AutoCRC TECHNICAL CONFERENCE 2011

A Three-Dimensional Computational Model of Arc Welding of Aluminium for the Automotive Industry

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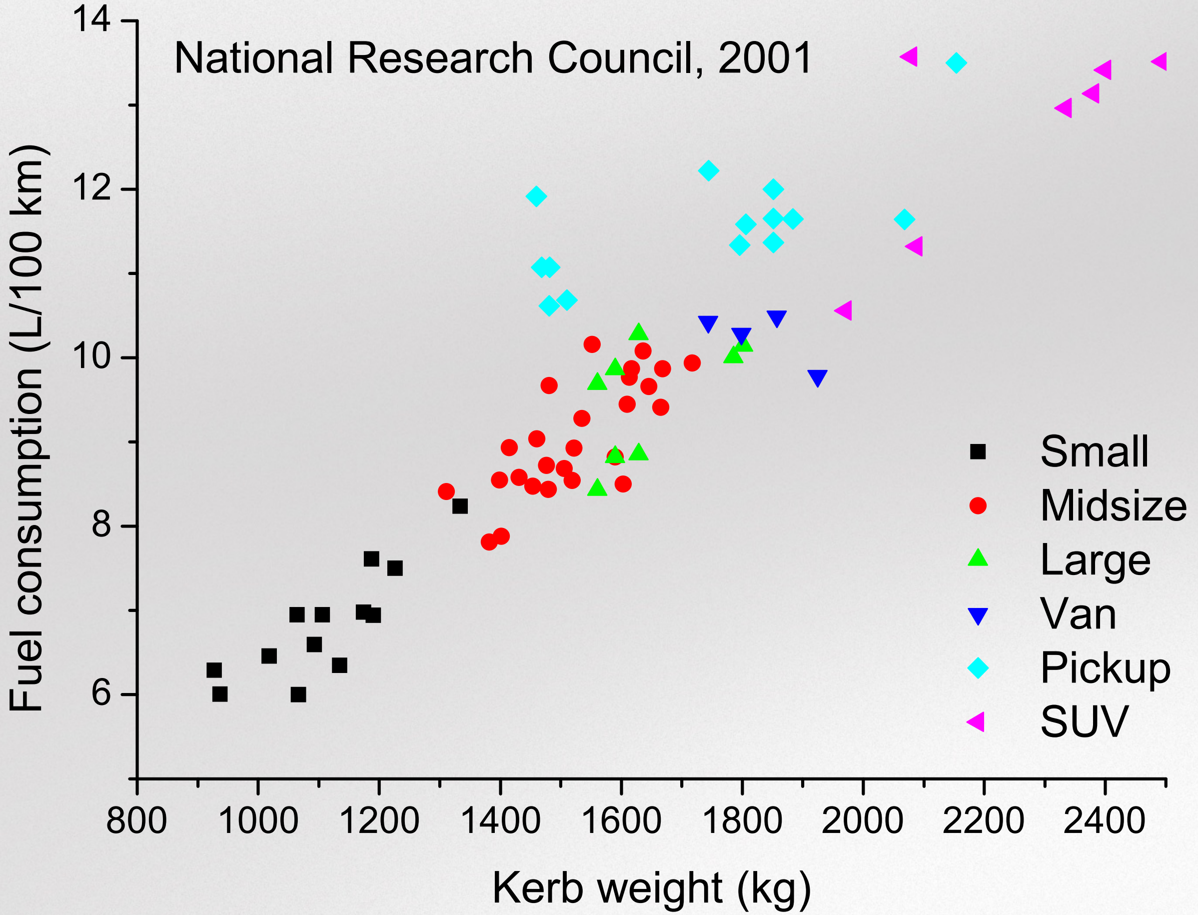
Fuel Consumption Increases with Vehicle Weight

