cracking. Interpass temperature should be maintained within the specified range.

DESIGN-ORIENTED CHALLENGES: CREEP BEHAVIOUR AND ALLOWABLE STRESS

SA 387 GR 9 is a chromium-molybdenum alloy steel widely used in high-temperature applications such as pressure vessels and power generation equipment and it provides excellent resistance to oxidation and creep, making it ideal for long-term service at elevated temperatures.

UNDERSTANDING CREEP

Creep is the time-dependent deformation of materials under constant stress and elevated temperatures. It is a critical factor in the design and operation of components that experience prolonged exposure to high temperatures, such as those made from SA 387 GR 9.

FACTOR INFLUENCING CREEP IN SA 387 GR 9

Temperature: Higher temperatures accelerate creep rates. For SA 387 GR 9, operational temperatures typically range from 500°C to 600°C.

Stress: The level of applied stress significantly impacts the creep rate. Higher stress levels increase the rate of deformation.

Microstructure: The alloy's microstructure, including grain size and the distribution of precipitates, affects its creep resistance. Fine, stable carbides can impede dislocation motion, enhancing creep resistance.

Service Environment: Factors such as oxidation and corrosion can exacerbate creep damage. SA 387 GR 9's chromium content provides some oxidation resistance, but additional protective measures may be required in aggressive environments.

STAGES OF CREEP

Primary Creep: Characterized by a decreasing creep rate, this initial stage is dominated by work hardening.

Secondary Creep: Also known as steady-state creep, this stage features a constant creep rate due to a balance between work hardening and recovery processes.

Tertiary Creep: Marked by an accelerating creep rate, this final stage leads to material failure due to the formation and growth of voids and cracks.

