MCE 329 NOTE

METALLURGY OF WELDING

Metallurgical Phenomena

Welding is a complex process that involves:
- Gas-metal & slag-metal reactions
- Solidification
- Metallurgical reactions in the solid state
• annealing & recovery
• grain growth
• precipitation
• phase transformation

These metallurgical phenomena control weld strength and ductility

Gas-Metal Reactions

• Reactive gases (especially N_2, 0_2, H_2) may be present in the arc atmosphere due to surface contamination, imperfect shielding, or purposeful additions.
• These gases dissociate in the arc and react rapidly with the high temperature, turbulent liquid metal in the weld pool.
• Once dissolved in the metal, oxygen and nitrogen combine with deoxidizers such as Si or AI. The resulting oxides or nitrides remain as small inclusions in the weld metal.
• Excess dissolved gas is rejected during solidification and may cause porosity (e.g. hydrogen in AI)
• Dissolved hydrogen can cause cracking in steels.

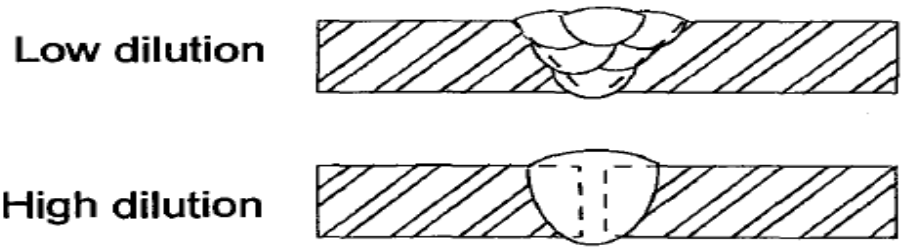
Slag-Metal Reactions

• Fluxes and slags interact with the molten weld metal
• The slags used in flux shielded processes are designed to absorb deoxidation products and other contaminants -
• The cleanliness and properties of the weld metal depend on the oxidation potential of the arc atmosphere and on the type of flux
• Highly basic fluxes reduce weld metal oxygen content and give superior notch toughness. Acid fluxes tend to give higher oxygen contents and poor notch toughness.

• Fluxes may also be used to modify weld metal composition by transfer of alloying elements from the slag to the liquid metal.

Dilution

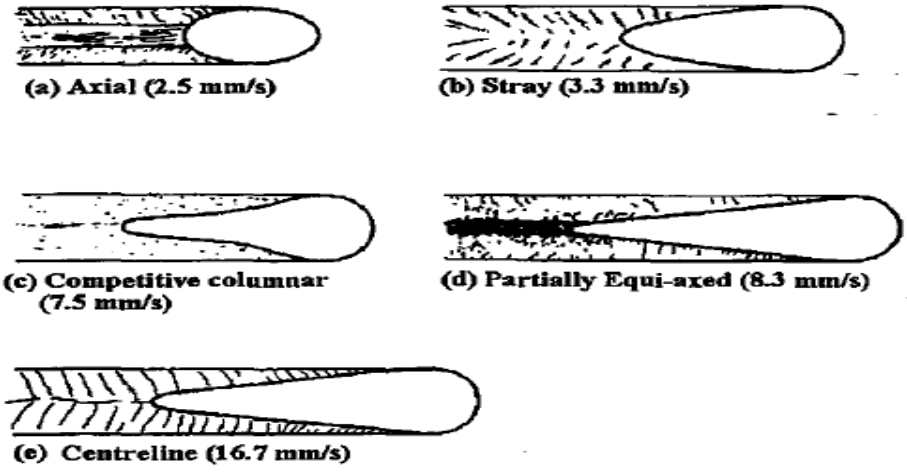
• Dilution results from mixing of filler and base metals
- Dilution ratio is the mass of base metal melted divided by the total mass of melted metal
• Weld pool mixing results in a uniform fused zone, except when large differences exist between filler and parent composition
• A sharp boundary lies between the fused zone and base metal
• Dilution is influenced by joint preparation, welding process and procedure



Solidification

❖ Factors controlling the solidification modes of metals are:
- temperature gradient
- composition
- rate of solidification

