Introduction

Online course on Analysis and Modelling of Welding

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Classification of Manufacturing Processes

- **Casting Processes**
  - Ingot Casting
  - Shape Casting
  - Power Metallurgy

- **Forming Processes**
  - Forging
  - Extrusion
  - Sheet Metal Forming

- **Joining Processes**

- **Machining Processes**
  - Turning, Boring
  - Drilling, Milling
  - Grinding
Classification of Joining Processes

Joining Processes

- Mechanical Fastening
- Adhesive Joining
- Soldering
- Brazing
- Welding
Different Welding Processes

Arc Welding:
- SMAW, GMAW
- GTAW, SAW
- FCAW, PAW

Resistance Welding:
- Spot, Seam, Projection

Solid state Welding:
- USW, FRW, EXW

Beam Processes:
- LBW, EBW
Five basic joint designs

- BUTT
- LAP
- TEE
- CORNER
- EDGE
Four basic types of fusion welds

- Bead / Surface Weld
- Groove Weld
- Fillet Weld
- Plug Weld
Bead / Surface Welds

- For butt welds
- No edge preparation
- Thin sheets of metal
- Building up surfaces
- Weld overlay
Groove Welds

- For butt welds
- Thicker materials
- Full thickness welding
- Detailed edge preparation
- Multi-pass welding
Groove preparations

Ref: Wikipedia, public domain. Contributed by Benrunge
Fillet Welds

- For Tee, Lap and Corner joints
- No edge preparation
Plug Welds

• Hole drilled on the top sheet
• To replace bolts and rivets
• When excess deposit is not desirable by design
Five Welding Positions

Arrow shows the direction of motion of the electrode / torch. The torch is held approximately normal to this direction.
Classification of Welding

- Fusion Welding
  - Consumable Electrode
  - Non-consumable Electrode
  - Flux protected
  - Inert gas protected

- Filler
  - Autogenous
  - Homogeneous
  - Inert gas protected

- Multi Pass
  - Single Pass
  - Heterogeneous
Some terminology

• Traverse rate: velocity of the welding source: m/s
• Heat Input: ratio of power to velocity: J/m
• Rate of heat input or heat intensity: W/m²
• Heat intensity distribution: Q(x,y)
Overview of few welding processes

- SMAW : Shielded (Manual) Metal Arc Welding
- GMAW: Gas Metal Arc (MIG) Welding
- GTAW: Gas Tungsten Arc (TIG) Welding
- PAW: Plasma Arc Welding
- SAW: Submerged Arc Welding
- EBW: Electron Beam Welding
- LBW: Laser Beam Welding
Electric Arc

- Generated between two conductors of electricity, upon application of voltage and separated by a small distance
- Presence of ionisable gas
- Sustained electric discharge through ionized gas column between the two electrodes
Role of gases in arc welding

- Inert / active
- Shielding effect
- Stability of arc

<table>
<thead>
<tr>
<th>Gas</th>
<th>Ionization Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>14.4 eV</td>
</tr>
<tr>
<td>O₂</td>
<td>13.2 eV</td>
</tr>
<tr>
<td>N₂</td>
<td>14.5 eV</td>
</tr>
<tr>
<td>H₂</td>
<td>13.5 eV</td>
</tr>
<tr>
<td>Ar</td>
<td>15.7 eV</td>
</tr>
<tr>
<td>He</td>
<td>24.5 eV</td>
</tr>
</tbody>
</table>

Arc characteristics

Electrode Polarities

• Direct Current Straight Polarity (DCSP) : Electrode is negative. Deeper penetration.

• Direct Current Reverse Polarity (DCEP) : Electrode is positive. Enhanced deposition rate for consumable electrode.

• Alternating Current (AC) : Polarity is switched at a frequency.
**DCEN**
- 70% Heat to workpiece
- 30% Heat to Electrode

**DCEP**
- 30% Heat to workpiece
- 70% Heat to Electrode
- Surface Cleaning

**AC**
- 50% Heat to workpiece
- 50% Heat to Electrode
- Surface cleaning half-the-time
Temporal profiles

Balanced Sine Wave

Unbalanced Sine Wave

Square Wave
Spatial-temporal characteristics of arc

- Voltage, Current, Efficiency
- Wave form: flat, square, sine, unbalanced sine etc.
- Pulsing effects (Peak value, base value)
- Frequency (Hz)
- Traverse rate (m/s)
- Electrode path: arc oscillation, frequency and amplitude etc.
What is in the Flux?