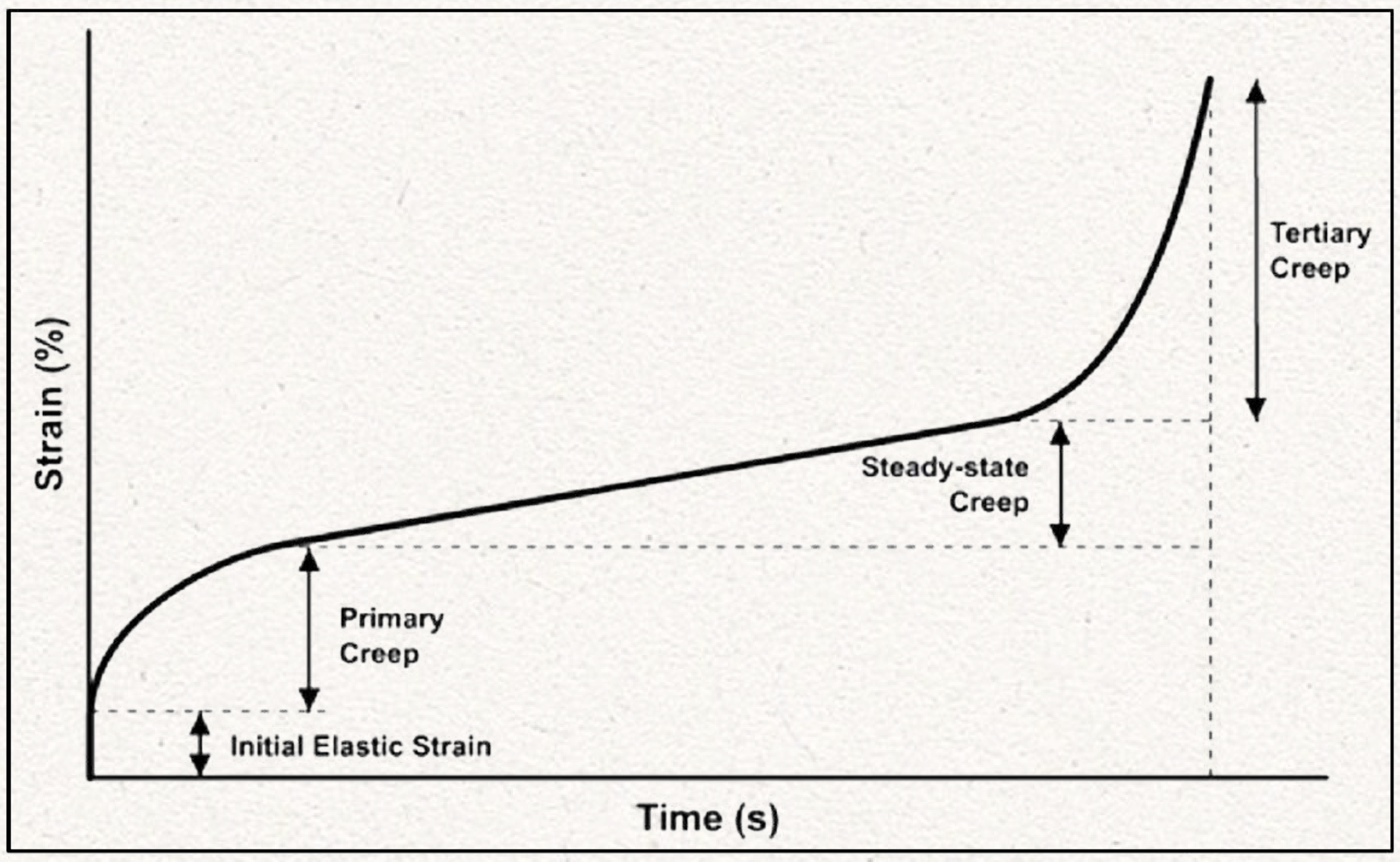

Figure 1 Schematic Diagram of Creep-test showing Strain as a function of Time.

IMPLICATIONS WITH CREEP BEHAVIOUR AND ALLOWABLE STRESS

Understanding the creep behavior of SA 387 GR 9 is essential for designing components that can withstand prolonged high-temperature service.

Engineers must consider creep data when selecting materials, designing for allowable stress, and establishing maintenance schedules.

Code Limitation for SA -387 Grade 9 Plates: SA-387 Grade 9 plates are not permitted for pressure vessel construction under ASME Section VIII Division 1 because they are not listed for allowable stress values in this code. To be used for pressure-retaining service, a material must be both listed and permitted in Section II, Part D of the ASME Boiler and Pressure Vessel Code (BPVC)

Absence of Allowable Stress Listings for SA-387 Grade 9 Plates in ASME Section VIII Division 1 : Allowable stress values in codes like ASME Section II, Part D are established based on rigorous testing and qualification procedures that demonstrate the material's mechanical properties, durability under stress, and resistance to deformation and failure. Since SA-387 Grade 9 plates may not have been through these specific tests or may not meet all the criteria specified by the ASME BPVC, their allowable stress values are not listed, thereby preventing their use in pressure vessel construction under this particular code section.

Challenges in Creep Damage: Regular inspection and monitoring is required to detect early signs of creep damage, allowing for timely intervention and preventing catastrophic failures which is quite challenging for operator to have regular maintaince break to check on the Equipment.

ALTERNATIVE SOLUTIONS

Considering the constraints of non-availability of allowable stress based on creep behavior, and focusing on chemical composition, mechanical properties, and welding suitability for high-temperature and high-pressure applications is crucial. Hence, SA 387 GR 91, a vanadium-modified alloy, plays a significant role in this context. Vanadium enhances tempering stability in quenched steel, leading to secondary hardening effects. This alloy refines grain structure, increases strength and yield ratio, enhances low-temperature toughness post-normalizing, and improves welding performance compared to SA 387 GR 9. These enhancements include stress relief during tempering, increased material flexibility and ductility, and improved hardness with enhanced wear resistance throughout the metal.

CHEMICAL PROPERTIES

Property	SA 387 GR 9	SA 387 GR 91
Chromium (Cr)	9%	9%
Molybdenum (Mo)	1%	1%
Vanadium (V)	-	0.06-0.10%
Nitrogen (N)	-	0.03-0.07%
Carbon (C)	0.15% max	0.08-0.12%
Silicon (Si)	0.50% max	0.20-0.50%
Manganese (Mn)	0.40-0.65%	0.30-0.60%
Phosphorus (P)	0.035% max	0.020% max
Sulfur (S)	0.035% max	0.010% max

Key Differences:

SA 387 GR 9: Does not contain vanadium or nitrogen.
SA 387 GR 91: Contains vanadium (0.06-0.10%) and nitrogen (0.03-0.07%).
Carbon Content: GR 91 has a lower carbon content (0.08-0.12%) compared to GR 9 (typically around 0.15% max).
Sulfur and Phosphorus: GR 91 has lower sulfur (0.010% max) and phosphorus (0.020% max) content compared to GR 9 (both 0.035% max), which can improve weldability and reduce susceptibility to brittleness.