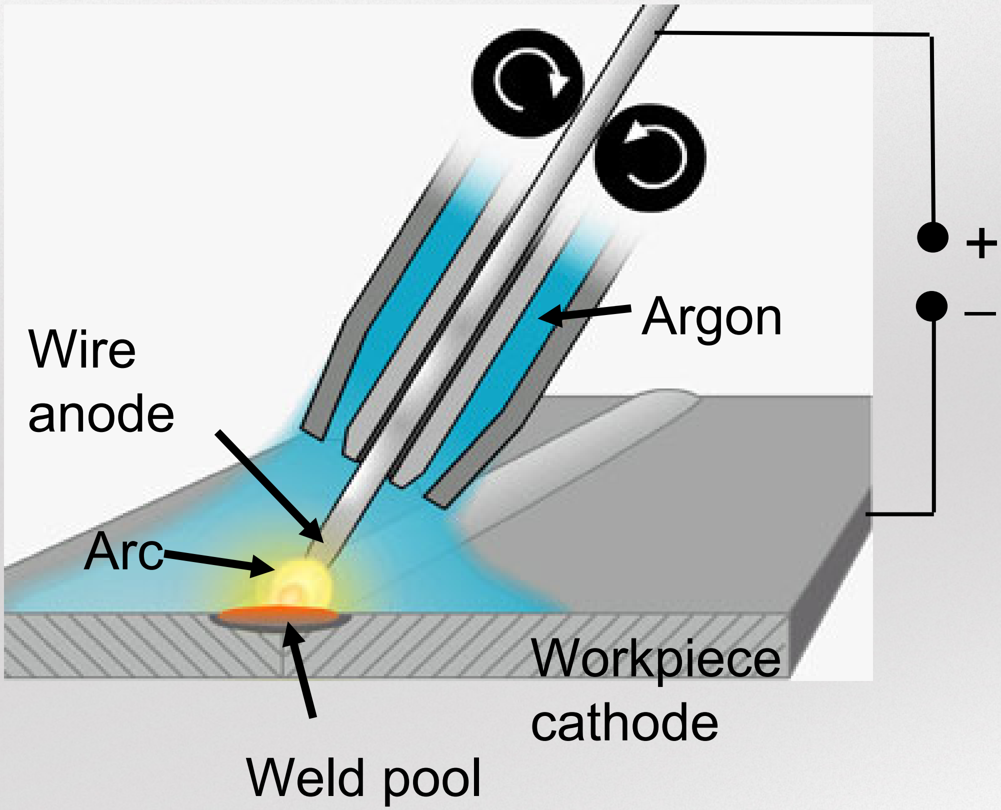


Steel is Being Replaced by Lighter Materials

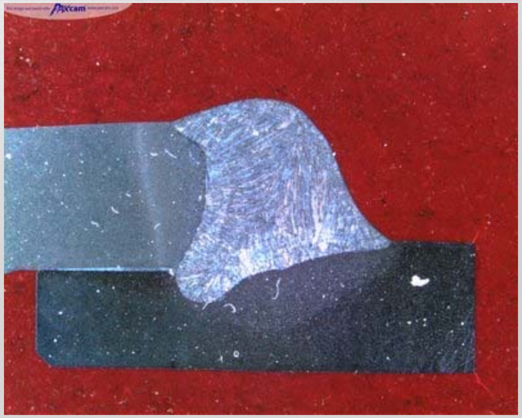
Materials Used in a Typical Family Car			
	1977	1999	2010
Total iron & steel	75%	66%	
High-strength steel	3.4%	10%	
Polymer composites	4.6%	7.5%	
Aluminium	2.6%	7.2%	8.6%
Magnesium	0.0%	0.2%	

