Welding of Dissimilar Materials Combinations for Automotive Applications

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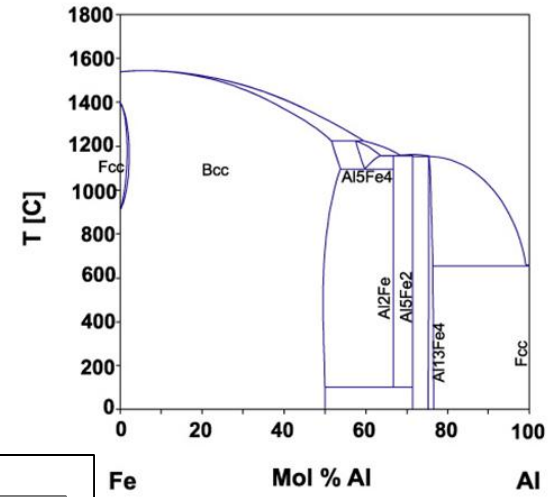
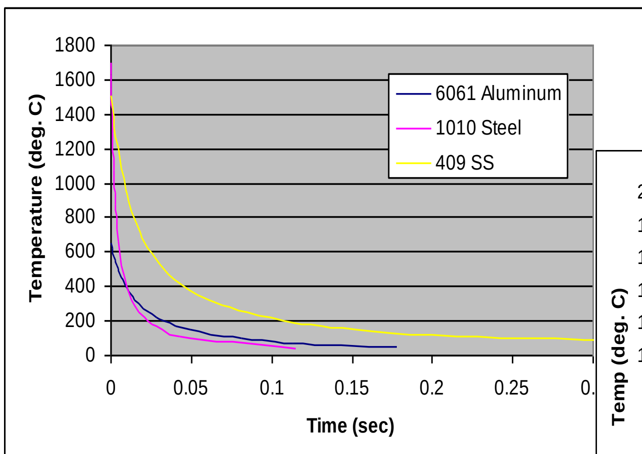
Metallurgical Aspects of Joining Aluminum to Steel

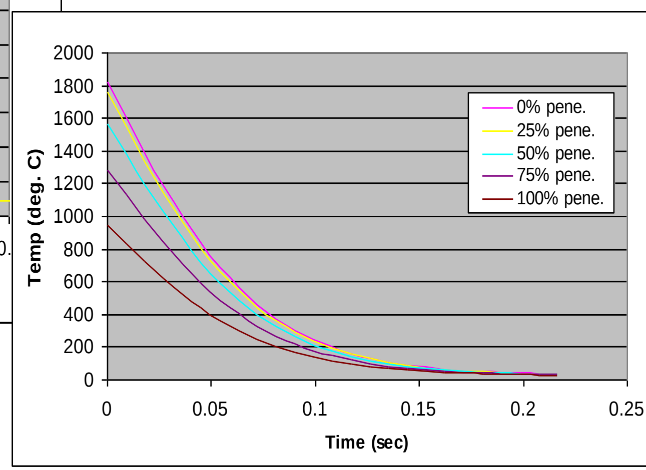
- Suppression of solidification defects
- Suppression of Fe_2Al_7
- Empirically observed critical cooling times
- Process selection to achieve necessary cooling times



ated Fe-Al phase diagram assessed by 1991Sei



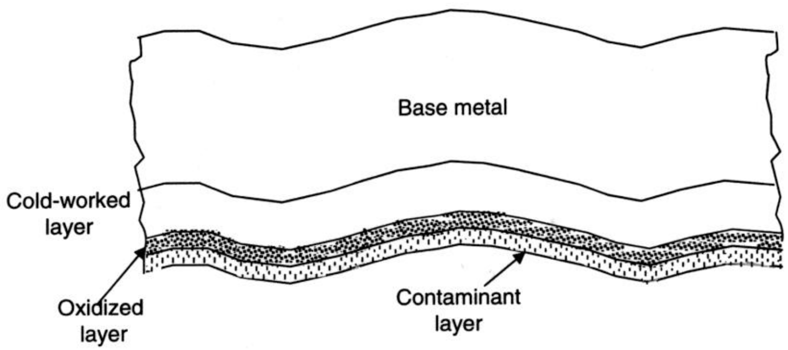
Cooling characteristics of magnetic pulse welds for a number of materials