These differences in chemical composition contribute to the enhanced mechanical properties, creep resistance, and weldability of SA 387 GR 91 compared to SA 387 GR 9, particularly in high-temperature and high-pressure applications.

MECHANICAL PROPERTIES

Property	SA 387 GR 9	SA 387 GR 91
Tensile Strength	85-110 ksi (585-760 MPa)	95-115 ksi (655-795 MPa)
Yield Strength	45 ksi (310 MPa) min	60 ksi (415 MPa) min
Elongation in 2 inches (50 mm)	18% min	20% min
Hardness	235 HBW max	250 HBW max
Impact Toughness (Charpy V-notch)	Not specified	41 J at -29°C min

These mechanical property differences make SA 387 GR 91 more suitable for demanding high-temperature and high-pressure applications, offering better strength, ductility, and toughness compared to SA 387 GR 9.

Additionally, the impact toughness, which measures the material's ability to absorb energy and resist fracture at specific temperatures, is not specified for SA 387 GR 9. This is due to the non-standardized allowable stress values, influenced by the material's creep behavior during prolonged high-temperature service.

For pressure vessels and high-pressure applications:

SA 387 GR 91: Has higher impact toughness and better mechanical properties, allowing for higher allowable stress values. This makes it suitable for severe service conditions, ensuring safety and reliability.
SA 387 GR 9: Lacks specified impact toughness, leading to more conservative allowable stress values to ensure safety, particularly in dynamic or low-temperature environments.

WELDING SUITABILITY

SA 387 GR 9 has good weldability with standard welding processes like SMAW, GTAW, and GMAW. It requires preheating between 150-200°C and post-weld heat treatment at 700-750°C to avoid cracking and ensure proper mechanical properties. However, it has moderate susceptibility to hydrogen-induced cracking, making the control of hydrogen content and the use of appropriate filler materials essential.

In comparison, SA 387 GR 91 offers enhanced weldability due to its refined grain structure and alloying elements. It demands more stringent preheating (200-300°C) and critical post-weld heat treatment (730-780°C) to achieve the desired mechanical properties and relieve residual stresses. SA 387 GR 91 is more susceptible to cracking if not properly preheated and post-weld heat treated, necessitating the use of matching filler metals and controlled welding procedures. Thus, while both grades are weldable, SA 387 GR 91 requires more precise control during the welding process.

MATERIAL AVAILABILITY

SA 387 GR 91 is widely available due to its extensive use in high-temperature and high-pressure applications, such as in power plants and petrochemical industries. It is offered in a broader range of thicknesses and sizes to meet the demands of various high-stress applications and is readily supplied by major distributors. Therefore, while both materials are accessible, SA 387 GR 91 is more readily available and in a wider range of specifications in comparison to the SA 387 GR 9.

CONCLUSION

This comprhensive study highlights SA 387 Grade 9 plates for their exceptional thermal fatigue and corrosion resistance in high-temperature, high-pressure environments, making them popular in industries like petrochemicals. However, challenges in welding, such as stress-induced and hydrogen-induced cracking, require precise techniques like preheating and post-weld heat treatment.

A significant finding is the absence of ASME Section VIII Division 1 allowable stress values for SA 387 Grade 9, limiting its use in pressure vessel construction under this code.

Though there are suggestions made based on ASME Section VIII, Division 1, UG-15 which permits engineers to use allowable stress values specified for a specific grade and product form of material across other product forms of the same grade. This provision enables flexibility in material selection for pressure vessel construction. For instance, while SA 387 Grade 9 lacks specified allowable stress values in the code, the ASME allows engineers to alternatively use allowable stress values specified for another product form of 9Cr-1Mo material, such as SA 213 TP T11 tubes, which are covered in the code.

Alternatives like SA 387 Grade 91, with superior mechanical properties and enhanced creep resistance due to vanadium and nitrogen additions, are recommended. Grade 91's improved weldability and broader availability in various specifications further enhance its suitability for critical applications.

In conclusion, while SA 387 Grade 9 offers substantial benefits, its constraints in ASME code compliance and welding challenges necessitate careful consideration. SA 387 Grade 91 emerges as a robust alternative for applications demanding adherence to ASME Sec VIII Div 1 and superior material performance.

When selecting an alternative material, always verify specific project requirements, including temperature and pressure ratings, and ensure compliance with applicable codes and standards such as ASME Sec VIII Div 1. This ensures that the chosen material meets all necessary criteria for safety, reliability, and performance.

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