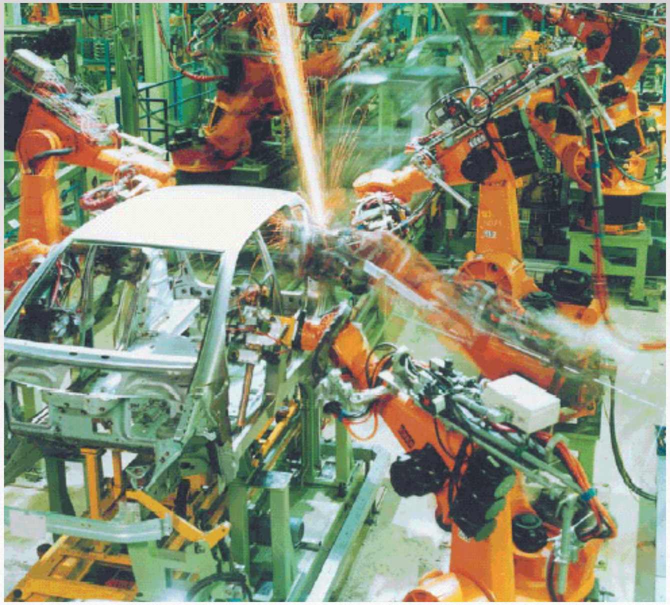
Chevrolet Impala engine cradle

Gas Metal Arc Welding is a Well-Developed Technology, but Welding of Aluminium can be Difficult



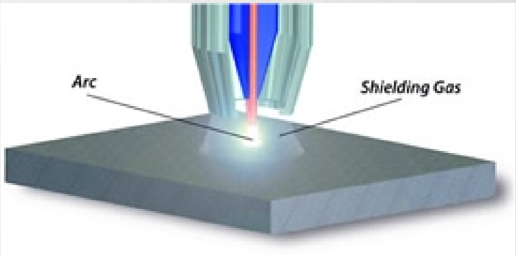
Current ~ 150 A
Power ~ 5 kW
Power density ~ 50 MW m^{-2}



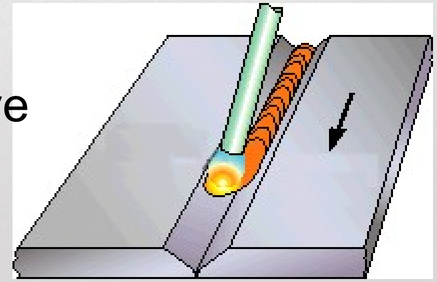


Realistic Modelling of Gas Metal Arc Welding is Difficult!

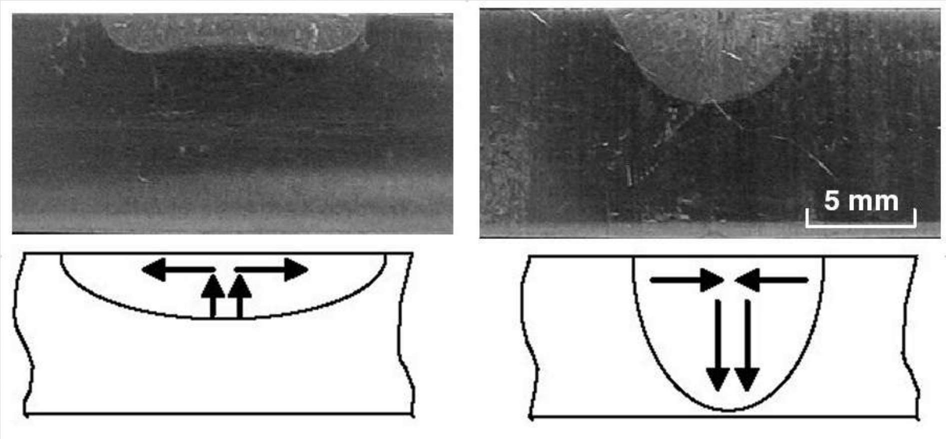
1) We have to model the arc plasma, electrode and workpiece self-consistently



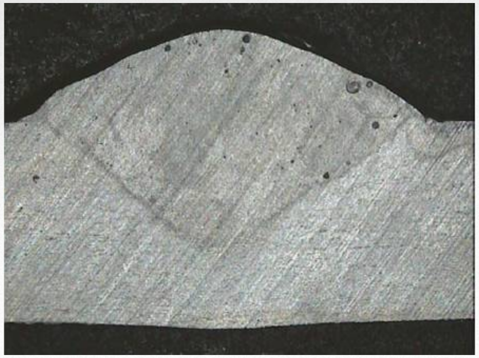
2) The arc moves relative to the workpiece