Weld Solidification Macrostructure



Annealing and Recrystallization

• Welding has little effect on the properties of ***annealed*** single phase alloys that are strengthened by ***solution strengthening***
- e.g. hot rolled low carbon steels, austenitic stainless steels, commercially pure aluminum, titanium and zirconium.
• However, when such materials are strengthened by cold work, the weld thermal cycle induces recrystallization and grain growth
• The welding heat anneals the heat affected zone, reducing its strength and increasing ductility

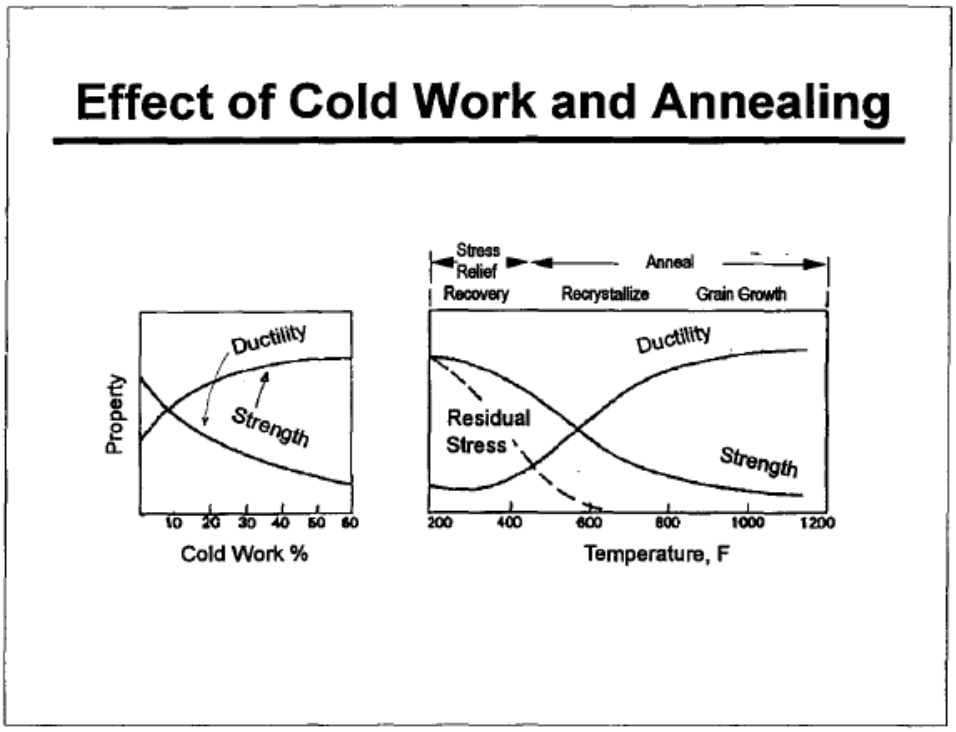


Figure x: the effect of cold work and annealing

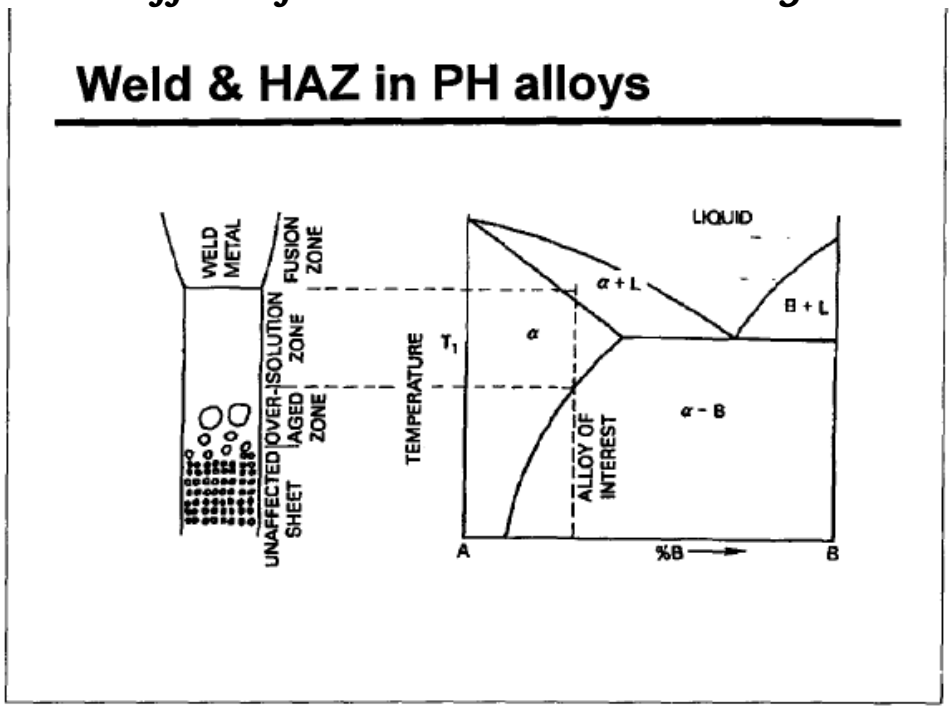


Figure xx: showing the weld and HAZ

Phase Transformations

•The properties of steels are influenced by the phase transformations they undergo on heating and cooling

• Iron solidifies as a body-centred crystal structure named delta-ferrite

• On further cooling it transforms to a face-centred cubic crystalline phase called gamma iron or austenite

