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BMM3643 Manufacturing Processes
Joining Processes
(Fusion Welding)

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Chapter Synopsis

This chapter will introduced students to a broad topic of joining processes. Joining processes such as welding, soldering, brazing and mechanical fastening. These processes are fundamental and important aspect in manufacturing and assembly operations.

Chapter Information

Lesson Objectives:

Joining Processes

Lesson Objective:

At the end of this lecture, students should be able to understand and explain the following:

- Basic principle of each fusion welding processes
- The relative advantages, limitations and capabilities of the each processes
- Description of the weld-zone features and defects exist in welded joints

CLASSIFICATION OF JOINING PROCESSES

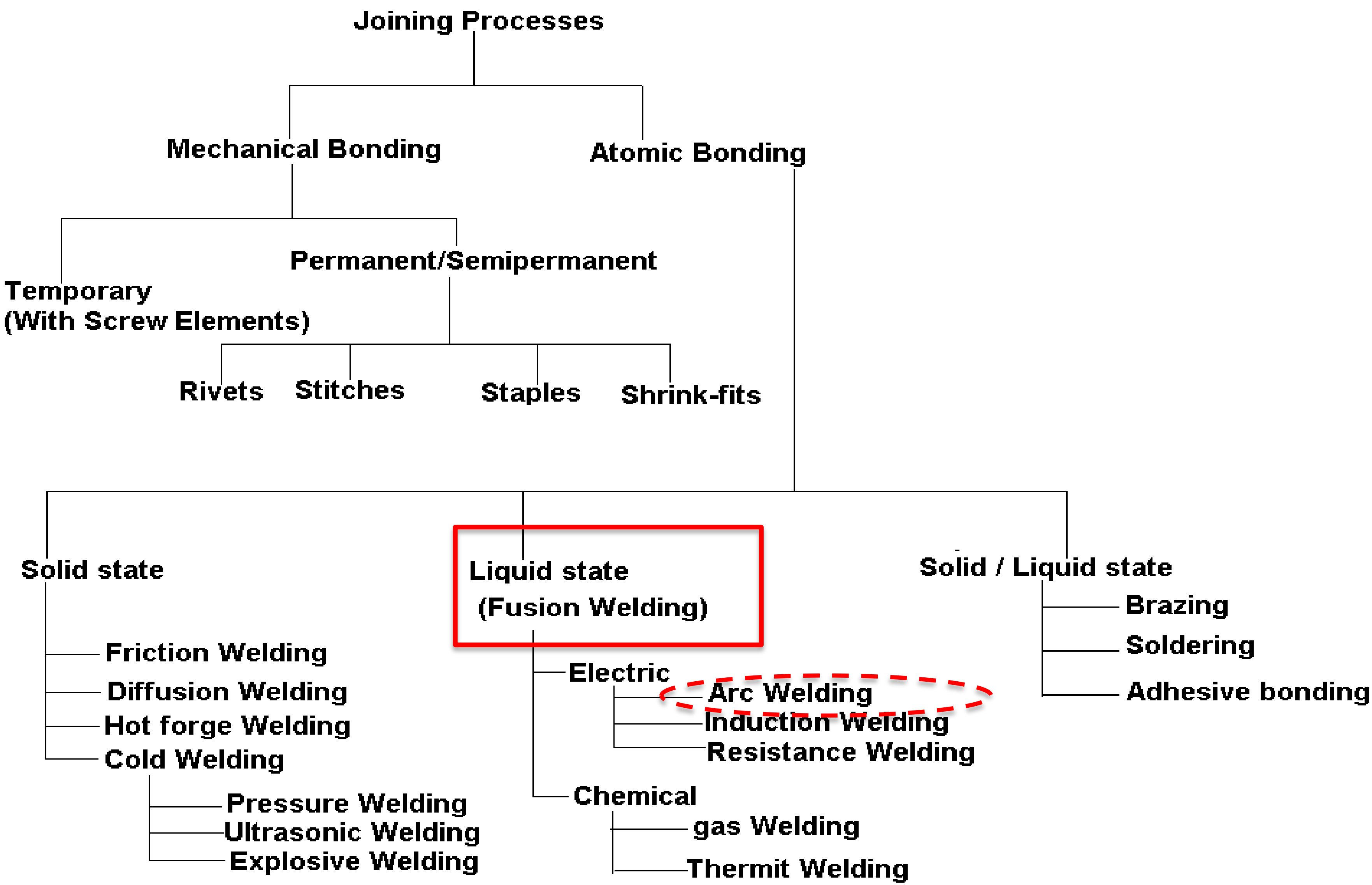


TABLE 30.1

General Characteristics of Fusion-welding Processes

Joining process	Operation	Advantage	Skill level required	Welding position	Current type	Distortion*	Typical cost of equipment ($)
Shielded metal arc	Manual	Portable and flexible	High	All	AC, DC	1–2	Low (1500+)
Submerged arc	Automatic	High deposition	Low to medium	Flat and horizontal	AC, DC	1–2	Medium (5000+)
Gas metal arc	Semiautomatic or automatic	Most metals	Low to high	All	DC	2–3	Medium (5000+)
Gas tungsten arc	Manual or automatic	Most metals	Low to high	All	AC, DC	2–3	Medium (2000+)
Flux-cored arc	Semiautomatic or automatic	High deposition	Low to high	All	DC	1–3	Medium (2000+)
Oxyfuel	Manual	Portable and flexible	High	All	—	2–4	Low (500+)
Electron beam, laser beam	Semiautomatic or automatic	Most metals	Medium to high	All	—	3–5	High (100,000–1 million)
Thermit	Manual	Steels	Low	Flat and horizontal	—	2–4	Low (500+)