3) The flow of metal in the weld pool has to be tracked

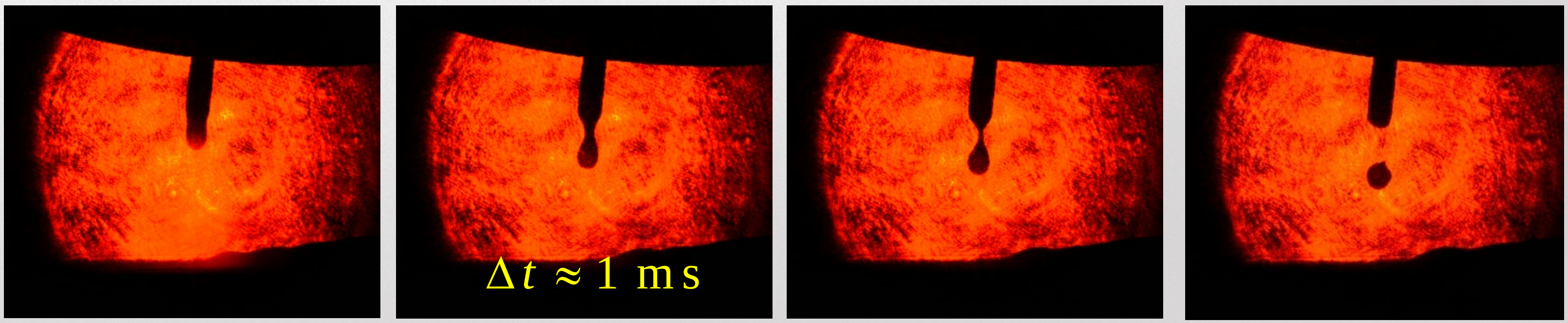


4) The surface of the molten weld pool has to be tracked

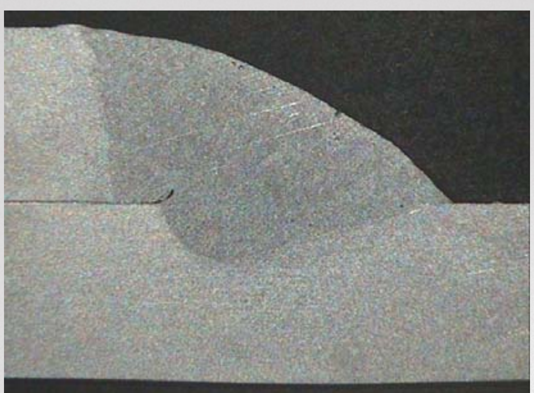


Realistic Modelling of GMA Welding is (Even More) Difficult!

5) The wire electrode melts, forming droplets that fall into weld pool

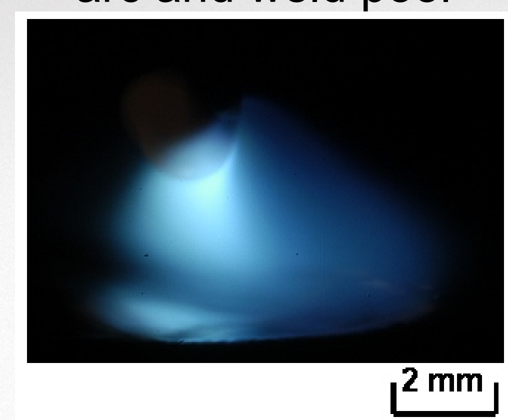


6) The geometry is fully 3-D (fillet weld)



7) Time-dependence is required to model start and end of weld

8) Metal vapour can strongly affect the arc and weld pool



Welding is Modelled with Fluid Dynamics Equations, with Plasma and Electromagnetic Effects Added

Mass: $$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0$$

Momentum: $$\frac{\partial (\rho \boldsymbol{v})}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}\boldsymbol{v}) = -\nabla P - \nabla \cdot \boldsymbol{\tau} + \boldsymbol{j} \times \boldsymbol{B} + \rho \boldsymbol{g}$$