Role of a Flux: Protection, Deoxidation, Stabilization and Metal Addition

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron oxide</td>
<td>Slag former, arc stabilizer</td>
</tr>
<tr>
<td>Titanium oxide</td>
<td>Slag former, arc stabilizer</td>
</tr>
<tr>
<td>Calcium fluoride</td>
<td>Slag former, fluxing agent</td>
</tr>
<tr>
<td>Potassium silicate</td>
<td>Arc stabilizer, Binder</td>
</tr>
<tr>
<td>Magnesium oxide</td>
<td>Fluxing agent</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Gas former</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>Gas former, Arc stabilizer</td>
</tr>
<tr>
<td>Ferro-manganese, Ferro-chrome</td>
<td>Alloying changes</td>
</tr>
<tr>
<td>Ferro-silicon</td>
<td>Deoxidizer</td>
</tr>
</tbody>
</table>
GMAW

Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras
Metal transfer modes

- **Globule transfer**
  - Droplets close to or larger than diameter of the electrode
  - Reach base material by gravity
  - Leads to spatter

- **Spray transfer**
  - Fine droplets
  - Reach base material by EM force

- **Short-circuit transfer**
  - Small and fast solidifying weld pools
Gas tungsten arc welding

Diagram showing:
- Inert gas supply
- AC or DC Welder
- Cooling water supply
- Drain
- Torch
- Work piece
- Foot pedal (optional)
- Solidified weld
- Filler wire
- Tungsten electrode
- Molten weld metal
- Arc
Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras
Plasma arc welding

Tungsten electrode
Plasma gas
Shielding gas
Power supply
Work piece
Transferred arc
Non transferred arc
Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras
Submerged Arc welding

- **Wire reel**
- **Flux hopper**
- **Contact tube**
- **Wire feed motor**
- **Unused flux recovery tube**
- **Voltage and current control**
- **Work piece**
- **Ground**

Granular flux covers the weld and the arc
SMAW

Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras
Electron beam welding

Schematic of a typical EBW gun
Laser beam welding

Basic features of an Nd : YAG laser
Intensity of heat sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Heat source intensity (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW, FCAW</td>
<td>$5 \times 10^6 - 5 \times 10^8$</td>
</tr>
<tr>
<td>GTAW, GMAW</td>
<td>$5 \times 10^6 - 5 \times 10^8$</td>
</tr>
<tr>
<td>PAW</td>
<td>$5 \times 10^6 - 10^{10}$</td>
</tr>
<tr>
<td>LBW, EBW</td>
<td>$10^{10} - 10^{12}$</td>
</tr>
</tbody>
</table>

Heat input vs power density

More damage to work piece

Gas Welding processes

Arc welding processes (GMAW, GTAW, etc.)

High energy beam welding processes (EBW, LBW)

Higher penetration, Welding speed, Weld quality, Capital cost

Power density of heat source

Less damage to work piece

### Summary of features

<table>
<thead>
<tr>
<th>Feature/Process</th>
<th>GTAW</th>
<th>GMAW</th>
<th>PAW</th>
<th>LBW</th>
<th>EBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Source</td>
<td>Arc</td>
<td>Arc</td>
<td>Plasma Arc</td>
<td>Laser beam</td>
<td>Electron beam</td>
</tr>
<tr>
<td>Protection</td>
<td>Shielding gas</td>
<td>Shielding gas</td>
<td>Shielding gas</td>
<td>None / Shielding gas</td>
<td>Vacuum</td>
</tr>
<tr>
<td>Rate of Heat Input</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Aspect Ratio of Weld</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Max Penetration</td>
<td>3 mm</td>
<td>5 – 10 mm</td>
<td>Up to 20 mm</td>
<td>25 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>Advantages</td>
<td>High quality weld</td>
<td>Continuous and Automated</td>
<td>Longer arc length</td>
<td>Any location where light can reach, high speed, accuracy</td>
<td>Precision, accuracy, deep and narrow welds</td>
</tr>
<tr>
<td>Materials Joined</td>
<td>Most common metals</td>
<td>Most common metals</td>
<td>Most common metals</td>
<td>Reflectivity Issues</td>
<td>Vacuum Issues</td>
</tr>
</tbody>
</table>

Ref: Materials and Processes in Manufacturing, 9th Edition by E. Paul DeGarmo et al., Wiley. ISBN: 9812530703
End of Introduction