4. Joining Processes

4.1. Classification of Joining Processes

The group of welding processes is a major proportion of possible joining processes as seen in Table 2. There are at least thirty-five different welding processes, and new ones are being created all the time. Welding processes are usually classified into two groups: fusion welding and solid phase welding. Some welding processes have one or more variants.

Table 2 Joining Processes

Joining Methods	Sub-methods	Joining Processes
Fusion Welding	Arc Welding	MMAW, SAW, GMAW, FCAW, electro-gas welding, arc stud welding
	Resistance process	Electroslag welding
	Resistance & pressure Welding	Spot, seam, projection, resistance butt, flash butt welding
	Chemical heating	Oxy-fuel gas welding, thermit welding
	Power Beam Processes	Laser welding, electron beam welding
Solid Phase Welding	Cold	Ultrasonic, explosive, roll bond welding
	Hot	Friction, friction stir, forge, roll bond welding
Brazing and Soldering		Torch brazing, furnace brazing, induction brazing, resistance brazing, dip brazing, infrared brazing, diffusion brazing, soldering.
Adhesive bonding	Thermo-plastic adhesives	Solvent evaporation adhesives, thermal adhesives, pressure sensitive adhesives
	Thermo-setting adhesives	Chemical catalysts (curing agents). Epoxy adhesives, pressure and / or temperature may be required.
Mechanical	Fasteners	Screws. Nuts and bolts. Rivets. Ties
Connections	Design	Snap lock, crimp lock.

Structural welding is undertaken mostly by one of the fusion welding processes, and the most common of these are described in more detail later. Welding may be used for surfacing as well as joining.

4.2. Fusion Weld Structure

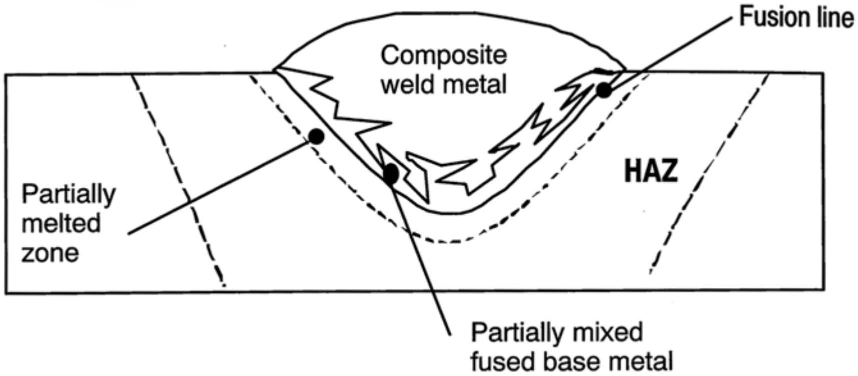

Figure 17 Structure of a Single Pass Weld

A fusion weld is one in which the heat of the process produces melting in the joint. Filler metal need not be added. Figure 17 shows the structure of a typical single weld bead on a plate surface.

The properties of the weld are governed by the metallurgical changes that occur during and after solidification of the weld metal and the heating and cooling cycle in the HAZ.

Ideally the weld metal, HAZ and base material would have physical properties as similar as possible. A significant variation in strength (over- or under-matching) causes a significant reduction in the ductility of the weld. If the weld undergoes plastic deformation, lower strength areas will suffer much higher levels of deformation than adjacent high strength areas. Differences in chemical composition can lead to galvanic corrosion in extreme environments and other problems. In practice this ideal is seldom achieved although some solid phase welding processes approach it. Welds therefore have lower performance than unwelded base material.

4.2.1. Weld Metal

Weld metal is material that has fused and solidified during welding. It will have an as-cast structure unless it is subsequently reheated. Solidification usually starts at the fusion line and columnar (elongated) grains grow inwards, finally meeting at the centre. The directional nature of solidification leads to the weld metal being anisotropic, which means that its properties (strength and ductility particularly) vary directionally.

The weld metal consists of a mixture of fused base material and the filler metal. In most arc-welding processes the weld pool is totally homogeneous, because arc, surface tension and convection forces vigorously stir the materials together.

The properties of welds depend on the cooling rate after solidification and the composition. Welds in normal structural steel grades have overmatching strength, although there is less than 0.13% carbon in the filler materials used. For many other materials, weld metal strength is lower than base material strength. The ductility of welds in normal structural steel grades is similar to or less than base material.

4.2.2. Partially Mixed Weld Metal

Where melting and solidification occurs rapidly, the mixing of filler and fused base material may be incomplete. The fused but unmixed base material usually occurs as ripples close to the fusion boundary. Where the filler metal and base metal have similar compositions (as in the case of structural steel welds) this layer has no significance and is not visible. Processes that are extremely fast, such as arc stud welding have less mixing of the fused base material with the filler.

4.2.3. Fusion Boundary

The so-called fusion line is the boundary of the weld pool. It appears as a line on sections through the weld, but is really a surface.

4.2.4. Partially Melted Zone

Some base materials melt over a wide temperature range. With these materials, partial fusion can occur close to the fusion boundary. An example would be leaded steel, where lead globules will melt some considerable distance from the fusion boundary. Partial melting is not desirable. Where it occurs, solidification and thermal contraction strains can cause cracking in the HAZ, a phenomenon known as liquation cracking. Most weldable materials have a composition that will not suffer this phenomenon.