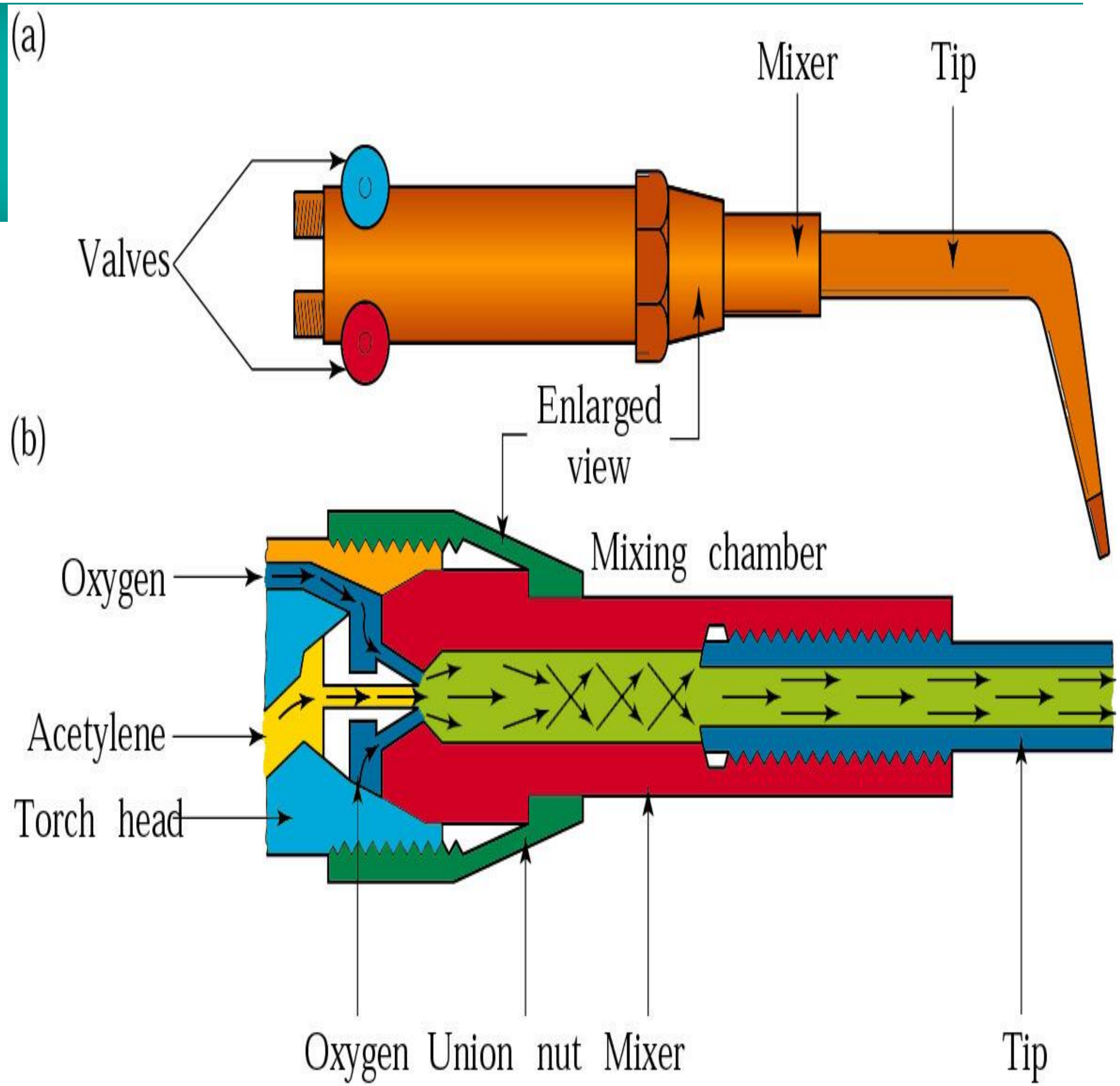
*1 = Highest; 5 = Lowest.

Source by Kalpakjian Book, 2014

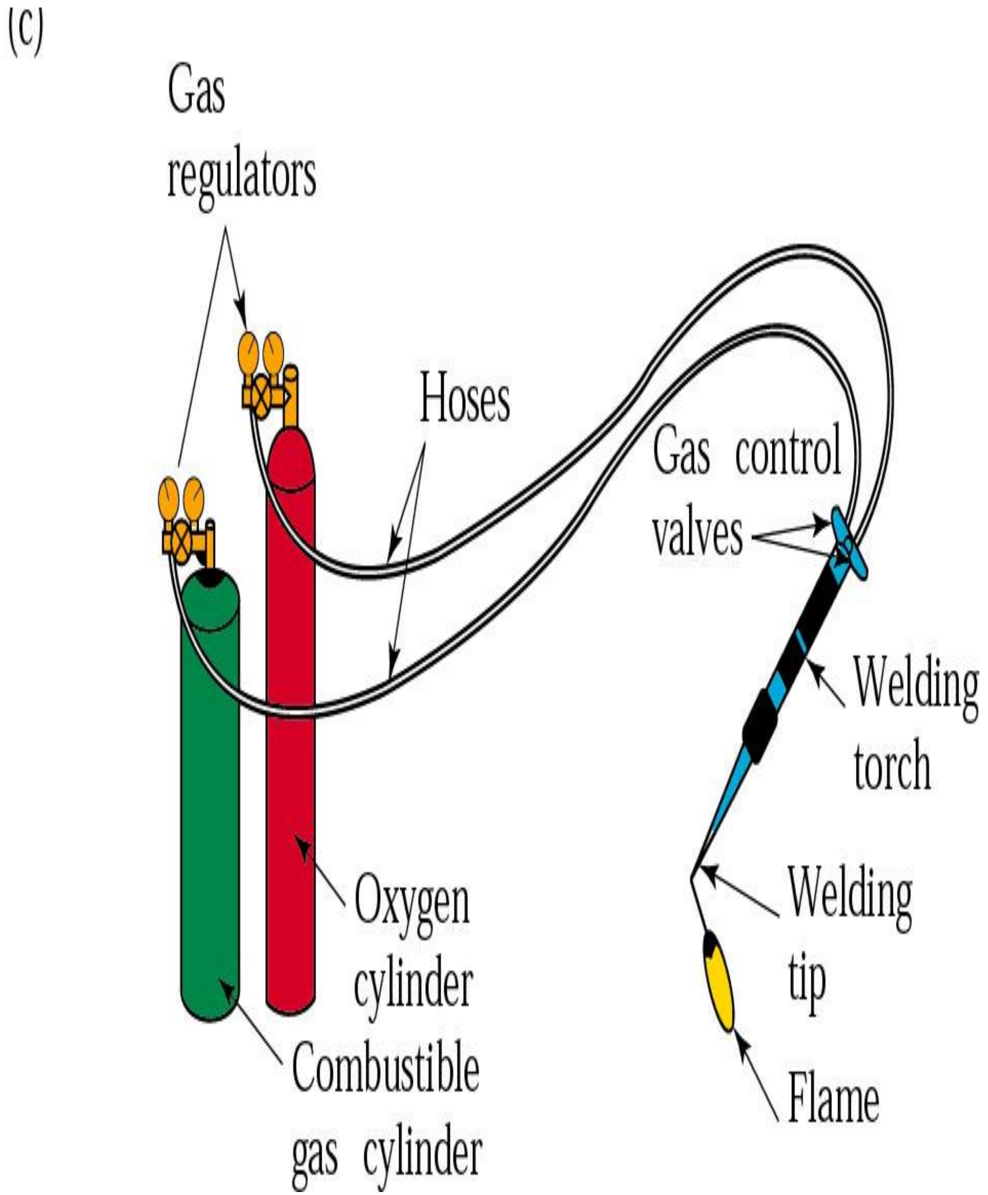
Oxyfuel-Gas Welding

- Oxyfuel-gas welding (OFW) – uses fuel gas combined with oxygen to produce flame in order to melt the metals at the joint
- Most common gas welding uses acetylene – oxyacetylene-gas welding (OAW)

General view of (a) oxyacetylene welding and (b) cross-section of a torch used in oxyacetylene welding. The acetylene valve is opened first; the gas is lit with a spark lighter or a pilot light; then the oxygen valve is opened and the flame adjusted.



(c) Basic equipment used in oxyfuel-gas welding. To ensure correct connections, all threads on acetylene fittings are left-handed, whereas those for oxygen are right-handed. Oxygen regulators are usually painted green, acetylene regulators red.

