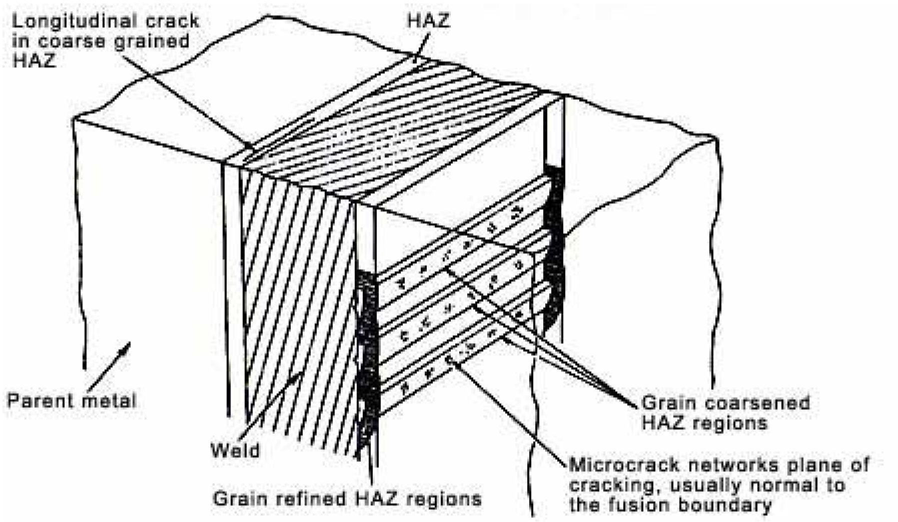
Welding Job Knowledge

Defects/imperfections in welds - reheat cracking



Location of reheat cracks in a nuclear pressure vessel steel

The characteristic features and principal causes of reheat cracking are described. General guidelines on best practice are given so that welders can minimise the risk of reheat cracking in welded fabrications.

Identification

Visual appearance

Reheat cracking may occur in low alloy steels containing alloying additions of chromium and molybdenum or chromium, molybdenum and vanadium when the welded component is being subjected to post weld heat treatment, such as stress relief heat treatment, or has been subjected to high temperature service (typically in the range 350 to 550°C). Cracking is almost exclusively found in the coarse grained regions of the heat affected zone (HAZ) beneath the weld, or cladding, and in the coarse grained regions within the weld metal. The cracks can often be seen visually, usually associated with areas of stress concentration such as the weld toe. Cracking may be in the form of coarse macro-cracks or colonies of micro-cracks. A macro-crack will appear as a 'rough' crack, often with branching, following the coarse grain region, (*Fig. 1a*). Cracking is always intergranular along the prior austenite grain boundaries (*Fig. 1b*). Macro-cracks in the weld metal can be oriented either longitudinal or transverse to the direction of welding. Cracks in the HAZ, however, are always parallel to the direction of welding.