4.2.5. Heat Affected Zone

The heat-affected zone (HAZ) is base material which is affected metallurgically by the heat of welding, but which has not fused. Microstructures in the HAZ can be complicated because the peak temperature and cooling rate are different at different distances from the fusion line as shown in Figure 18. Close to the fusion-line, the temperature peak during the welding cycle is close to melting point. As distance increases, the peak temperature is lower and the heating and cooling rates are lower.

The width and properties of the HAZ are related to the size of the weld pool. Large weld pools (high arc energy) create wider HAZs, but they cool more slowly. Conversely small weld pools (low arc energy) tend to create narrower HAZs, but they can cool rapidly. Preheating can be used to reduce the cooling rate. HAZs are typically 3 to 6mm wide, but can be more or less than this if the arc energy is particularly high or low. Welds in thin material (less than 4mm) typically exhibit wide HAZs.

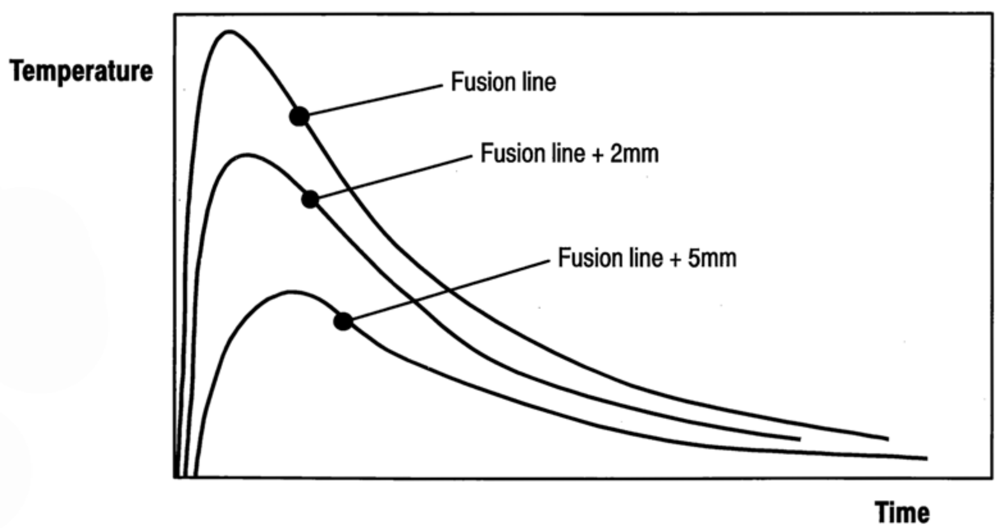

Figure 18 Thermal cycles at different parts of the HAZ

The metallurgical changes that occur in the HAZ depend on the material welded, peak temperature and cooling rate. The HAZ of cold worked material will be annealed and softened. In age hardenable materials, some areas will be solution treated and softened, other areas will be over-aged and softened, others may be aged and hardened. In some

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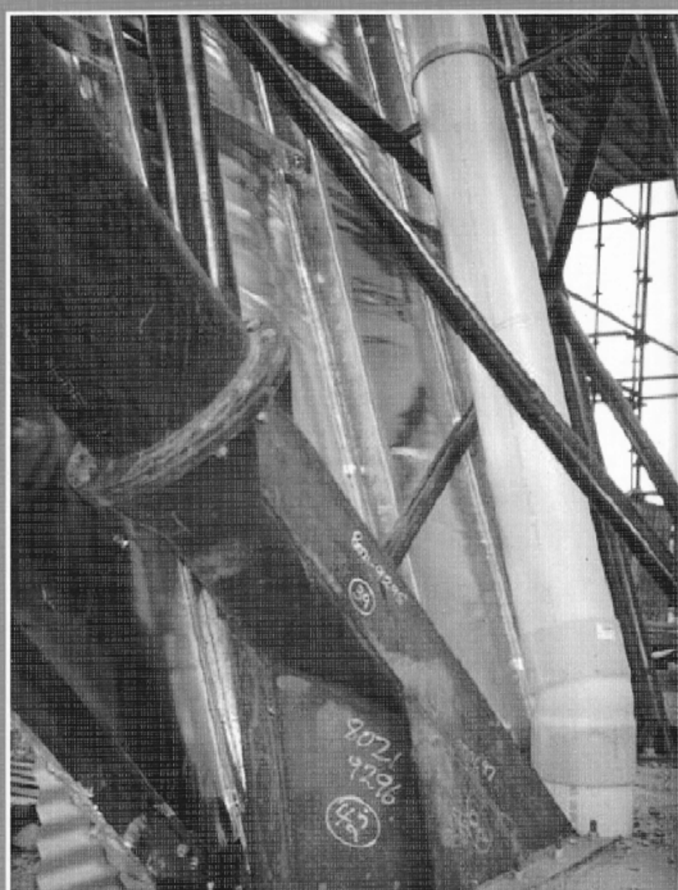

by John Taylor BSc, Sen.MWeldI

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