• The austenite subsequently transforms back to a body-centred cubic form known as alpha iron or ferrite

A welded joint consists of:

- ❖ weld metal

Melted and re-solidified base metal mixed with filler metal (if added)

- ❖ heat affected zone (HAZ)

The region around the weld whose properties or microstructure are affected by the thermal cycle- reheating also alters the structure of under1ying weld metal in multi-pass welds

- ❖ and base metal

Welding defects

1. Incomplete fusion and joint penetration.

2. Inclusions: oxides, slag and tungsten.

3. Geometric imperfections: undercutting, underfill, excessive reinforcement, surface irregularities, drop through and mismatch.
4. Metallurgical Defects:

a) Defects related to segregation:
hot cracking and micro fissures;
cold cracking, delayed cracking, porosity and subsurface shrinkage.

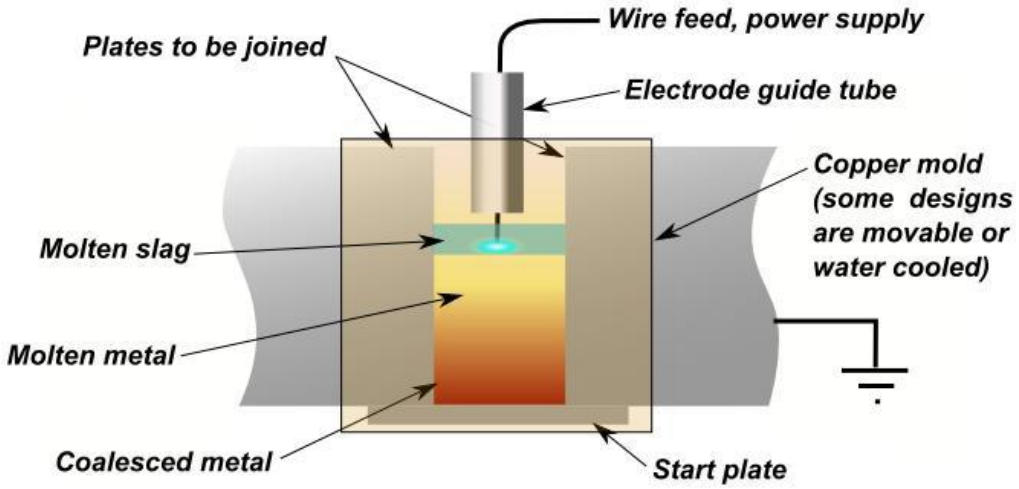
b) Imperfections induced by metallurgical reactions:
embrittlement;
metallurgical notches.
5. Other imperfections: arc strikes, weld spatter