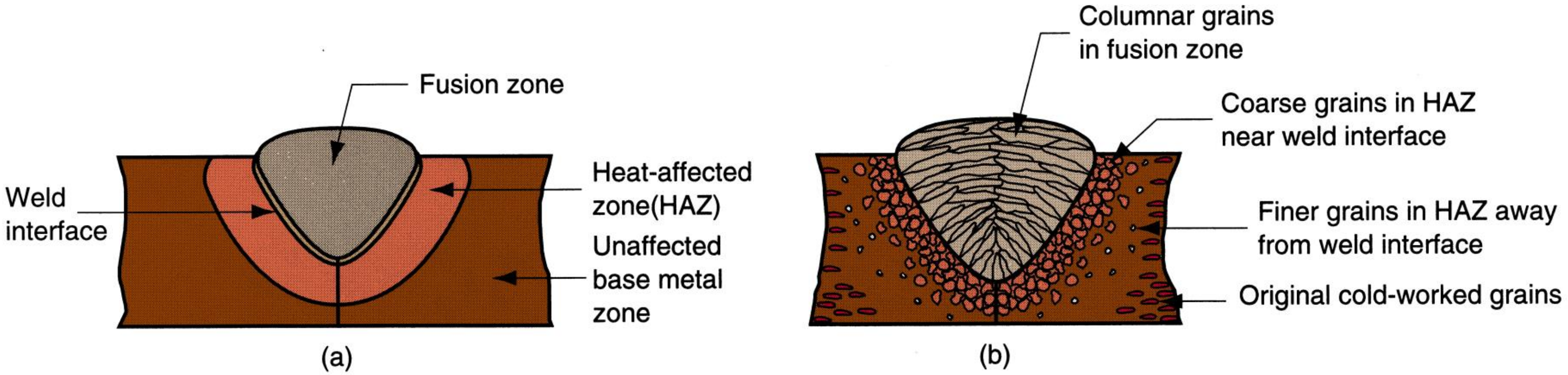


Features of A Fusion Welded Joint

Typical fusion weld joint in which filler metal has been added consists of:

1. Fusion zone – melted metals
2. Weld interface – interfaces between melted part (fusion zone) and unmelted part (HAZ)
3. Heat affected zone (HAZ) – unmelted metals
4. Unaffected base metal zone

TYPICAL FUSION WELDED JOINT



Cross section of a typical fusion welded joint:
(a) principal zones in the joint, and (b) typical grain structure

Source by Kalpakjian Book, 2014

Heat Affected Zone (HAZ)

- Experienced temperatures below melting point, but high enough to cause microstructural changes in the solid metal
- Chemical composition same as base metal, but this region has been heat treated so that its properties and structure have been altered
  - Effect on mechanical properties in HAZ is usually negative, and it is here that welding failures often occur

Filler Metals

- Filler metals are used to supply additional material to weld zone during welding.
- These filler metals in the form of rods or wire may/not be coated with flux.
- The purpose is to retard oxidation of the surfaces of the parts being welded by generating a gaseous shield around the weld zone.

Filler Metals (cont.)

- Functions of welding flux:
  - – cleans the surfaces to be welded,
  - – removes contaminants, primarily oxides,
  - – produces a gaseous shield around the welding zone preventing oxidation,
  - – produces a slag that as it solidifies protects the cooling weld pool.

Welding practice and equipment

- The equipment for oxyfuel gas welding consists of:
  - Welding torch – available in various sizes, connected by hoses to high pressure gas cylinders.
  - The high-pressure gas cylinders are equipped with pressure gages and regulators.
  - During welding process, safety equipments must be observed. E.g. goggles with shaded lenses, face shields, gloves, and protective clothing.

TYPE OF WELDED JOINTS

Source by Kalpakjian Book, 2014

Weldability

- It is a distinct measure of a material's ability to be welded.
- The quality of results may vary greatly with variations in the process parameters, such as electrode material, shielding gases, welding speed and cooling rate.
- Also influencing weldability are mechanical and physical properties of welded materials e.g. strength, toughness, ductility, melting point etc.

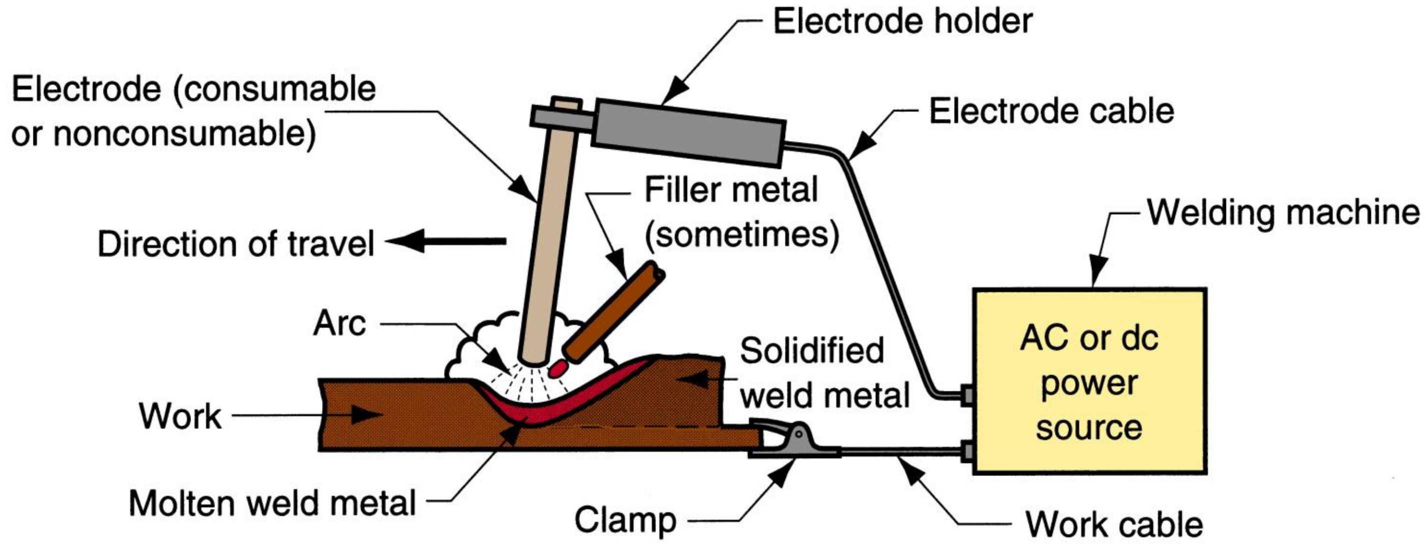
Weldability (cont.)

- Here is a brief summary of the general weldability characteristics of metals and alloys:
  - Plain-carbon steels: weldability is excellent for low-carbon steel, fair to good for medium carbon steel, poor for high carbon steel.
  - Aluminium alloys: these are weldable at high rate of input. Aluminium alloys containing Zn and Cu are considered unweldable.
  - Tungsten: this is weldable under well-controlled conditions.

Arc Welding (Electric Welding)

- Also known as electric welding due to heat required is obtained from electrical energy.
- It involves electrodes.
- An arc is produced between the tip of the electrodes and the workpiece to be welded, by the use of an AC or a DC power supply.
- A pool of molten metal is formed near electrode tip.
- As electrode is moved along joint, molten weld pool will solidifies.
- This arc generates temperatures of about 30 000 °C, much higher than those developed in oxyfuel gas welding.