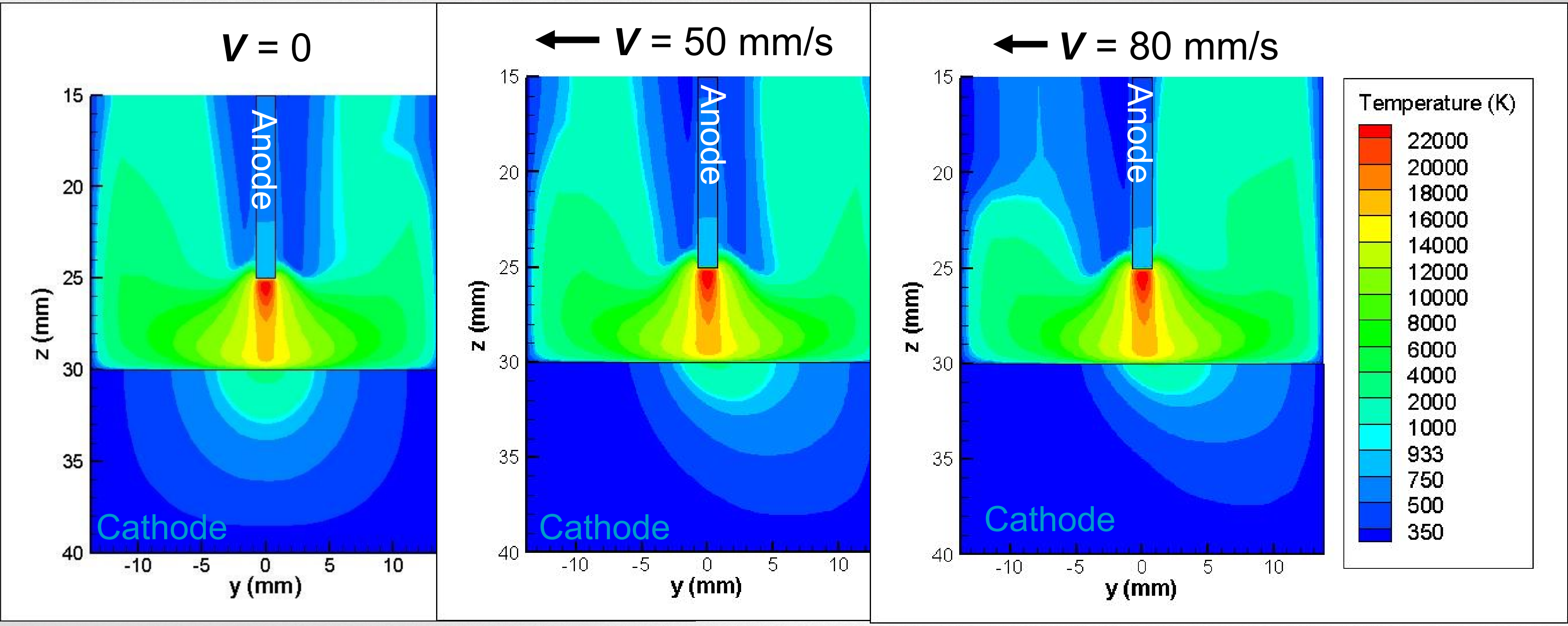
Energy: $$\frac{\partial (\rho h)}{\partial t} + \nabla \cdot (\rho \boldsymbol{v} h) = \frac{\boldsymbol{j}^2}{\sigma} - U - \nabla \cdot \left(\frac{k}{c_p} \nabla h \right) + \frac{5 k_B}{2 e c_p} \boldsymbol{j} \cdot \nabla h$$

Charge: $$\nabla \cdot \boldsymbol{j} = 0$$

Also: $$\boldsymbol{j} = -\sigma \nabla \phi, \quad \nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{j}$$