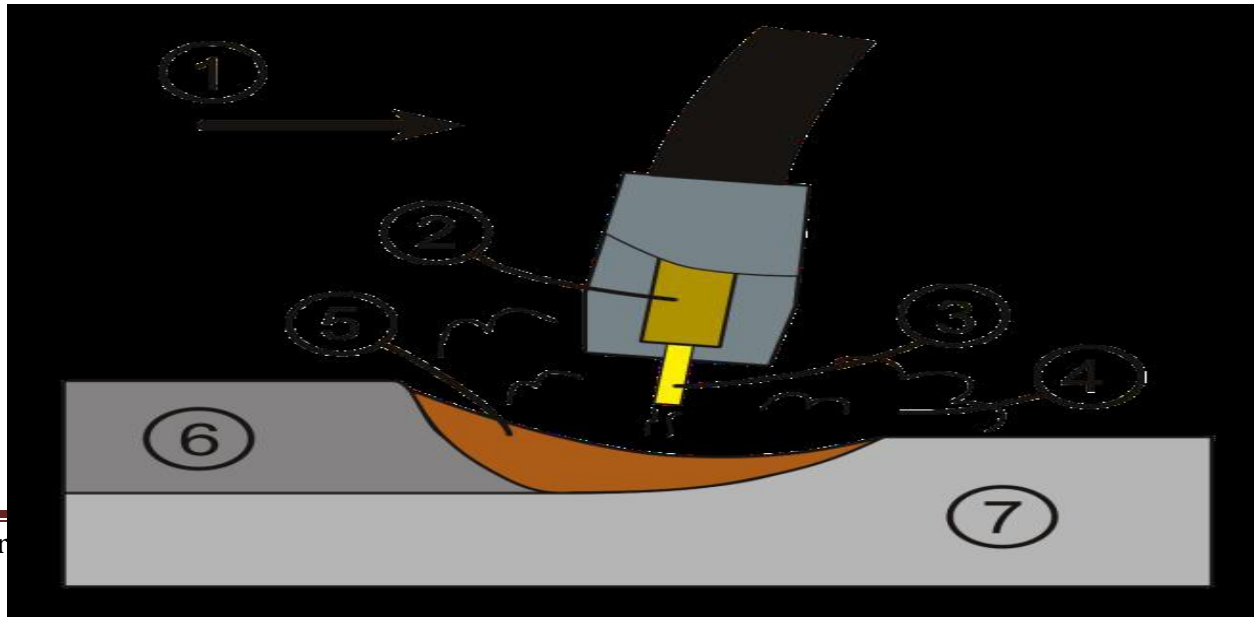
When a weld is made, following factors occur:

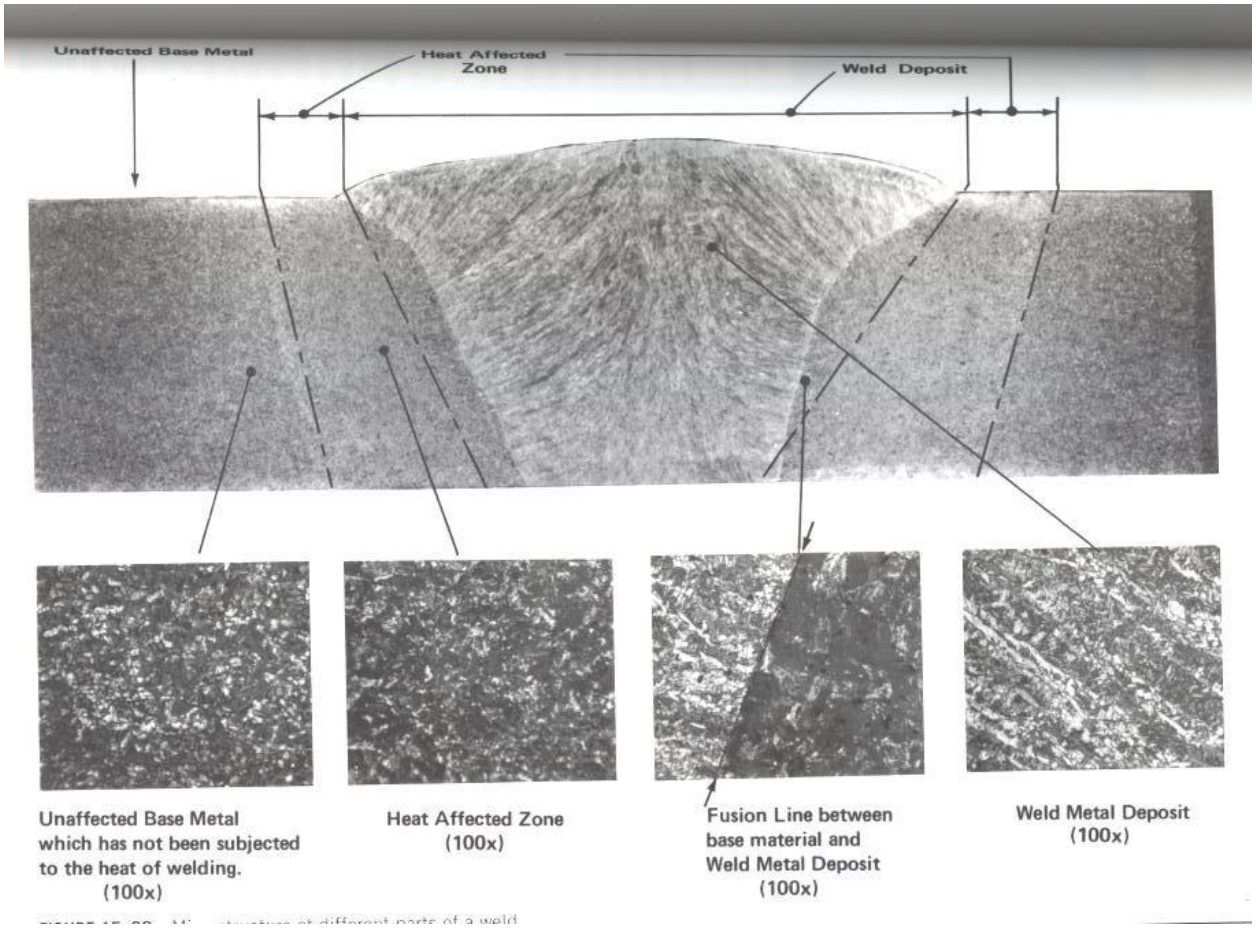
- ❖ The changes of temperature
- ❖ The growth of dimensions
- ❖ The phase transformation etc.