Arc Welding



The basic configuration and electrical circuit of an arc welding process

Source by Kalpakjian Book, 2014

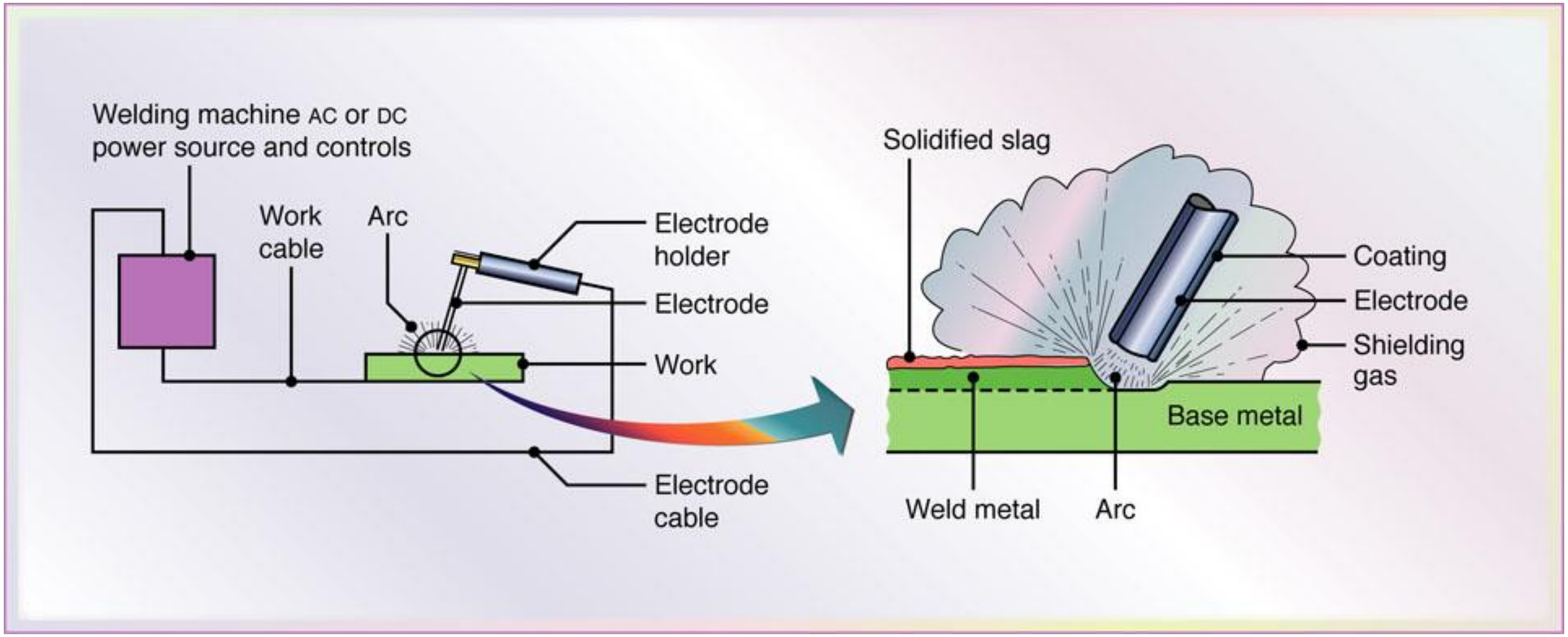
Arc Welding Processes

- *Consumable* – consumed during welding process
  - Source of filler metal in arc welding
- *Nonconsumable* – not consumed during welding process
  - Any filler metal must be added separately

Consumable electrode methods

1. Shielded metal arc welding (SMAW), or manual metal arc welding (MMA) or stick welding.
   - The oldest, simplest and most versatile joining processes
   - The electric current is used to strike an arc between the base material with a consumable coated electrode or 'stick'.

SHIELDED-METAL ARC WELDING



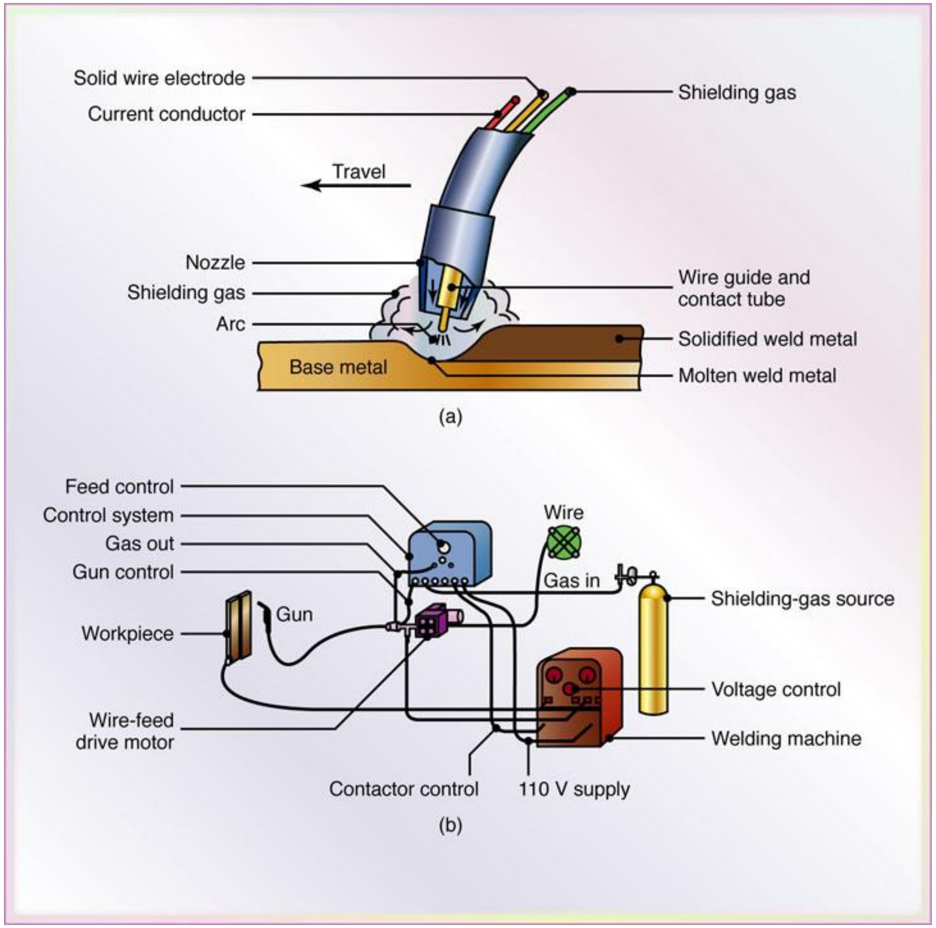
Schematic illustration of the shielded metal-arc welding process. About 50% of all large-scale industrial welding operations use this process.

Source by Kalpakjian Book, 2014

Consumable electrode methods (cont.)

2. Gas metal arc welding (GMAW) uses a continuous wire feed as an electrode and an shielding gas to protect the weld from contamination.
   - When using an inert gas as shield it is known as **Metal Inert Gas (MIG) welding.**
   - GMAW welding speeds are relatively high due to the automatically fed continuous electrode, but is less versatile because it requires more equipment than the simpler SMAW process.
3. Submerged-arc Welding