Cooling characteristics for 0.8-mm resistance spot welds on mild steel

Mechanisms of Solid-State Bonding

- Contaminant displacement/ interatomic bonding



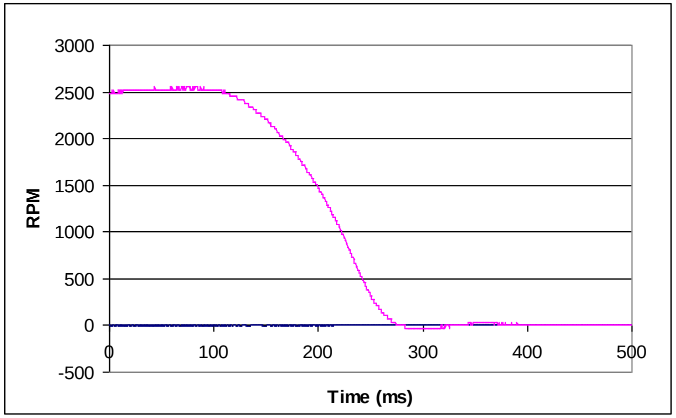
$$f = C\left(\frac{R}{R+1}\right)^2$$

- **Oxide/contaminant dissolution**
- **Second material gettering**

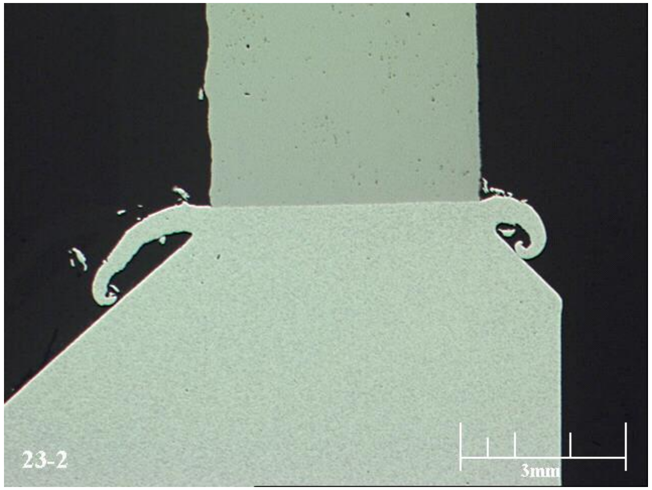
Metal	Oxide	K_{eq}
Al	**Al_2O_3**	**3×10^{-29}**
Fe	**Fe_2O_3**	**1×10^{-15}**
Ti	**TiO_2**	**1×10^{-01}**

$$f = \frac{1}{1+\left[\frac{t^*}{t}\exp-\frac{Q_2}{R}\left(\frac{1}{T^*}-\frac{1}{T_s}\right)\right]^{\frac{3}{2}}}$$

- Process characteristics
  - Inertia and direct-drive friction welding variants
  - Low surface velocities
  - Short heating times
  - Forging only in the aluminum