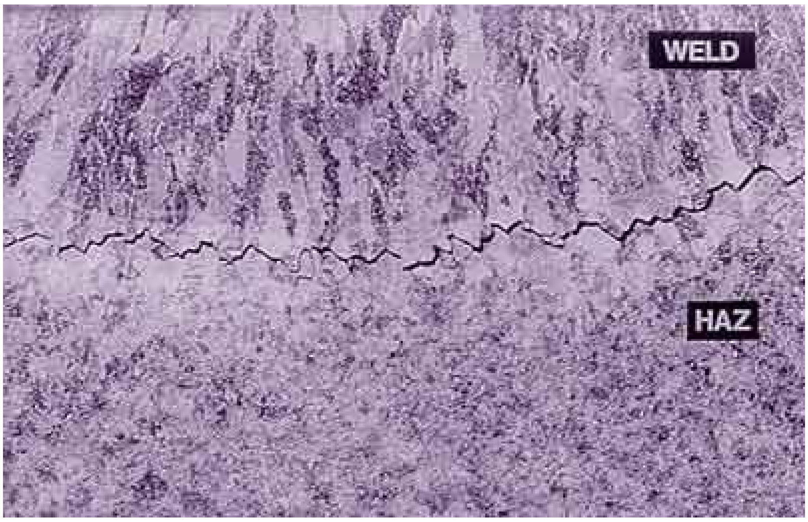


Fig.1a. Cracking associated with the coarse grained heat affected zone

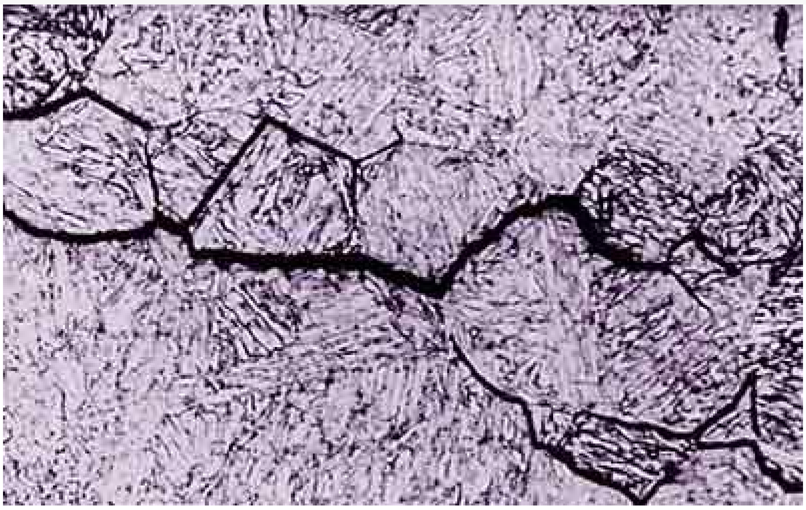


Fig.1b. Intergranular morphology of reheat cracks

Micro-cracking can also be found both in the HAZ and within the weld metal. Micro-cracks in multipass welds will be found associated with the grain coarsened regions which have not been refined by subsequent passes.

Causes

The principal cause is that when heat treating susceptible steels, the grain interior becomes strengthened by carbide precipitation, forcing the relaxation of residual stresses by creep deformation at the grain boundaries. The presence of impurities which segregate to the grain boundaries and promote temper embrittlement, e.g. antimony, arsenic, tin, sulphur and phosphorus, will increase the susceptibility to reheat cracking. The joint design can increase the risk of cracking. For example, joints likely to contain stress concentration, such as partial penetration welds, are more liable to initiate cracks. The welding procedure also has an influence. Large weld beads are undesirable, as they produce coarse columnar grains within the weld metal and a coarse grained HAZ which is less likely to be refined by the subsequent pass, and therefore will be more susceptible to reheat cracking.

Best practice in prevention

The risk of reheat cracking can be reduced through the choice of steel, specifying the maximum impurity level and by adopting a more tolerant welding procedure / technique.

Steel choice

If possible, avoid welding steels known to be susceptible to reheat cracking. For example, A 508 Class 2 is known to be particularly susceptible to reheat cracking, whereas cracking associated with welding and cladding in A508 Class 3 is largely unknown. The two steels have similar mechanical properties, but A508 Class 3 has a lower Cr content and a higher manganese content. Similarly, in the higher strength, creep-resistant steels, an approximate ranking of their crack susceptibility is as follows:

5 Cr 1Mo	lower risk
2.25Cr 1 Mo	↓
0.5Mo B	↓
0.5Cr 0.5Mo 0.25V	higher risk

Thus, in selecting a creep-resistant, chromium molybdenum steel, 0.5Cr 0.5Mo 0.25V steel is known to be susceptible to reheat cracking but the 2.25Cr 1Mo which has a similar creep resistance, is significantly less susceptible.

Unfortunately, although some knowledge has been gained on the susceptibility of certain steels, the risk of cracking cannot be reliably predicted from the chemical composition. Various indices, including ΔG1, P_{SR} and Rs, have been used to indicate the susceptibility of steel to reheat cracking. Steels which have a value of ΔG1 of less than 2, P_{SR} less than zero or Rs less than 0.03, are less susceptible to reheat cracking

$$\Delta G1 = 10C + Cr + 3.3Mo + 8.1V - 2$$

$$P_{SR} = Cr + Cu + 2Mo + 10V + 7Nb + 5Ti - 2$$

$$Rs = 0.12Cu + 0.19S + 0.10As + P + 1.18Sn + 1.49Sb$$

Irrespective of the steel type, it is important to purchase steels specified to have low levels of impurity elements (antimony, arsenic, tin, bismuth, sulphur and phosphorus). To avoid weld metal reheat cracking, it is necessary to ensure that welding consumables deposit weld metal with appropriately low levels of these impurities, and preferably to avoid coarse columnar grains. Following several instances of weld metal reheat cracking in thick-wall 2.25%Cr-1%Mo-0.25%V reactor vessels, impurities in the flux were identified as being responsible for the cracking, and an equation given for the desired upper limit of these additional impurities.

$$K = Pb + Bi + 0.03Sb \text{ (ppm)}$$

The compositional factor K must be less than 1.5 to achieve freedom from this form of cracking.

