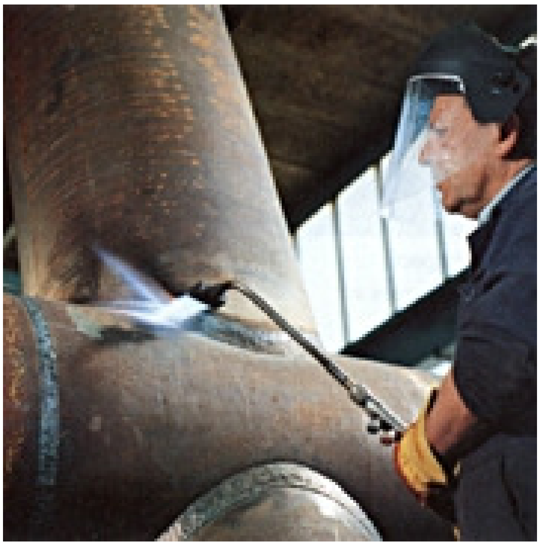
Welding Job Knowledge

Weldability of materials - Steels



In arc welding, as the weld metal needs mechanical properties to match the parent metal, the welder must avoid forming defects in the weld. Imperfections are principally caused by:

- poor welder technique;
- insufficient measures to accommodate the material or welding process;
- high stress in the component.

Techniques to avoid imperfections such as lack of fusion and slag inclusions, which result from poor welder techniques, are relatively well known. However, the welder should be aware that the material itself may be susceptible to formation of imperfections caused by the welding process. In the materials section of the Job Knowledge for Welders, guidelines are given on material weldability and precautions to be taken to avoid defects.

Material types

In terms of weldability, commonly used materials can be divided into the following types:

- Steels
- Stainless steels
- Aluminium and its alloys
- Nickel and its alloys
- Copper and its alloys
- Titanium and its alloys
- Cast iron

Fusion welding processes can be used to weld most alloys of these materials, in a wide range of thickness. When imperfections are formed, they will be located in either the weld metal or the parent material immediately adjacent to the weld, called the heat affected zone (HAZ). As chemical composition of the weld metal determines the risk of imperfections, the choice of filler metal may be crucial not only in achieving adequate mechanical properties and corrosion resistance but also in producing a sound weld. However, HAZ imperfections are caused by the adverse effect of the heat generated during welding and can only be avoided by strict adherence to the welding procedure. This part of the materials section of Job Knowledge for Welders considers the weldability of carbon-manganese (C-Mn) steels and low alloy steels.

Imperfections in welds

Commonly used steels are considered to be readily welded. However, these materials can be at risk from the following types of imperfection:

- porosity;
- solidification cracking;
- hydrogen cracking;
- reheat cracking.

Other fabrication imperfections are lamellar tearing and liquation cracking but using modern steels and consumables, these types of defects are less likely to arise.
In discussing the main causes of imperfections, guidance is given on procedure and welder techniques for reducing the risk in arc welding.

Porosity

Porosity is formed by entrapment of discrete pockets of gas in the solidifying weld pool. The gas may originate from poor gas shielding, surface contaminants such as rust or grease, or insufficient deoxidants in the parent metal (autogenous weld), electrode or filler wire. A particularly severe form of porosity is 'wormholes', caused by gross surface contamination or welding with damp electrodes.
The presence of manganese and silicon in the parent metal, electrode and filler wire is beneficial as they act as deoxidants combining with entrapped air in the weld pool to form slag. Rimming steels with a high oxygen content, can

only be welded satisfactorily with a consumable which adds aluminium to the weld pool. To obtain sound porosity-free welds, the joint area should be cleaned and degreased before welding. Primer coatings should be removed unless considered suitable for welding by that particular process and procedure. When using gas shielded processes, the material surface demands more rigorous cleaning, such as by degreasing, grinding or machining, followed by final degreasing, and the arc must be protected from draughts.

Solidification cracking

Solidification cracks occur longitudinally as a result of the weld bead having insufficient strength to withstand the contraction stresses within the weld metal. Sulphur, phosphorus, and carbon pick up from the parent metal at high dilution increase the risk of weld metal (solidification) cracking especially in thick section and highly restrained joints. When welding high carbon and sulphur content steels, thin weld beads will be more susceptible to solidification cracking. However, a weld with a large depth to width ratio can also be susceptible. In this case, the centre of the weld, the last part to solidify, will have a high concentration of impurities increasing the risk of cracking.

Solidification cracking is best avoided by careful attention to the choice of consumable, welding parameters and welder technique. To minimise the risk, consumables with low carbon and impurity levels and relatively high manganese and silicon contents are preferred. High current density processes such as submerged-arc and CO_2 , are more likely to induce cracking. The welding parameters must produce an adequate depth to width ratio in butt welds, or throat thickness in fillet welds. High welding speeds also increase the risk as the amount of segregation and weld stresses will increase. The welder should ensure that there is a good joint fit-up so as to avoid bridging wide gaps. Surface contaminants, such as cutting oils, should be removed before welding.

Hydrogen cracking

A characteristic feature of high carbon and low alloy steels is that the HAZ immediately adjacent to the weld hardens on welding with an attendant risk of cold (hydrogen) cracking. Although the risk of cracking is determined by the level of hydrogen produced by the welding process, susceptibility will also depend upon several contributory factors:

- material composition (carbon equivalent);
- section thickness;
- arc energy (heat) input;
- degree of restraint.