Moving Arc, Solid Workpiece:
Welding Speed Affects Temperature in Workpiece

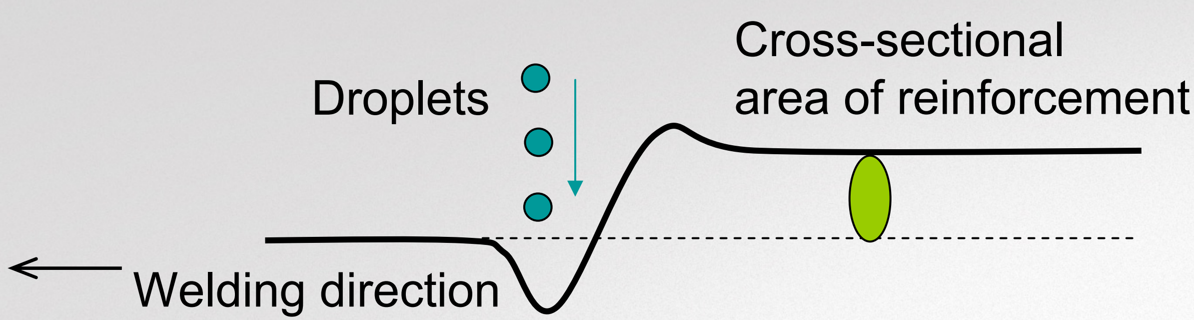
200 A arc, Al alloy workpiece



Molten Workpiece with Surface Deformation:
Equilibrium Surface Method used to Determine Weld Pool Surface

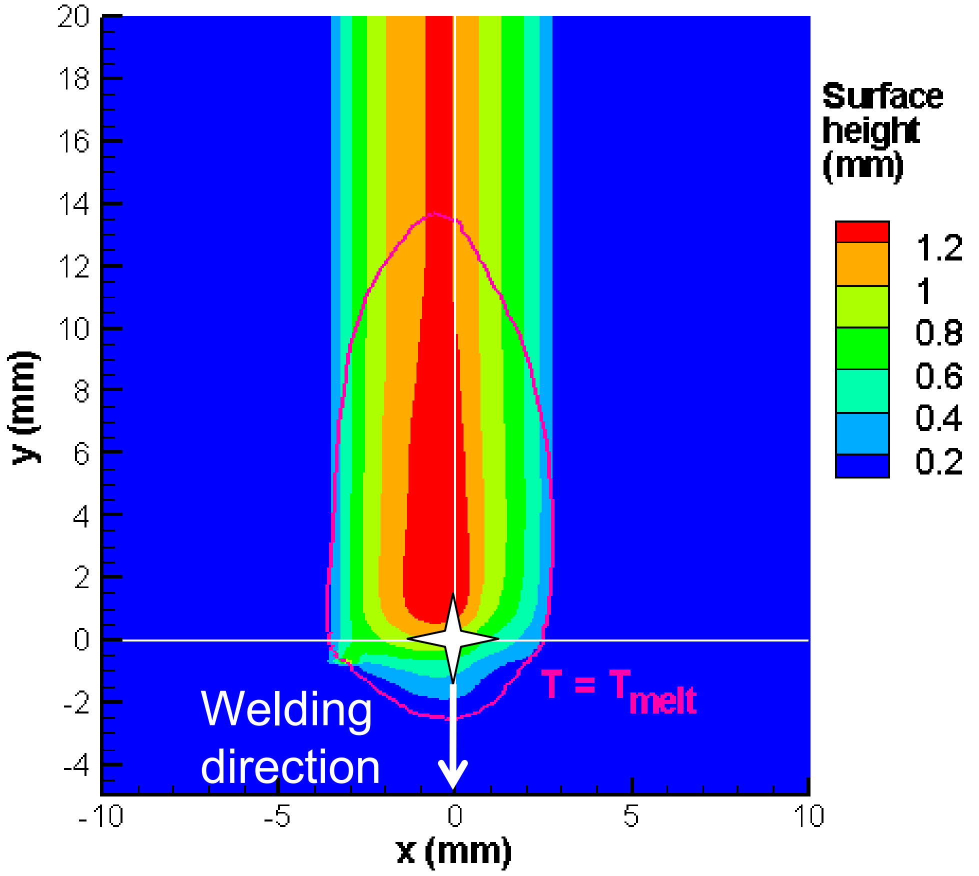
Surface energy minimised, taking into account

