Welding Job Knowledge

Defects - hydrogen cracks in steels - prevention and best practice

Preheating of a jacket structure to prevent hydrogen cracking

Techniques and practical guidance on the avoidance of hydrogen cracks are described.

Preheating, interpass and post heating to prevent hydrogen cracking

There are three factors which combine to cause hydrogen cracking in arc welding:

1. hydrogen generated by the welding process
2. a hard brittle structure which is susceptible to cracking
3. tensile stresses acting on the welded joint

Cracking generally occurs when the temperature has reached normal ambient. In practice, for a given situation (material composition, material thickness, joint type, electrode composition and heat input), the risk of hydrogen cracking is reduced by heating the joint.

Preheat

Preheat, which slows the cooling rate, allows some hydrogen to diffuse away, and generally reduces the hardness, and therefore susceptibility to cracking, of hard, crack-sensitive microstructural regions. The recommended levels of preheat for carbon and carbon manganese steel are detailed in EN 1011-2: 2001 (which incorporates nomograms derived from those in BS 5135: 1984). The preheat level may be as high as 200°C for example, when welding thick section steels with a high carbon equivalent (IIW CE) value.

Interpass and post-heating

As cracking rarely occurs at temperatures above ambient, maintaining the temperature of the weldment during fabrication is equally important. For susceptible steels, it is usually appropriate to maintain the preheat temperature for a given period, typically between two to three hours, to enable the hydrogen to diffuse away from the weld area. In crack-sensitive situations, such as welding higher IIW CE steels or under high restraint conditions, the temperature and heating period should be increased, typically 250-300°C for three to four hours. For many steels, post-weld heat treatment (PWHT) may be used immediately on completion of welding, i.e. without allowing the preheat temperature to fall. However, in practice, as inspection can only be carried out at ambient temperature, there is the risk that 'rejectable' defects will only be found after PWHT. Also, for highly hardenable steels, a second heat treatment may be required to temper the hard microstructure present after the first PWHT.

Under certain conditions, more stringent procedures (with a higher preheat temperature and/or a lower weld metal hydrogen level) are needed to avoid cracking than those derived from the nomograms for estimating preheat in Fig. C2 of EN 1011-2. Section C.2.9 of this standard mentions the following conditions:

1. high restraint, including welds in section thicknesses above approximately 50mm, and root runs in double bevel joints
2. thick sections (≥ approximately 50mm)
3. low carbon equivalent steels (C-Mn steels with C ≤ 0.1% and IIW CE ≤ approximately 0.42)
4. 'clean' or low sulphur steels (S ≤ approximately 0.008%), as a low sulphur and low oxygen content will increase the hardenability of a steel.

5. alloyed weld metal where preheat levels to avoid HAZ cracking may be insufficient to protect the weld metal. Low hydrogen processes and consumables should be used. Schemes for predicting the preheat requirements to avoid weld metal cracking generally require the weld metal diffusible hydrogen level and the weld metal tensile strength as input.

Use of austenitic and nickel alloy weld metal to prevent cracking

In situations where preheating is impractical, or does not prevent cracking, it will be necessary to use an austenitic consumable. Austenitic stainless steel and nickel alloy electrodes will produce a weld metal which at ambient temperature has a higher solubility for hydrogen than ferritic steel. Thus, any hydrogen formed during welding becomes locked in the weld metal, with very little diffusing to the HAZ on cooling to ambient temperature.

A commonly used austenitic MMA electrode is 23Cr:12Ni, e.g. from EN 1600: 1997. However, as nickel alloys have a lower coefficient of thermal expansion than stainless steel, nickel alloy electrodes are preferred, to reduce the shrinkage strain, when welding highly restrained joints. Figure 1 is a general guide on the levels of preheat when using austenitic electrodes. When welding steels with up to 0.2%C, a preheat would not normally be required. However, above 0.4%C a minimum temperature of 150°C will be needed to prevent HAZ cracking. The influence of hydrogen level and the degree of restraint are also illustrated in the figure.