GAS METAL-ARC WELDING



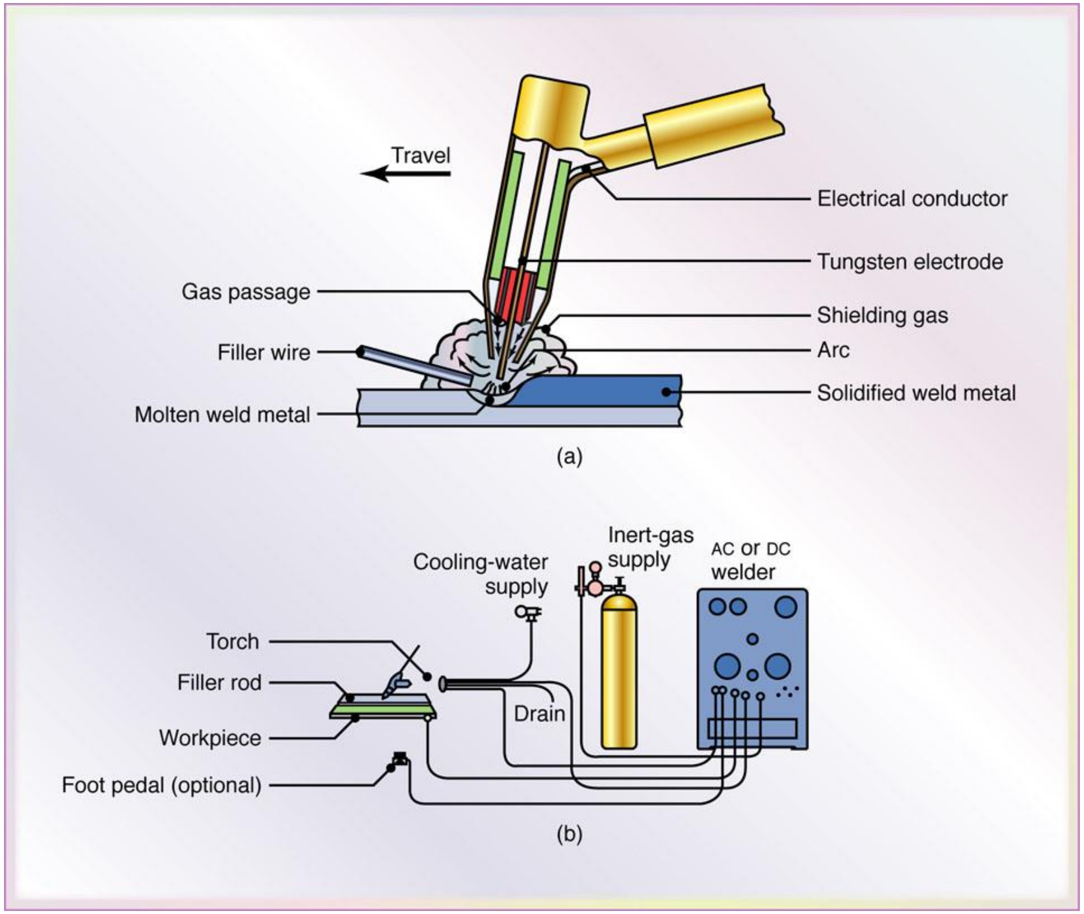
(a) Schematic illustration of the gas metal-arc welding process, formerly known as MIG (for metal inert gas) welding. (b) Basic equipment used in gas metal-arc welding operations.

Source by Kalpakjian Book, 2014

Non-consumable electrode methods

1. Gas tungsten arc welding (GTAW), or **tungsten inert gas (TIG) welding**, uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material.
   – useful for welding thin materials.
   – characterized by a stable arc and high quality welds, but it requires high operator skill and can only be accomplished at relatively low speeds.
   – used on nearly all weldable metals, though it is most often applied to stainless steel and light metals.
   – often used when quality welds are extremely important, such as in aircraft structure and naval applications.
2. Plasma-arc Welding
3. Atomic-hydrogen Welding

GAS-TUNGSTEN ARC WELDING



(a) The gas tungsten-arc welding process, formerly known as TIG (for tungsten inert gas) welding. (b) Equipment for gas tungsten-arc welding operations.

Source by Kalpakjian Book, 2014

Weld Quality

- Welding discontinuities can be caused by inadequate or careless application of welding technologies or by poor operator training.
- The major discontinuities that affect weld quality are:
  - porosity,
  - slag inclusions,
  - incomplete fusion & penetration,
  - weld profile,
  - cracks,
  - lamellar tears,
  - surface damage
  - residual stresses

Weld Quality (cont.)

1. Porosity

- Caused by gaseous released during melting of the weld area but trapped during solidification, chemical reactions or contaminants
- They are in form of spheres or elongated pockets
- Porosity can be reduced by
  - Proper selection of electrodes
  - Improved welding techniques
  - Proper cleaning and prevention of contaminants
  - Reduced welding speeds

Weld Quality (cont.)

2. Slag Inclusions

- Compounds such as oxides ,fluxes, and electrode-coating materials that are trapped in the weld Zone
- Prevention can be done by following practices :
  - Cleaning the weld bed surface before the next layer is deposited
  - Providing enough shielding gas
  - Redesigning the joint

Weld Quality (cont.)

3. Incomplete Fusion

- Produces lack of weld beads
- Practices for better weld :
  - Raising the temperature of the base metal
  - Cleaning the weld area, prior to the welding
  - Changing the joint design and type of electrode
  - Providing enough shielding gas

Weld Quality (cont.)

4. Lack of Penetration

- Incomplete penetration occurs when the depth of the welded joint is insufficient
- Penetration can be improved by the following practices :
  - Increasing the heat Input
  - Reducing the travel speed during the welding
  - Changing the joint design
  - Ensuring the surfaces to be joined fit properly

Weld Quality (cont.)

5. Weld Profile

- Underfilling results when the joint is not filled with the proper amount of weld metal.
- Undercutting results from the melting away of the base metal and consequent generation of a groove in the shape of a sharp recess or notch.
- Overlap is a surface discontinuity usually caused by poor welding practice and by the selection of improper material.

Weld Quality (cont.)

6. Cracks

- Cracks occur in various directions and various locations
- Factors causing cracks:
  - Temperature gradients that cause thermal stresses in the weld zone
  - Variations in the composition of the weld zone.
  - Embrittlement of grain boundaries
  - Inability if the weld metal to contract during cooling

Weld Quality (cont.)

7. Lamellar tears

- Occurred due to the shrinkage of the restrained components in the structure during cooling.
- Can be avoided by providing for shrinkage of the members & changing the joint design

8. Surface Damage

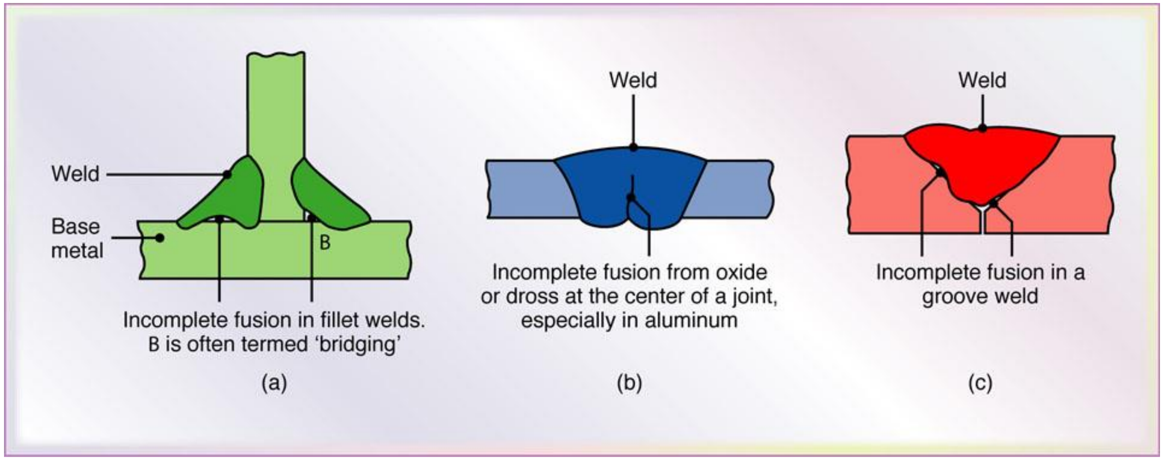
- These discontinuities may adversely affect the properties of welded structure, particularly for notch sensitive metals.