- **Surface tension and surface curvature**
- **Gravity (buoyancy)**
- **Arc pressure**
- **Droplet pressure**
- **Conservation of droplet volume**



Addition of Droplets to the Weld Pool Raises the Surface Height

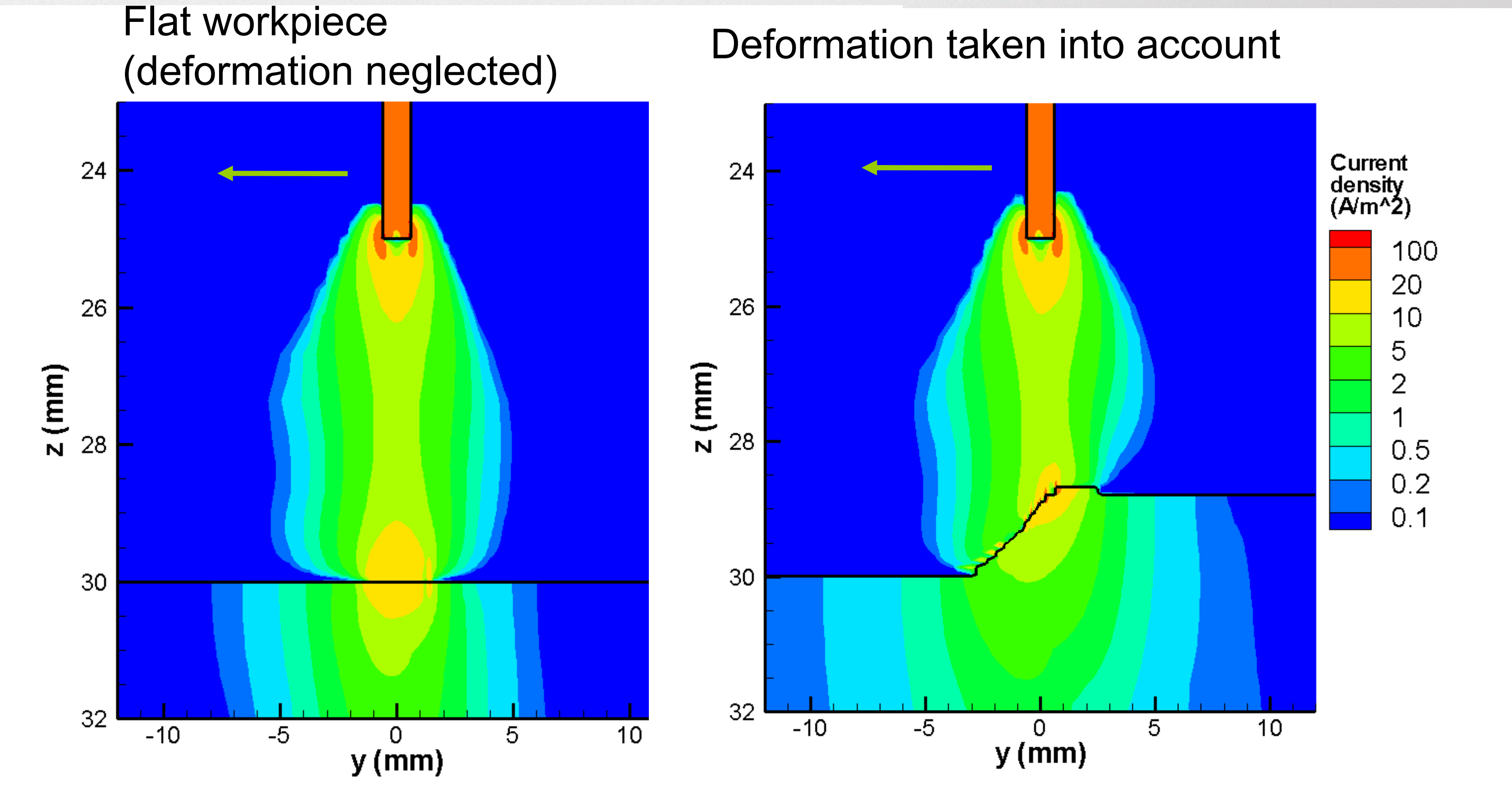
95 A arc, 15 mm/s welding speed, Al alloy (AA 5754) workpiece



