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Engineering, Materials & Metallurgical Consulting

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Welding Metallurgy of Heat Resistant Austenitic Stainless Steels: Cracking of Welds

Are you vexed experiencing cracking of your weldments in Heat Resistant Stainless Steels in spite of adhering to weld protocols?

Several specialty heat resistant austenitic stainless steels have been developed to meet or exceed exceptional service requirements. These include heat resistant alloys that are used in elevated temperature (above 650°C) service and nitrogen alloyed (yes, nitrogen that was once considered as a bad non-metallic inclusion) used in demanding corrosion environments.

Apart from our discussions in application notes on heat resistant alloys, it is well acknowledged that heat resistant alloys used in elevated temperature service (ASTM A 297, A351, A560, A608, A447 and alike Cast Alloy Standards) used in power generation and petrochemical industry; **possess higher carbon content as it imparts superior elevated-temperature strength**. Some popular alloys based on standard corrosion resistant austenitic, stainless steel series 300, with additional carbon content, such as 304H and 316H. The "**H**" designation represents carbon in the high range than nominal specification, 0.04-0.10 w/w %. Cast alloys in this group, for example all the grades of ASTM A 297, including HK modified HK 30, HK40, HK50, HP modified HP45, HP modified HP-Nb/Cb containing carbon contents of 0.40% wt. or higher. Typical carbon content in standard alloy grades of ASTM A 297 is 0.25-0.75% wt.

Most of the Fe-Cr-Ni and Fe-Ni-Cr group alloys have high chromium contents for improved elevated temperature resistance and high nickel content to stabilize the austenite phase to prevent embrittlement. It is worth noting that higher nickel content heat resistant alloys will not work well in high sulphur or sulphide environment owing to formation of low temperature melting point eutectic nickel sulphide that leads to cracking and eventually rapid creep failure of the part. Modern alloys also contain carbide formers and grain refiners, including Niobium (Columbium), Titanium, Molybdenum and Tungsten that improve high temperature creep strength.

Selection criteria used my metallurgists, materials and design engineers, and manufacturing engineers includes creep resistance, thermal fatigue resistance, thermal cycling and resistance to different forms of high temperature corrosion (acting singly or together) such as oxidation, carburization, nitridation, and sulphidation. Although mechanical properties, corrosion resistance, availability, fabricability and costs are all important when selecting materials for these demanding applications, it is the stability of the microstructure and the properties of the material following extended service that dictate material selection, ultimate performance and lower-life-cycle cost.

Now-a-days the ability to repair the material after extended service is also gaining importance in the industry. The microstructure and properties of the materials used at elevated temperature may degrade due to various reasons. As a consequence of this degradation, the materials become more susceptible to cracking in service, during plant shut downs or when repair welding is attempted. The cracking and embrittlement phenomenon of corrosion- and heat-resistant alloys include **reheat cracking**, **sigma phase formation**, **chi-phase formation** and **aging embrittlement**. A pragmatic approach to field repair welding of service-

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embrittled ASTM A 297 HK 40/ A351 HK40 which involves local annealing to dissolve carbides for enough ductility in the weld area that cracking does not occur beside the repair welds.

Reheat cracking, is usually associated with the Heat Affected Zone (HAZ) of restrained welded joints during either post-weld heat treatment or elevated temperature service (where it is often known as **relaxation cracking)**. Reheat cracking occurs in wide range of materials including austenitic and ferritic steels (ASTM A 217 Grades and alike wrought equivalent grades) and nickel-base alloys, and it was first observed by the power generation industry. Metallurgical examination reveal that reheat cracking is attributed to the formation of intragranular precipitates. In addition, this precipitation strengthens the grain interiors and transfers the strain necessary for the relief of residual welding and system stresses to the grain boundaries. Overall effect thus is reduced creep ductility leading to intergranular failure. Most reformer tube failures are prominently due to loss of ductility rather than loss high temperature strength. Dilemma exists that most engineers and plant operators think otherwise.

Relaxation cracking is associated with long-term exposure of heavy-section or highly restrained weldments in the temperature range 500-700°C. This form is cracking is similar to reheat cracking in mechanism, except that the time to failure is typically in the range 10,000 to 100,000 hours. This has been a prominent prevailing problem in large components made out of high carbon alloys (304H, 316H, 321H, 800H) that cannot be rendered post-weld stress-relief treatment. Ironically, both stress relaxation and carbide precipitation occur simultaneously, leading to inter-granular cracking, prominently in the HAZ of circumferential or longitudinal welds.

American Welding Society (AWS) classifies only a few filler metals to match these high temperature base metals. Except for 308H and 316H compositions, primary ferrite solidification is impossible to achieve in these filler metals (310, 310H, 330, 330H, 19-10H, NiCrCoMo-covered electrodes and bare wires).

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