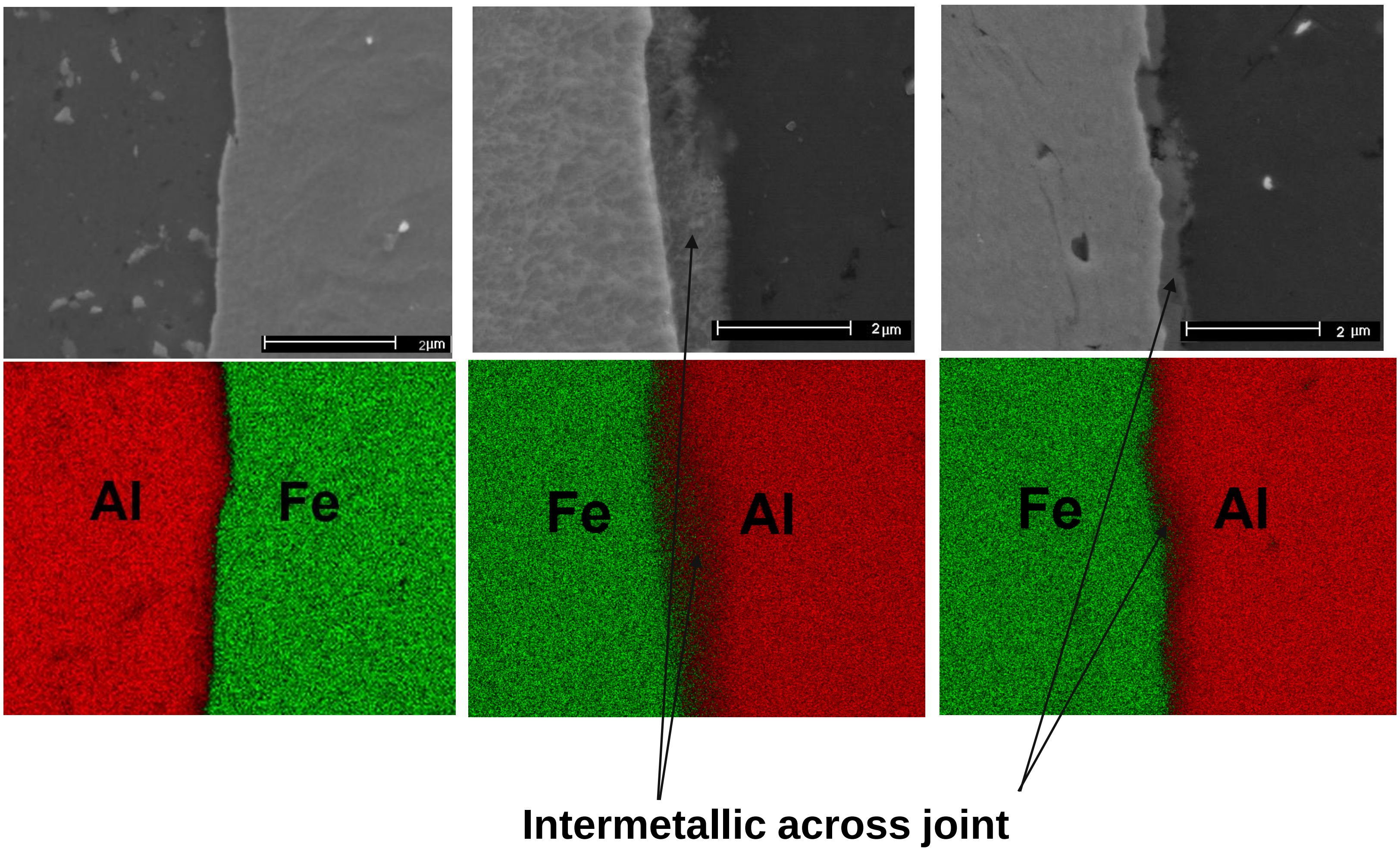


Deceleration profile for an inertia weld between aluminum and steel

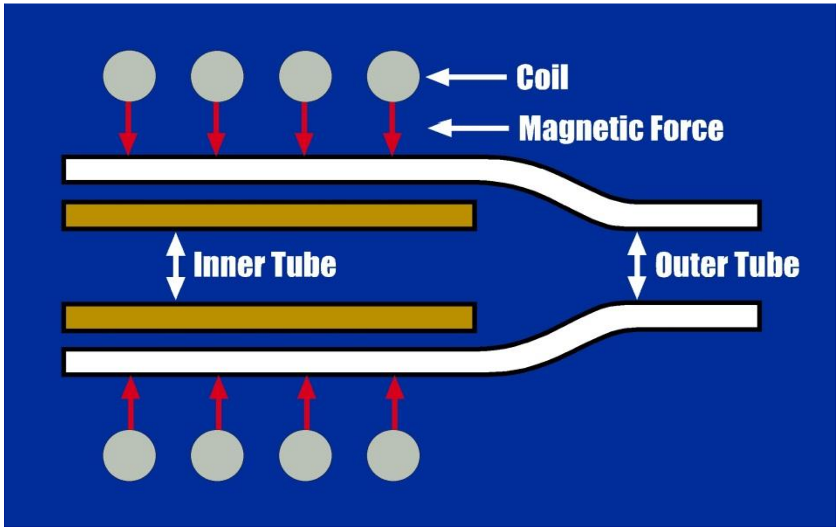


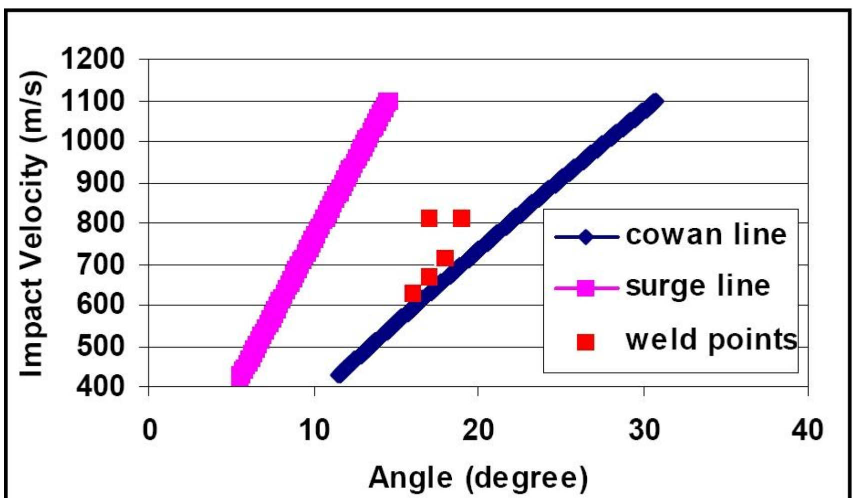
Macrosection of an aluminum to steel inertia friction weld

Intermittent Nature of Intermetallic Formation



Governing Equations Relating MPW Processing and Contact Velocities





$$\frac{d^2B}{dr^2}+\frac{1}{r}\frac{dB}{dr}+k^2B=0$$

Maxwell equation defined in cylindrical components