Welding procedure and technique

The welding procedure can be used to minimise the risk of reheat cracking by:

- Producing the maximum refinement of the coarse grain HAZ
- Limiting the degree of austenite grain growth
- Eliminating stress concentrations

The procedure should aim to refine the coarse grained HAZ by subsequent passes. In butt welds, maximum refinement can be achieved by using a steep-sided joint preparation with a low angle of attack to minimise penetration into the side-wall, (*Fig 2a*). In comparison, a larger angle V preparation produces a wider HAZ, limiting the amount of refinement achieved by subsequent passes, (*Fig 2b*). Narrow joint preparations, however, are more difficult to weld, due to the increased risk of lack of side-wall fusion.

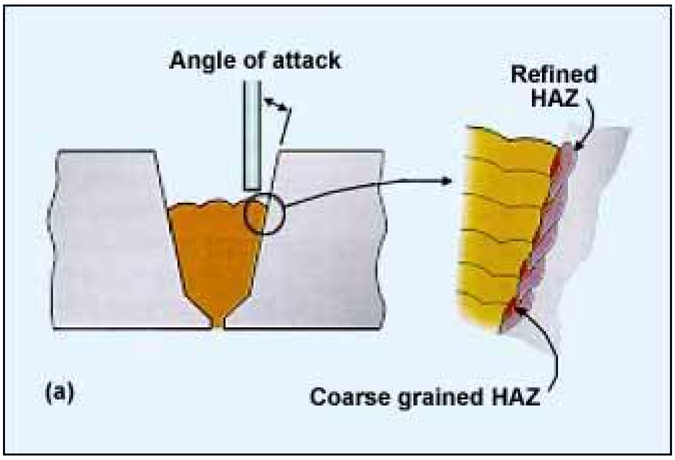


Fig.2a. Welding in the flat position - high degree of HAZ refinement

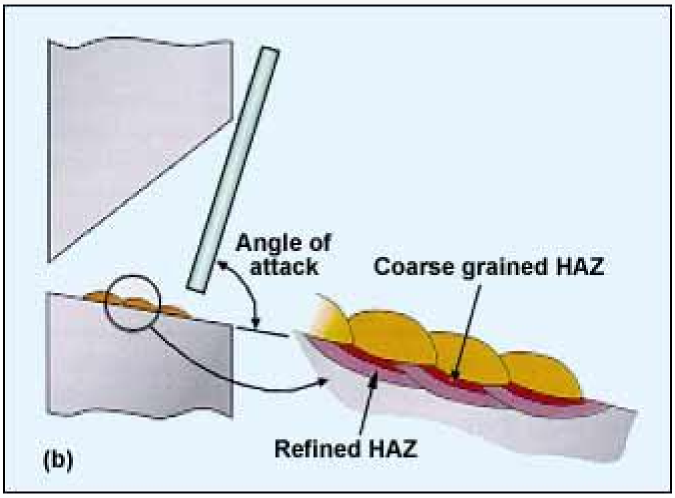


Fig.2b. Welding in the horizontal/vertical position - low degree of HAZ refinement

Refinement of the HAZ can be promoted by first buttering the surface of the susceptible plate with a thin weld metal layer using a small diameter (3.2mm) electrode. The joint is then completed using a larger diameter (4 - 4.8mm) electrode, which is intended to generate sufficient heat to refine any remaining coarse grained HAZ under the buttered layer.

The degree of austenite grain growth can be restricted by using a low heat input. However, precautionary measures may be necessary to avoid the risk of hydrogen-assisted cracking and lack-of-fusion defects. For example, reducing the heat input will almost certainly require a higher preheat temperature to avoid hydrogen-assisted cracking.
The joint design and welding technique adopted should ensure that the weld is free from localised stress concentrations which can arise from the presence of notches. Stress concentrations may be produced in the following situations:

- welding with a backing bar
- a partial penetration weld leaving a root imperfection
- internal weld imperfections such as lack of sidewall fusion
- the weld has a poor surface profile, especially sharp weld toes

The weld toes of the capping pass are particularly vulnerable, as the coarse grained HAZ may not have been refined by subsequent passes. In susceptible steel, the last pass should never be deposited on the parent material, but always on the weld metal, so that it will refine the HAZ. Grinding the weld toes with the preheat maintained has been successfully used to reduce the risk of cracking in 0.5Cr 0.5Mo 0.25V steels.