The rate of cooling or quench is of primary importance and this is controlled by the process, procedure, metal and mass.

Example: The electroslag has the lowest cooling rate among welding methods, while the gas metal arc has a much faster cooling rate.





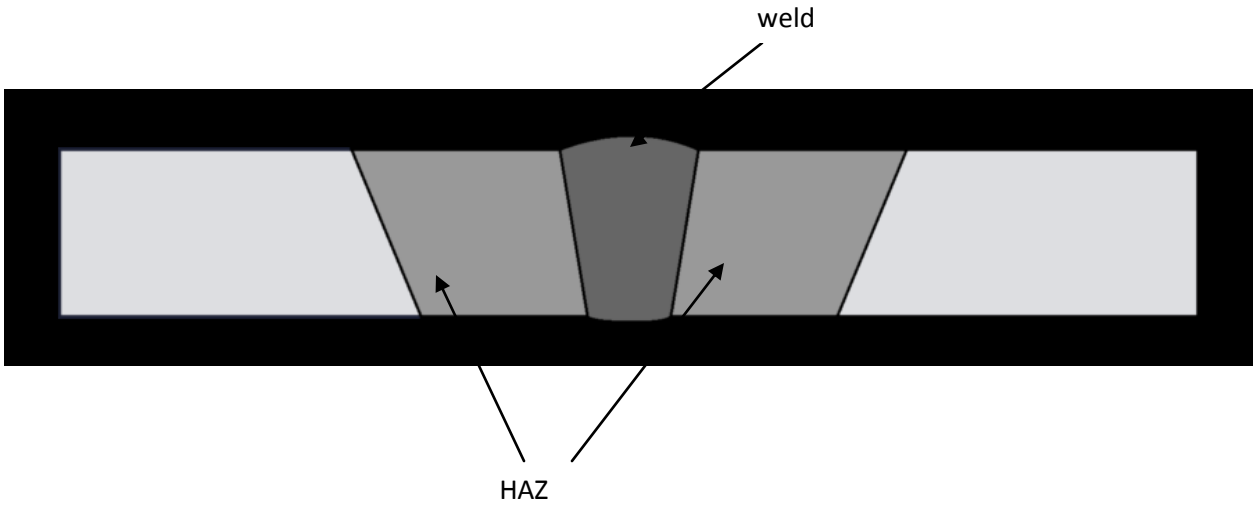


The heat-affected-zone (HAZ)

The area between the interface of the deposited weld metal, and extending into the base metal far enough that any phase change occurs, is known as the heat-affected-zone (HAZ).

 HAZ is a portion of the weld since it influences the sevice life of the weld.

HAZ is the most critical in many welds. For instance, when welding hardenable steel, HAZ can increase in hardness to an undesirable level. When welding hardened steel, HAZ can become a softened zone since the heat of the weld has annealed the hardended metal.


weld
HAZ