$$P=\frac{\mu_o\cdot n^2\cdot f_2}{2\cdot L^2}\cdot I^2(\;)$$

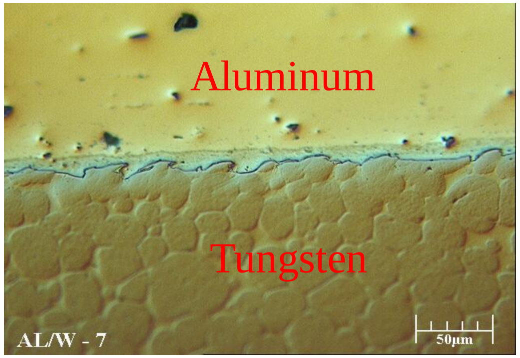
Pressure on the flier as defined by the Maxwell equation

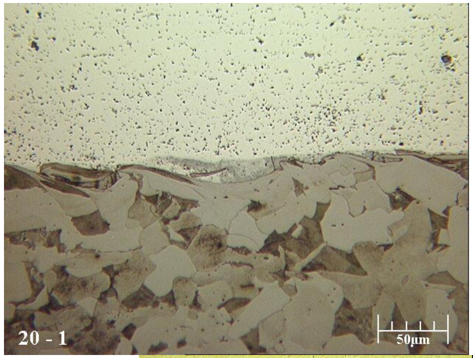
$$v=\frac{A_s\cdot\mu_o\cdot n^2\cdot f_2}{2\cdot L_s^2\cdot m}\cdot I^2(\;)\cdot t_s$$

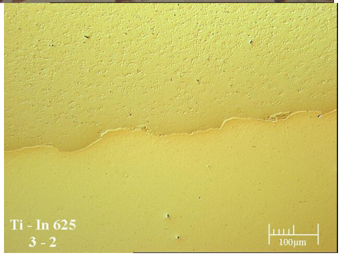
Flier velocity derived from the magnetic pressure and part geometry

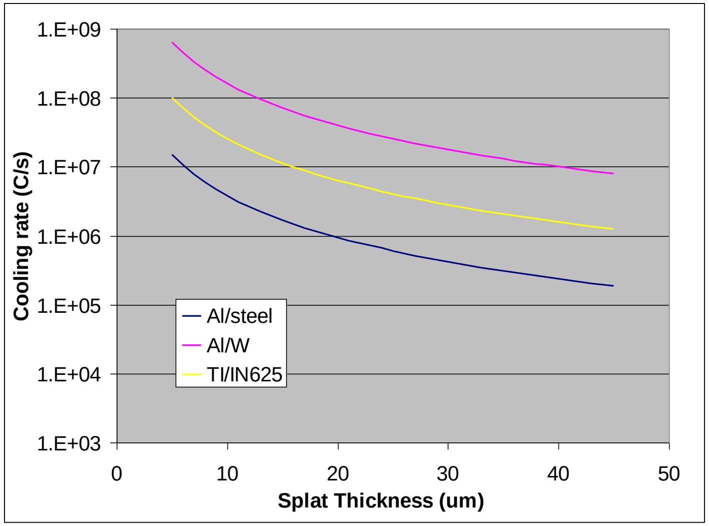
Metallurgical Implications of MPW Thermal Cycles

