Brittleness in Carbon Steels

Users of Carbon Steels in the Oil and Gas industry, in North America, have, since the last few years, noticed piping spool components, specified to ASME/ASTM requirements, approved for use up to a service temperature of −29°C (−20°F), fail due to brittle fracture, generally during vice temperature of −29°C (−20°F), fail to meet the chemical and mechanical properties specified. For example, when tested, some carbon steel flanges, and some of the failed flanges such as ASTM A350 LF2 CL1, certified to −46°C (−50°F) also indicated degraded toughness values as low as 3J (2.2 ft-lb) at temperatures well above −46°C (−50°F).

This brittle fracture risk, is a potential hazard to equipment integrity, reliability, and process safety. ABSA (IB16-018) therefore, concludes that “This may be a concern since flanges made of SA-105 material are commonly exempted from impact testing per ASME Section VIII, Division 1 paragraphs UG-20(f), UCS-66, or ASME B31.3 paragraph 323 for temperature -29°C (-20°F) and greater.”

According to Charles Becht, “All ASME B31.3 Figure 323.2.2A Curve B materials are considered to be potentially at risk, although the issue has not been found in pipe manufactured from plate material.” Investigations revealed brittle transgranular cleavage cracks caused by two Failure Mechanisms. Steel chemistry, and coarse grain microstructure, originating from cost cutting efforts of some steel manufacturers that led to modification of steel chemistry and ferritic-pearlitic microstructures with a large grain size.

Determination of grain sizes by means of replicas and through metallographic sectioning, established that toughness is strongly related to microstructure and grain size.

Steel Chemistry

The % of Mn in steel was reduced to barely meet the minimum requirement of the specification. Some of the failed steels had a Mn:C ratios as low as 1.8, resulting in poor toughness and leading to failures during hydrostatic testing or upset conditions.

Carbon steels with a low Mn to C ratio, i.e., Mn/C ≤ 5 are known to exhibit poor low temperature impact properties with a strong temperature transition shift to higher temperatures.

Micro alloying with V, Nb, Ti, and B was leveraged to comply with the mechanical properties required by the ASTM/ASME standard.

Micro-alloying with Titanium, Vanadium, and Niobium has been extensively deployed in the manufacture of low carbon steels to increase steel strength, and Grain size refinement has been used to increase impact toughness. V, Nb, and Al are nitride formers. Austenitising temperature increases, are known to cause grain coarsening in boron treated carbon steels. The amount of grain coarsening is dependent not on the total boron content of the steel, but on the amount of boron present in the steel after any free nitrogen has been tied up as boron nitride precipitates. It is therefore, the nitrogen content of the steel that controls the amount of nitride formation, and in effect the degree of grain pinning, regardless of whether it is Ti and Al nitride that forms.
Deliberate additions of unprotected B to commercially rolled CS rods have been shown to promote the formation of coarser ferrite grain size.

According to Walter J. Sperko, Boron is known to cause directional re-crystalization on the 100 crystal plane at 30 to 45° to the pipe axis resulting in very low toughness at 45° to the pipe or fitting axis. This is precisely the direction that maximum shear loading occurs for pipe under pressure, and because of this crystal orientation alignment, axial or circumferential impact specimens will not identify the material as having low toughness.

ANSI B16.5 does not mandate heat treatment of ASTM A105 flanges below Class 300.

However, NACE SP0472 cautions that welds of P1 materials, that is Carbon Steel, manufactured with the deliberate additions of micro-alloying elements such as Ti, V, Nb and B, may require additional preheat and higher PWHT temperatures, to obtain the mandated HAZ hardnesses. However, the heat treatment could adversely affect toughness values.

While the presence of > 0.05% Ti in B containing Low-Carbon Steel has been found to lead to deteriorating toughness, variations in the weld metal titanium and boron contents have been known to cause a wide variation in the weld metal microstructure.

Micro-alloying of carbon steels, therefore calls for a very tight material balance of nitride formers and B and customized to the processing route (heat treatment).

Failure investigations conducted by the Belgian Welding Institute (BWI), indicated that the large grain size of some of the investigated flanges, as well as, significant variation within one specific flange proved that while mentioned on the accompanying EN 10204: 3.1B certificate, the heat treatment performed on the flange was found deficient.

Failure Analysis on an A350LF2 Weld Neck Flange of the Discharge Piping of an Ethylene Compressor in a Petrochemical Complex, confirmed that poor normalizing practice, was a major contributor to the failure. SEM fractology identified the presence of a continuous threadlike rod of inclusions.

As a corrective action, it is therefore recommended that all CS piping spool components, in operation, transporting hazardous materials at temperatures below 0°C be subjected to a preliminary FFS survey, to include PMI and micrograph, before being put back in service at the designed operational parameters.

As a preventive action, to reduce the future potential for brittle fracture in carbon steel, it is recommended that only impact tested CS piping and fittings be procured. They must be accompanied with an MTR certified to at least EN10294, 3.1B specification, which identifies its heat and batch number, and the material standard (ASTM/ASME) to which it is manufactured...

Addition requirements to be incorporated should include:

- Vacuum degassing, to ensure the removal of free N,
- Ca Killed Steels to ensure inclusion removal,
- A Mn/C ratio ≥ 5
- An ASTM E1112 Grain size of 7 or finer
- Grain size of 8 or finer for low temperature CS, such as A350 Gr.LF2
- Normalizing heat treatment
- Limiting the V, Ti, Nb content, ideally to 0.02% each, and V + Nb< 0.03% or at least to ASTM A20 limits and
- B to 0.001–0.004%, that is 5 ppm maximum.
- An NDE examination to exclude the presence of detectable cracks.

REFERENCES:

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