The amount of hydrogen generated is determined by the electrode type and the process. Basic electrodes generate less hydrogen than rutile electrodes (MMA) and the gas shielded processes (MIG and TIG) produce only a small amount of hydrogen in the weld pool. Steel composition and cooling rate determines the HAZ hardness. Chemical composition determines material hardenability, and the higher the carbon and alloy content of the material, the greater the HAZ hardness. Section thickness and arc energy influences the cooling rate and hence, the hardness of the HAZ.

For a given situation therefore, material composition, thickness, joint type, electrode composition and arc energy input, HAZ cracking is prevented by heating the material. Using preheat which reduces the cooling rate, promotes escape of hydrogen and reduces HAZ hardness so preventing a crack-sensitive structure being formed; the recommended levels of preheat for various practical situations are detailed in the appropriate standards e.g. BS EN1011-2:2001. As cracking only occurs at temperatures slightly above ambient, maintaining the temperature of the weld area above the recommended level during fabrication is especially important. If the material is allowed to cool too quickly, cracking can occur up to several hours after welding, often termed 'delayed hydrogen cracking'. After welding, therefore, it is beneficial to maintain the heating for a given period (hold time), depending on the steel thickness, to enable the hydrogen to diffuse from the weld area.

When welding C-Mn structural and pressure vessel steels, the measures which are taken to prevent HAZ cracking will also be adequate to avoid hydrogen cracking in the weld metal. However, with increasing alloying of the weld metal e.g. when welding alloyed or quenched and tempered steels, more stringent precautions may be necessary.

The risk of HAZ cracking is reduced by using a low hydrogen process, low hydrogen electrodes and high arc energy, and by reducing the level of restraint. Practical precautions to avoid hydrogen cracking include drying the electrodes and cleaning the joint faces. When using a gas shielded process, a significant amount of hydrogen can be generated from contaminants on the surface of the components and filler wire so preheat and arc energy requirements should be maintained even for tack welds.

Reheat cracking

Reheat or stress relaxation cracking may occur in the HAZ of thick section components, usually of greater than 50mm thickness. The more likely cause of cracking is embrittlement of the HAZ during high temperature service or stress relief heat treatment. As a coarse grained HAZ is more susceptible to cracking, low arc energy input welding procedures reduce the risk. Although reheat cracking occurs in sensitive materials, avoidance of high stresses during welding and elimination of local points of stress concentration, e.g. by dressing the weld toes, can reduce the risk.

Weldability of steel groups

PD CEN ISO/TR 15608:2005 identifies a number of steels groups which have similar metallurgical and welding characteristics. The main risks in welding these groups are:

Group 1. Low carbon unalloyed steels, no specific processing requirements, specified minimum yield strength R eH ≤ 460Nmm² .

For thin section, unalloyed materials, these are normally readily weldable. However, when welding thicker sections with a flux process, there is a risk of HAZ hydrogen cracking, which will need increased hydrogen control of the consumables or the use of preheat.

Group 2. Thermomechanically treated fine grain steels and cast steels with a specified miniumum yield strength R eH > 360N/mm 2 .

For a given strength level, a thermomechanically processed (TMCP) steel will have a lower alloy content than a normalised steel, and thus will be more readily weldable with regard to avoidance of HAZ hydrogen cracking and the achievement of maximum hardness limits. However, there is always some degree of softening in the HAZ after welding TMCP steels, and a restriction on the heat input used, so as not to degrade the properties of the joint zone (e.g. ≤2.5kJ/mm limits for 15mm plate).

Group 3. Quenched and tempered steels and precipitation hardened steels (except stainless steels), R_{eH}>360N/mm^2

These are weldable, but care must be taken to adhere to established procedures, as these often have high carbon contents, and thus high hardenability, leading to a hard HAZ susceptibility to cracking. As with TMCP steels, there maybe a restriction on heat input or preheat to avoid degradation of the steel properties.

Groups 4, 5 and 6. Chromium-molybdenum and chromium-molybdenum-vanadium creep resisting steels.

These are susceptible to hydrogen cracking, but with appropriate preheat and low hydrogen consumables, with temper bead techniques to minimise cracking, the steels are fairly weldable. Postweld heat treatment is used to improve HAZ toughness in these steels.

Group 7. Ferritic, martensitic or precipitation hardened stainless steels.

When using a filler to produce matching weld metal strength, preheat is needed to avoid HAZ cracking. Postweld heat treatment is essential to restore HAZ toughness.

Group 8. Austenitic stainless steels.

These steels do not generally need preheat, but in order to avoid problems with solidification or liquation cracking upon welding, the consumables should be selected to give weld metal with a low impurity content, or if appropriate, residual ferrite in the weld metal.

Group 9. Nickel alloy steels, Ni≤10%.

These have a similar weldability to Groups 4, 5 & 6.

Group 10. Austenitic ferritic stainless steels (duplex).

In welding these steels, maintaining phase balance in the weld metal and in the HAZ requires careful selection of consumables, the absence of preheat and control of maximum interpass temperature, along with minimum heat input levels, as slow cooling encourages austenite formation in the HAZ.

Group 11. High carbon steels.

These steels will be less weldable owing to their increased carbon content with respect to Group 1. It is likely that care over the choice of consumables and the use of high preheat levels would be needed.

It is important to obtain advice before welding any steels that you do not have experience in.

References

1. BS EN 1011-2:2001 'Welding - recommendations for welding of metallic materials - part 2: Arc welding of ferritic steels' British Standards Institution, March 2001.

2. PD CEN ISO/TR 15608:2005 'Welding - guidelines for a metallic material grouping system' British Standards Institution, October 2005.