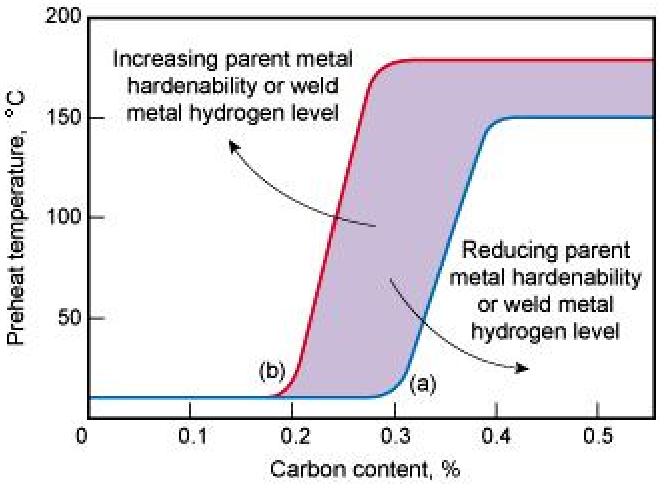

Fig.1 Guide to preheat temperature when using austenitic MMA electrodes at 1-2kJ/mm a) low restraint (e.g. material thickness <30mm) b) high restraint (e.g. material thickness >30mm)

Best practice in avoiding hydrogen cracking

Reduction in weld metal hydrogen

The most effective means of avoiding hydrogen cracking is to reduce the amount of hydrogen generated by the consumable, ie by using a low hydrogen process or low hydrogen electrodes.

Welding processes can be classified as high, medium, low, very low and ultra low, depending on the amount of weld metal hydrogen produced in a standard test block. The weld metal diffusible hydrogen levels (ml/100g of deposited metal, measured in a test weld, as specified in BS EN ISO 3690:2001), and the hydrogen scale designations of EN 1011-2: 2001 are as follows:

High	>15	Scale A
Medium	>10 <15	Scale B
Low	>5 <10	Scale C
Very low	>3 <5	Scale D
Ultra-low	≤3	Scale E

Figure 2 from Bailey et al illustrates the relative amounts of weld metal hydrogen produced by the major welding processes. MMA, in particular, has the potential to generate a wide range of hydrogen levels. Thus, to achieve the lower values, it is essential that basic electrodes are used, and they are baked in accordance with the manufacturer's recommendations, or taken from special packaging immediately before use, and exposed to ambient conditions for no longer than the time period specified by the manufacturer. For the MIG process, cleaner wires will be required to achieve very low hydrogen levels.

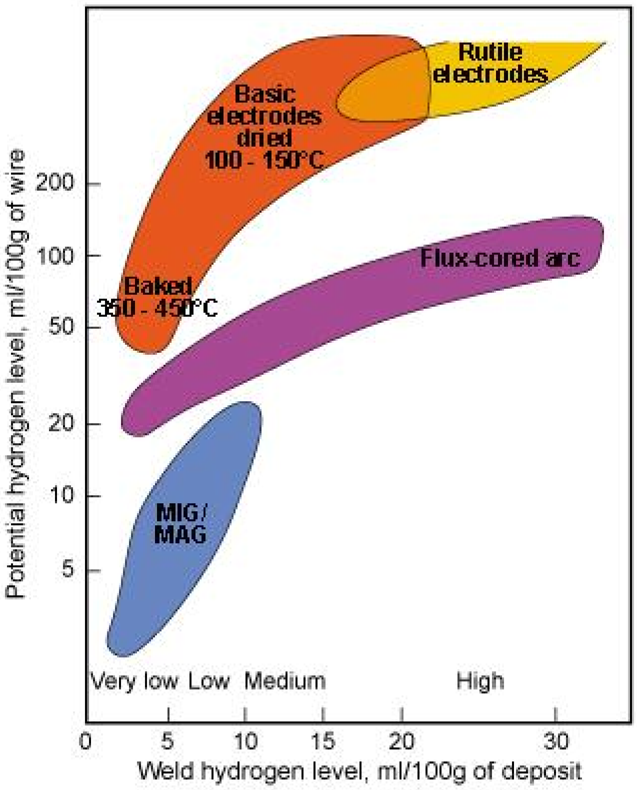

Fig.2 General relationships between potential hydrogen and weld metal hydrogen levels for arc welding processes