Weld Quality (cont.)

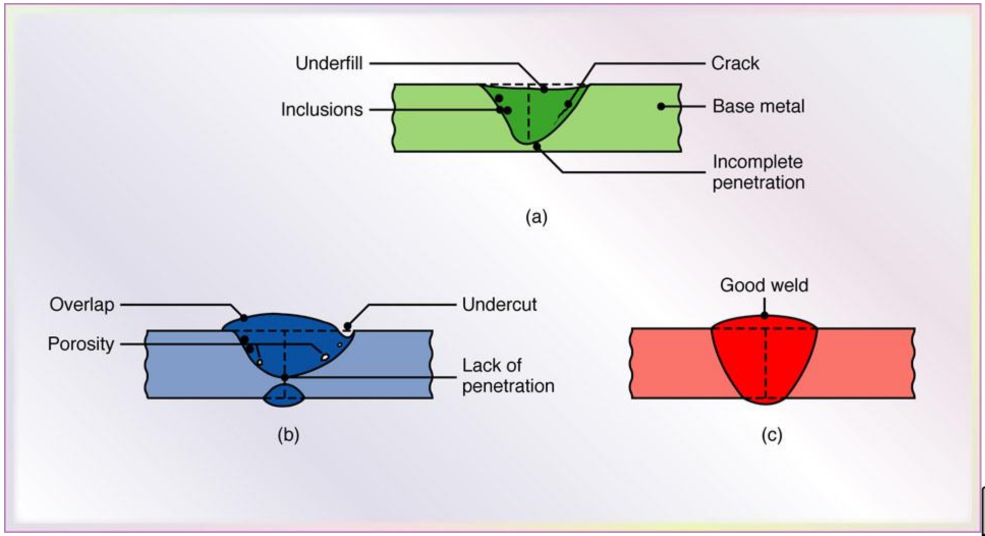
9. Residual Stresses

- Because of localized heating & cooling during welding, expansion and contraction of the weld area can cause the following defects:
  - Distortion, Warping and buckling of welded parts
  - Stress corrosion cracking
  - Further distortion if a portion of the welded structure is subsequently removed
  - Reduced fatigue life

DISCONTINUITIES AND DEFECTS IN FUSION WELDS



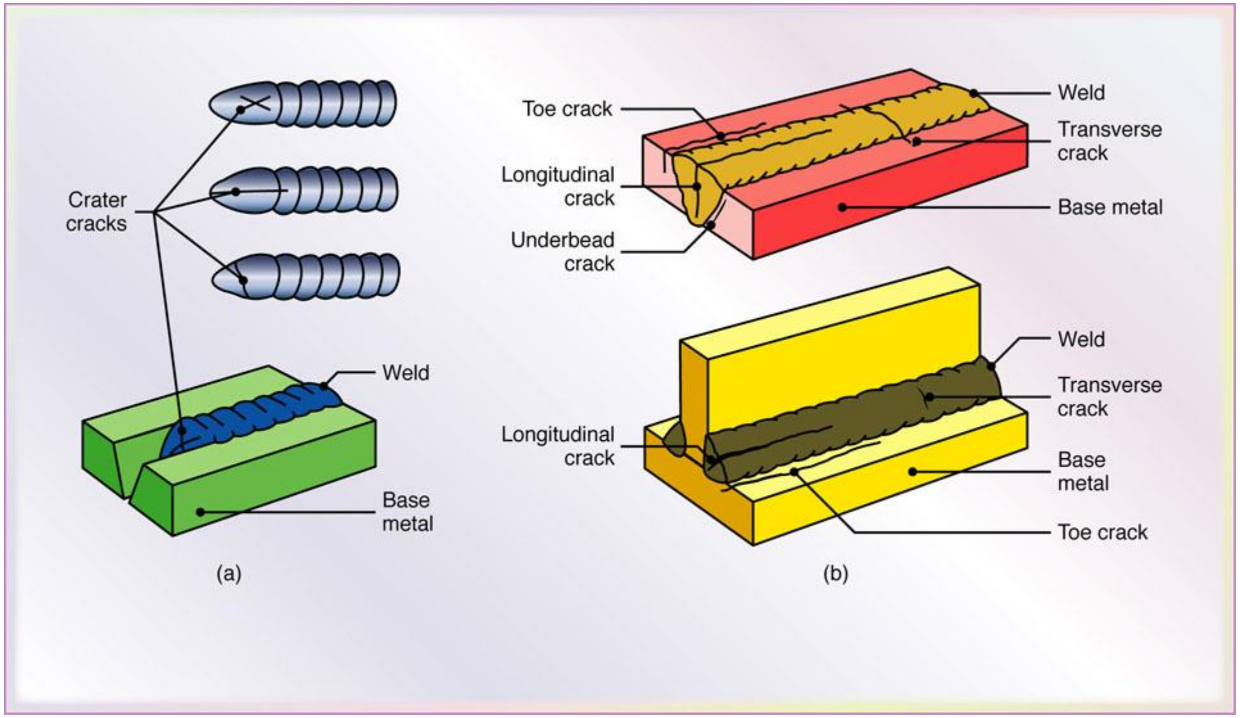
Examples of various discontinuities in fusion welds.



Examples of various defects in fusion welds.