- Cooling rates seen here comparable with other pulse welding processes
  - Percussion welding
  - Electro-spark deposition
- Rapid cooling rates imply rapid solidification
  - Suppression of solidification related segregation
  - Reduced liquation cracking
  - Reduced solidification cracking
- Rapid cooling rates suppress solid state precipitation reactions
  - Suppression of intermetallic phases
  - Reduction in solid-state-related cracking
- Rapid cooling rates responsible for the wide range of materials joinable by MPW





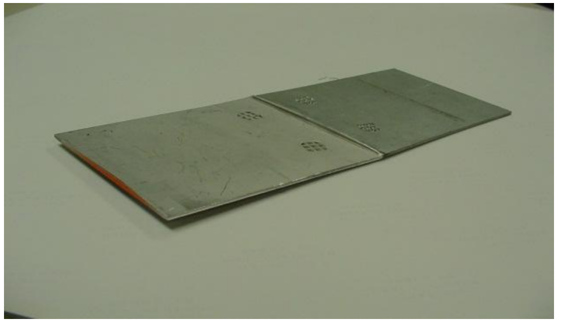




Resistance Welding Processes

- Resistance spot welding
  - Prior use of transition materials
  - Thermal cycles as short as 200 ms
  - Resolidification as bonding mechanism
  - Button pullout behavior
  - Benefits of welding onto galvanized steel
- Resistance butt welding
  - Short duration thermal cycles
  - Forging similar to friction welding

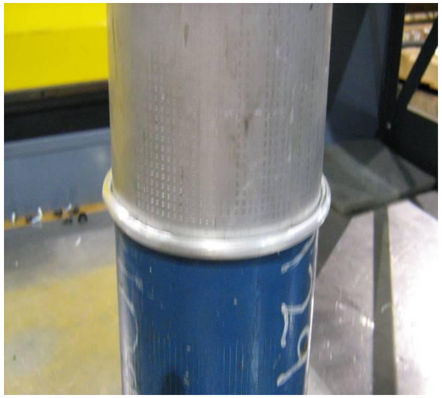
Direct resistance spot welds made between 1-mm Al and 0.8-mm galvanized steel sheet

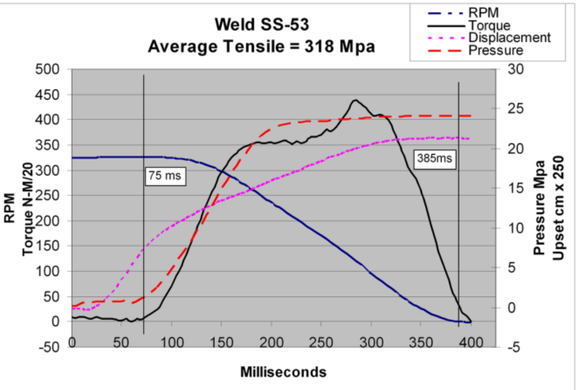


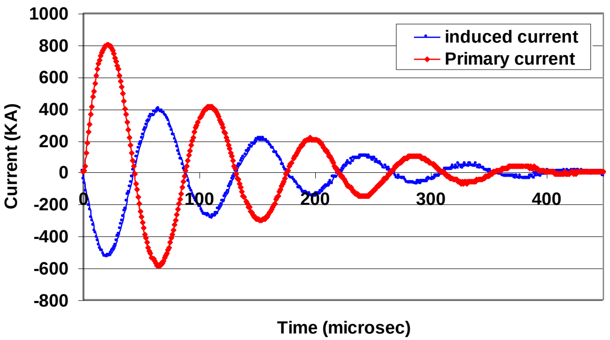
Resistance butt joint between 1-mm 5754 Al and 1-mm galvanized steel sheet

Dissimilar Metals Welding - Summary

- Mechanisms of bonding for solid-state and fusion processes
- Short thermal cycles a necessity
- Fusion and solid-state variations possible
- Suppression of intermetallics key to effective joining
- Range of candidate processing technologies demonstrated in a preliminary way







Questions?

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