12. Weldability and Welding Defects

Weldability is defined by the AWS as the capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in intended service. A satisfactory weld joint would be expected to match the strength, ductility, toughness and corrosion resistance of the materials joined over the range of service conditions the joint experiences. Weldability is a determination of the difficulty in achieving this ideal. If difficulties are experienced, the designer needs to know the impact of the problems on the intended service.

Structural steels are designed for excellent weldability, and are the benchmark against which all other materials are compared. The weldability of structural steel is improving all the time. Today's controlled rolled AS 3678 Grade 350 and 400 plate materials are far less likely to suffer HAZ cracking than steel produced 25 years ago. Then steels required more carbon and manganese to attain the same strength in the as-rolled or normalised conditions.

There are too many factors influencing weldability for it to be regarded other than as a qualitative term. Physical material properties that reduce weldability include the following:

- Higher melting temperature - lower weldability. Example - tungsten,
- Lower vaporisation temperature - lower weldability. Examples -lead, zinc
- Higher thermal conductivity - lower weldability. (More power is required to overcome heat loss). Examples - copper, gold, silver
- Higher thermal expansion - lower weldability because of higher residual stresses and distortion. Example stainless steel.

Metallurgical factors affecting weldability are:

- Material with a wide freezing range tends to suffer solidification cracking. Some impurities, such as sulphur can form low melting constituents. Heat treatable aluminium alloys have a high risk of solidification cracking because of their wide freezing range.
- High temperature oxidation affects wetting and reduces weldability. Example - stainless steel, aluminium alloys
- Gas solubility in the liquid weld metal can affect the risk of porosity
- Solid phase changes can lead to weld embrittlement or loss of corrosion performance. Steel with a high hardenability has a high risk of hydrogen cracking. Precipitation of sigma phase in stainless steel reduces ductility and corrosion performance.

Weldability is not just a material property. The component form and surface condition are also important. The presence of surface coatings can lead to poor welds. Weldability is a function of the welding method. Resistance spot welding of materials with high electrical and thermal conductivity is difficult or impossible, because this process requires electrical resistance at the weld junction for heating to occur. The joint shape and weldment size influences the selection of the appropriate welding process. Joint geometry, location, position, access and erection methods affect the ease of welding and the level of skill required. The shape, sequence of assembly and size of the structure affects the degree of weld restraint and the risk of cracking.

Design requirements influence weldability to a major extent. Welds in simple single-phase alloys in the annealed condition can be expected to match the strength and ductility of the base material. However, welds in higher strength materials are less likely to have as high strength and ductility as the base material. Where a material is strengthened by mechanical working or heat treatment (or both) the strength of the weld is usually determined by the ability to perform the same process on the weldment. Usually such treatment is impractical and the weldability of such materials is therefore low. Problems that can occur depend on the strengthening mechanism.

- Welds and HAZs in cold worked metals will have lower strength, because of annealing in the HAZ and the lack of work hardening in the weld metal. The ductility of the weld may well be superior. It is usually impossible to work harden the weld.
- Welds in fully age hardened material will have low strength unless they are solution treated and age hardened. This is usually impractical. The heat of welding will result in over-aging in the HAZ, which will often lead to low ductility.
- The strength of welds in steel with up to 300 MPa yield stress easily matches the base material. Any consumable can be used. As the strength of the steel increases, the choice of matching strength consumables becomes more limited. The highest specified minimum yield strength possible in the as-welded condition is 700 MPa. Higher weld strengths are possible in some cases (maraging steels), but only if the weld metal is heat-treated.

The designer needs to be aware of these factors and ensure design is based on the properties of the weld, as is the practice adopted by some standards. The allowable stress in aluminium welds is usually far less than for unwelded base materials. The difference is dependent on the strengthening mechanism in the base material.

Service environment also affects weldability. If a weldment is to be exposed to elevated or low temperature or corrosive environments, it becomes more difficult to make welds with acceptable properties. There are fewer options for choice of suitable materials. Welding with a wide range of arc energy may produce acceptable welds in normal conditions. High arc energy can lead to poor toughness at low temperatures. It can also worsen corrosion performance by increasing the risk of detrimental phase precipitation (such as sigma phase in stainless steels).

Weldability assessment should consider all the above factors. It is normally undertaken by a review of previous experiences with similar materials in similar situations. Simple testing for weldability is impractical because of the complication. Testing for weldability is synonymous with testing for cracking risk.

12.1. Weld Flaws, Non-Conformities and Defects

All commercial material contains imperfections and welds are likely to contain more than bulk materials. In this book, the following terms are used.

- A Flaw, Discontinuity or Imperfection: A deviation from perfection in a material. This includes atomic scale imperfections such as solute atoms, lattice vacancies, dislocations and larger imperfections such as impurity particles as well as those described below. The three terms are synonymous although the term "flaw" tends to denote a lowering in quality.
- Non-conformity: A flaw that if found, fails to meet the prescribed standard, but does not necessarily cause rejection of the material.
- A Defect: A flaw that when assessed fails to meet the prescribed standard, and causes rejection of the material. The material has to be repaired or scrapped.