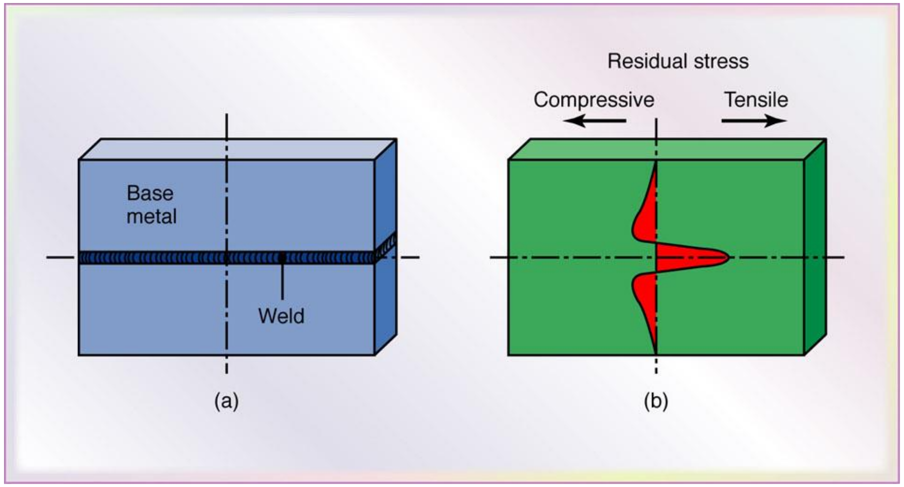
Source by Kalpakjian Book, 2014

CRACKS IN WELDED JOINTS

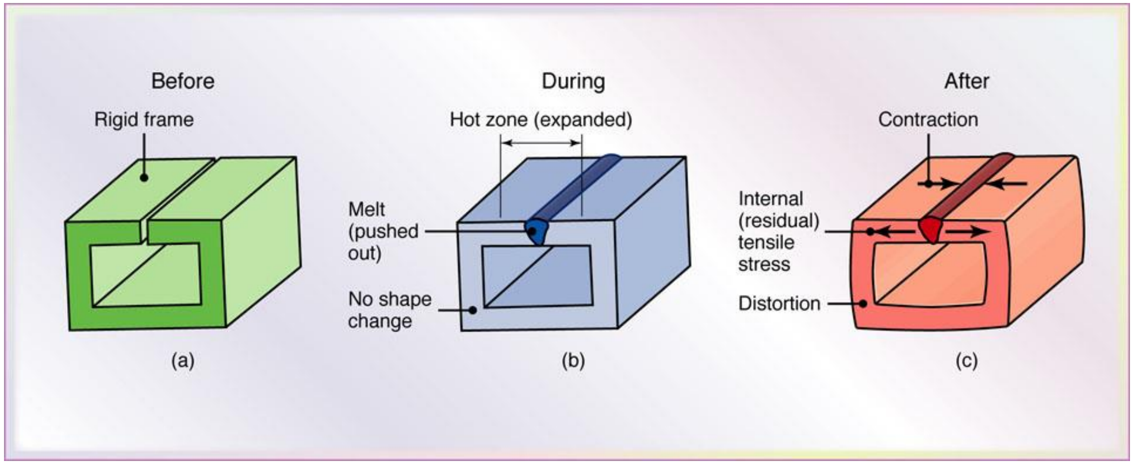


Types of cracks developed in welded joints. The cracks are caused by thermal stresses, similar to the development of hot tears in castings.

RESIDUAL STRESSES AND DISTORTION



Residual stresses developed in a straight butt joint. Note that the residual stresses in (b) must be internally balanced.



Distortion of a welded structure.

Source by Kalpakjian Book, 2014

Weld Quality (cont.)

<u>Stress relieving of weld</u>

- Preheating reduces problems caused by preheating the base metal or the parts to be welded
- Heating can be done electrically,in furnace,for thin surfaces radiant lamp or hot air blast
- Some other methods of stress relieving : hammering or surface rolling

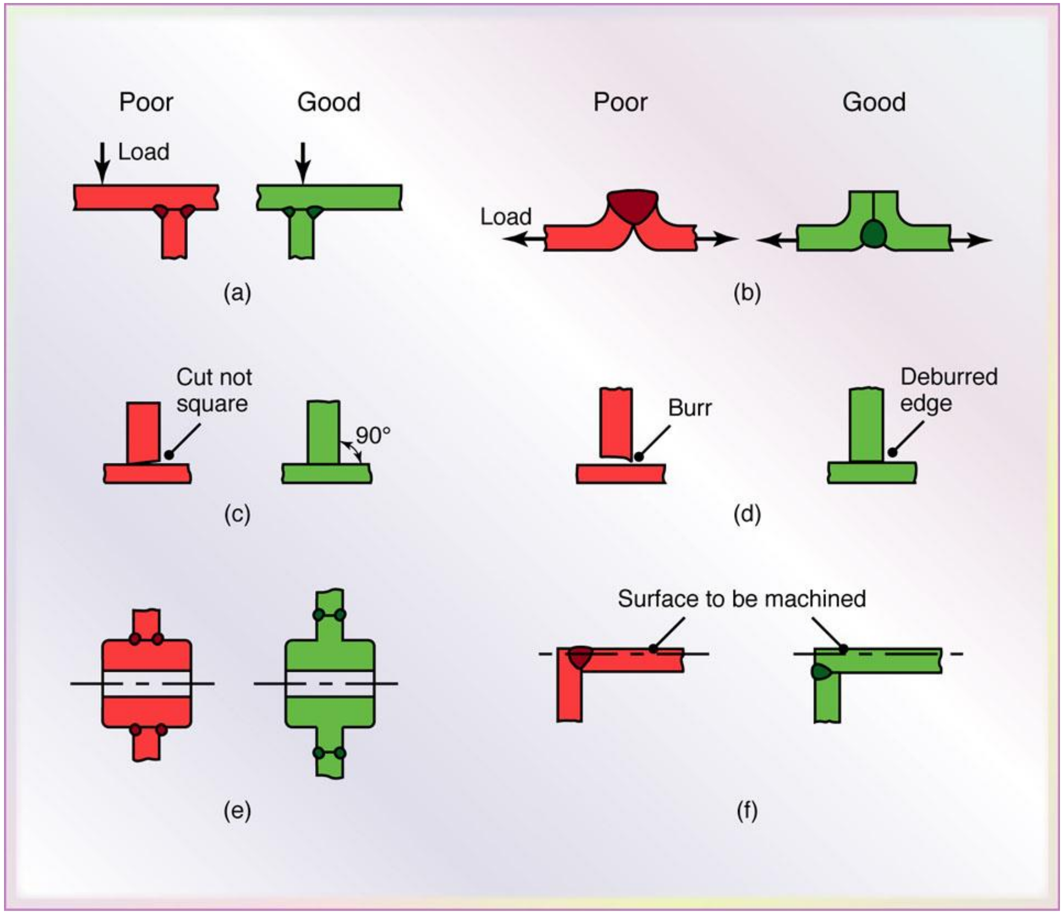
Welding Process Selection

- Considerations:
  - Configuration of the components to be joint, joint design, thickness and size of the components, number of joints required
  - Methods used to manufacture the components
  - Types of materials involved
  - Application and service requirements - type of loading, any stresses generated and environment
  - Location, accessibility and ease of welding
  - Effects of distortion, warping, appearance and discoloration
  - Costs involved – preparation, joining and post processing
  - Costs of equipment, materials, labor and skills required