General guidelines

The following general guidelines are recommended for the various types of steel, but requirements for specific steels should be checked according to EN 1011-2: 2001 -

Mild steel (CE <0.4)

- readily weldable, preheat generally not required if low hydrogen processes or electrodes are used
- preheat may be required when welding thick section material, high restraint and with higher levels of hydrogen being generated

C-Mn, medium carbon, low alloy steels (CE 0.4 to 0.5)

- thin sections can be welded without preheat, but thicker sections will require low preheat levels, and low hydrogen processes or electrodes should be used

Higher carbon and alloyed steels (CE >0.5)

- preheat, low hydrogen processes or electrodes, post-weld heating and slow cooling required.

More detailed guidance on the avoidance of hydrogen cracking is described in EN 1011-2: 2001.

Practical Techniques

The following practical techniques are recommended to avoid hydrogen cracking:

1. clean the joint faces and remove contaminants such as paint, cutting oils, grease
2. use a low hydrogen process, if possible
3. bake the electrodes (MMA) or the flux (submerged arc) and then either store them warm or restrict the duration of exposure to ambient conditions, all in accordance with the manufacturer's recommendations
4. reduce stresses on the weld by avoiding large root gaps and high restraint
5. if preheating is specified in the welding procedure, it should also be applied when tacking or using temporary attachments
6. preheat the joint to a distance of at least 75mm from the joint line, ensuring uniform heating through the thickness of the material
7. measure the preheat temperature on the face opposite that being heated. Where this is impractical, allow time for the equalisation of temperature after removing the preheating before the temperature is measured
8. adhere to the preheat and minimum interpass temperature, and heat input requirements
9. maintain heat for approximately two to four hours after welding, depending on crack sensitivity
10. In situations where adequate preheating is impracticable, or cracking cannot be avoided, austenitic electrodes may be used

Acceptance standards

As hydrogen cracks are linear imperfections which have sharp edges, they are not permitted for welds meeting the quality levels B, C and D in accordance with the requirements of EN ISO 5817.

Detection and remedial action

As hydrogen cracks are often very fine and may be sub-surface, they can be difficult to detect. Surface-breaking hydrogen cracks can be readily detected using visual examination, liquid penetrant or magnetic particle testing techniques. Internal cracks require ultrasonic or radiographic examination techniques. Ultrasonic examination is preferred, as radiography is restricted to detecting relatively wide cracks that are parallel to the beam. As the formation of cracks may be delayed for many hours after completion of welding, the delay time before inspection, according to the relevant fabrication code, should be observed. Most codes will specify that all cracks should be removed. A cracked component should be repaired by removing the cracks with a safety margin of approximately 5mm beyond the visible ends of the crack. The excavation is then re-welded. To make sure that cracking does not re-occur, welding should be carried out with the correct procedure, i.e. preheat and an adequate heat input level for the material type and thickness. However, as the level of restraint will be greater and the interpass time shorter when welding within an excavation compared to welding the original joint, it is recommended that a higher level of preheat is used (typically by 50°C).

References

BS 5135:1984 Arc Welding of Carbon and Carbon Manganese Steels (now superseded by EN 1011-1: 2009 and EN 1011-2: 2001)

BS EN ISO 3690:2001 Welding and allied processes - Determination of hydrogen content in ferritic steel arc weld metal.

EN 1011 Welding - Recommendations for Welding of Metallic Materials

Part 1: 2009 - General Guidance for Arc Welding

Part 2: 2001 - Arc Welding of Ferritic Steels

BS EN 1600: 1997 Welding consumables. Covered electrodes for manual metal arc welding of stainless and heat resisting steels. Classification.

EN ISO 13916: 1997 Welding - Guidance on the Measurement of Preheating Temperature, Interpass Temperature and Preheat Maintenance Temperature

EN ISO 5817: 2007 Welding - Fusion-welded joints in steel , nickel, titanium and their alloys (Beam welding excluded). Quality levels for imperfections

N Bailey et al, Welding steels without hydrogen cracking, Woodhead Publishing, (1993) pp.105.

Which standards stipulate delay time before inspection welds? by Richard Pargeter

Evaluation of necessary delay before inspection for hydrogen cracks by Richard Pargeter