In most NDT publications, the term "defect" is synonymous with "non-conformity". The distinction is subtle and only becomes important when considering random inspection or acceptance based on a fitness-for-purpose assessment.

12.2. Types of Flaws

12.2.1. Fusion Flaws

Incomplete fusion and incomplete penetration flaws are sharp edged thin voids, which are largely straight and are axial to the weld. They may cause substantial loss of cross section increasing stresses. In addition, their sharp edges concentrate stress increasing the risk of brittle failure or fatigue.

12.2.1.1 Incomplete Fusion

For a weld to be created, the weld metal must completely fuse to both components, which have to be heated to melting temperature. Incomplete fusion can occur at the sidewall or between weld runs and it is primarily caused by failure to heat the base materials sufficiently or failure of the fused filler material to wet the components. The severity of the defect depends on the extent and its orientation. In the worst case, the components do not fuse at all and the weld can be separated.

Factors that increase the risk of incomplete fusion are:

- Absence of a flux to help wetting (GMAW has a high risk but FCAW does not)
- High thermal mass. (Thick sections, high thermal conductivity and low preheat temperature)
- Low arc energy (short circuiting mode GMAW has the highest risk)
- Tight weld preparations that restrict the ability to angle the arc towards the fusion face. Horizontal position Tee joints are particularly prone.
- Surface contamination, particularly the tenacious oxide films on aluminium.
- Dissimilar weld and base material

12.2.1.2 Incomplete Penetration

This fault is the inability to melt to a sufficient depth in a relatively thick joint. The most likely cause is wrong joint design: an excessively tight weld gap or large root face. It can also be due to excessive travel speed, low welding current, or misplacement of the weld run.

12.2.2. Shape Flaws

There may be excessive or insufficient weld deposit (overfill, excessive fillet size, excessive cap height). These defects may act as stress concentrators.

Overroll or overlap forms a sharp re-entrant angle at the weld toe and a crevice. There is concentration of stresses, and the possibility of crevice corrosion.

Undercut is caused when base material is melted by the arc, but is not refilled by weld metal. It often results in stress concentrations where stress is highest anyway.

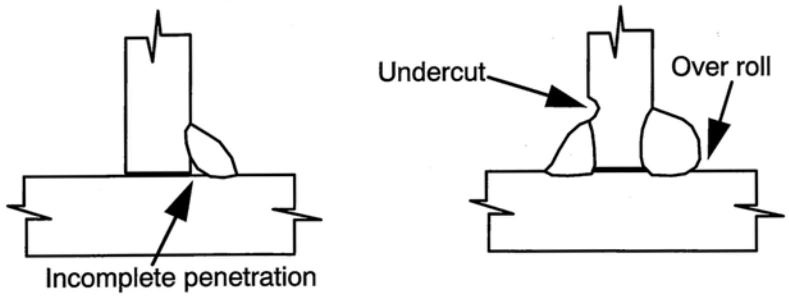

Figure 45 Typical Weld Shape Flaws

Misalignment and distortion also degrade the ability of the weldment to carry loads.

Spatter is globular weld metal which is ejected from the weld pool or arc and which sticks to the adjacent base material. If not removed it will degrade subsequent surface coatings.

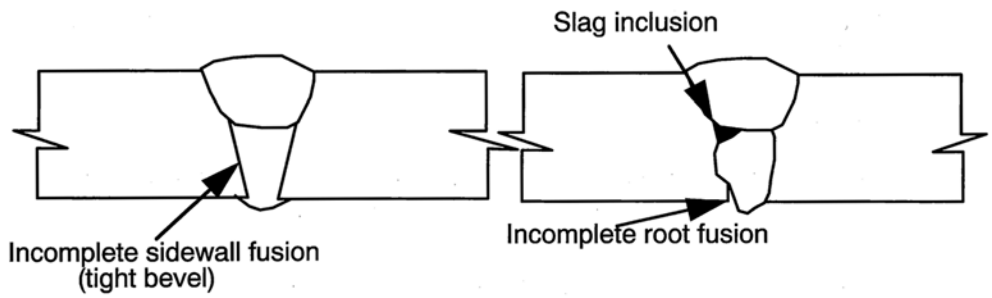

Figure 46 Typical Fusion Flaws

12.2.3. Gas and Slag Entrapment

Porosity is caused when gases are trapped in weld metal. Steel in its liquid state absorbs quantities of nitrogen and hydrogen, which normally escapes during solidification. Gas is trapped in some circumstances and forms spherical bubbles. When the problem is severe, wormholes are formed, which are elongated pores.

Slag inclusions occur when slag is not completely removed between passes, or when conditions are such that the slag rolls ahead of the arc. The prime causes of these defects are poor manipulative technique by the welder and lack of care when interpass cleaning.

Tungsten inclusions occur during GTAW if pieces of tungsten break off the electrode. Poor electrode preparation and accidentally touching the welding electrode into the weld pool are the main causes of the problem.

12.2.4. Arc Strikes

These are defects on the base material caused by accidental stray arcing. They are most likely with processes where the electrode is live all the time (MMAW and arc gouging).

AISC

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by John Taylor BSc, Sen.MWeldI

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