Joint Design

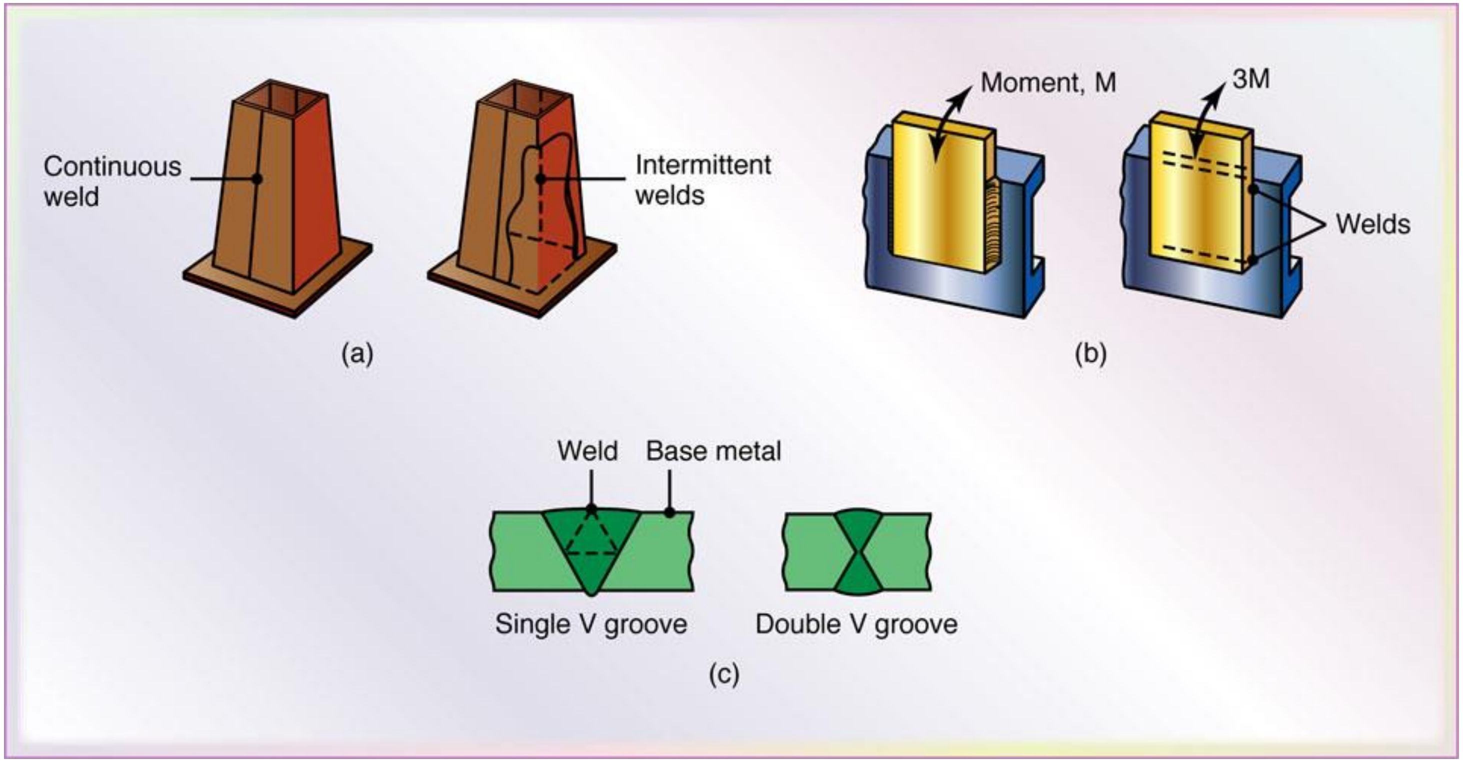
- Important design guidelines that MUST be considered:
  - ✓ Minimize the number of joints – time consuming & costly
  - ✓ Select the suitable weld locations – to avoid excessive local stresses or stress concentrations, better appearance
  - ✓ Weld location should not interfere with any subsequent of the joined components

WELD DESIGN



Some design guidelines for welds. *Source*: After J.G. Bralla.

WELD DESIGN



Examples of weld designs that can be used.

Testing of Welded Joints: Destructive Techniques

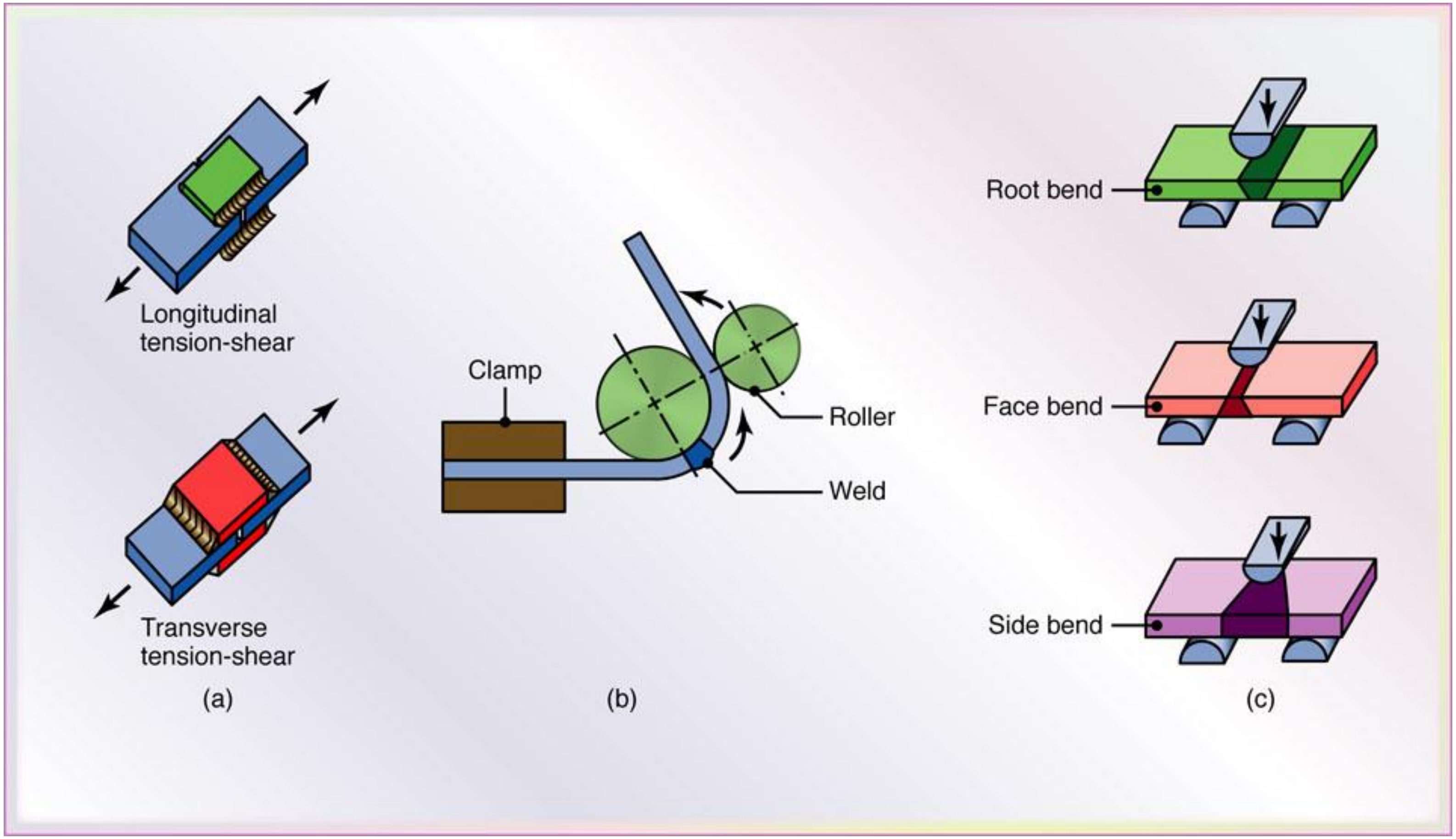
Tension Test

- Longitudinal & transverse tension tests are performed
- Stress strain curves are obtained

Tension-Shear Test

- Specifically prepared to simulate actual welded joints and procedures.
- Specimen subjected to tension and shear strength of the weld metal

WELD TESTING



(a) Specimen for longitudinal tension-shear testing; specimen for transfer tension-shear testing; (b) wraparound bend test method; (c) three-point bending of welded specimens.

Source by Kalpakjian Book, 2014

Testing of Welded Joints: Destructive Techniques

Bend test

- Determines ductility and strength of welded joints.
- The welded specimen is bend around a fixture
- The specimens are tested in three-point transverse bending
- These tests help to determine the relative ductility and strength of the welded joints

Testing of Welded Joints: Destructive Techniques

i. Fracture Toughness Test

ii. Corrosion & creep tests

iii. Testing of spot welds

-Tension-Shear -Twist

-Cross-tension -Peel

Testing of Welded Joints: Non-Destructive testing

- Often weld structures need to be tested Non-Destructively
- Non-Destructive testing are :
  - Visual
  - Radiographic (X-rays)
  - Magnetic-particle
  - Liquid-penetrant
  - Ultrasonic

End of chapter
Joining Processes