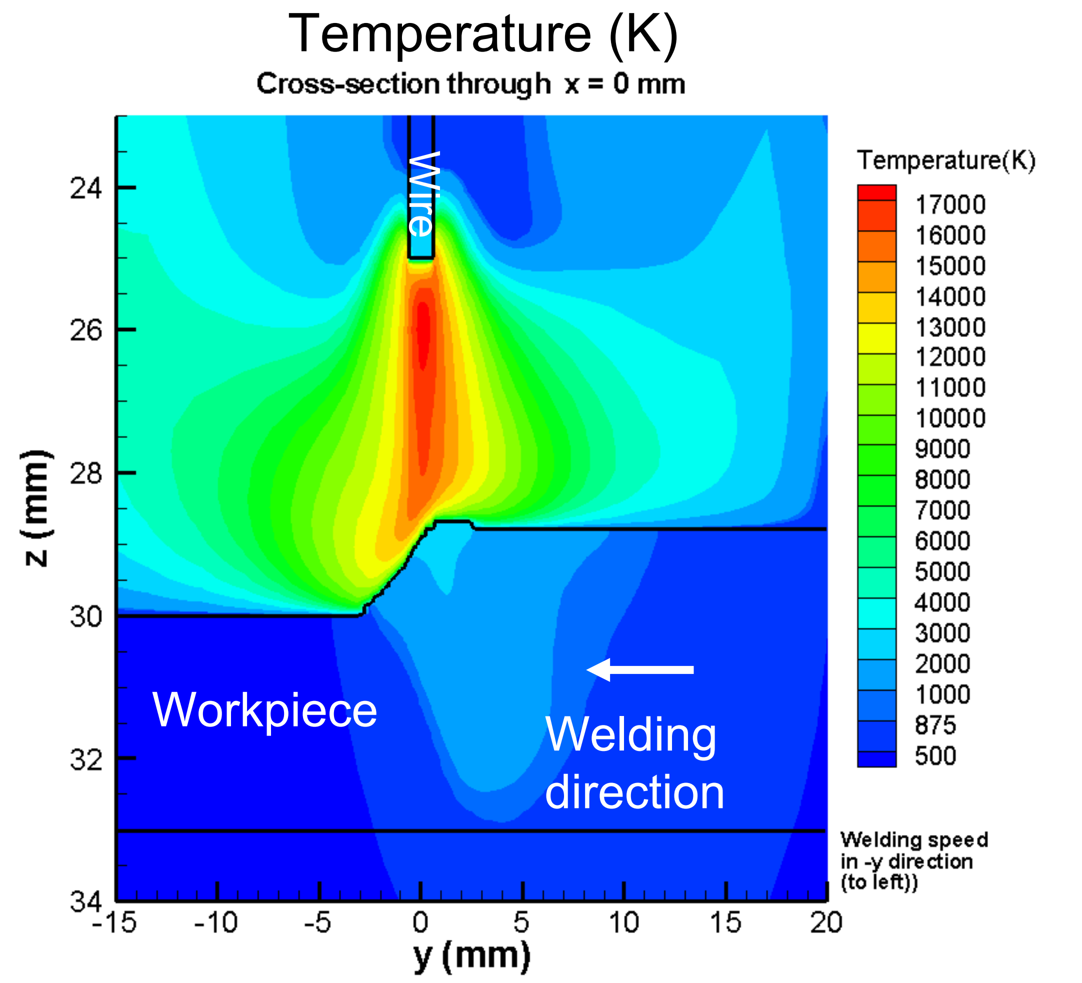
Height of weld pool surface (mm)

Current Density at Workpiece is Strongly Affected by Deformation of Weld Pool Surface

95 A arc, 15 mm/s welding speed, Al alloy (AA 5754) workpiece

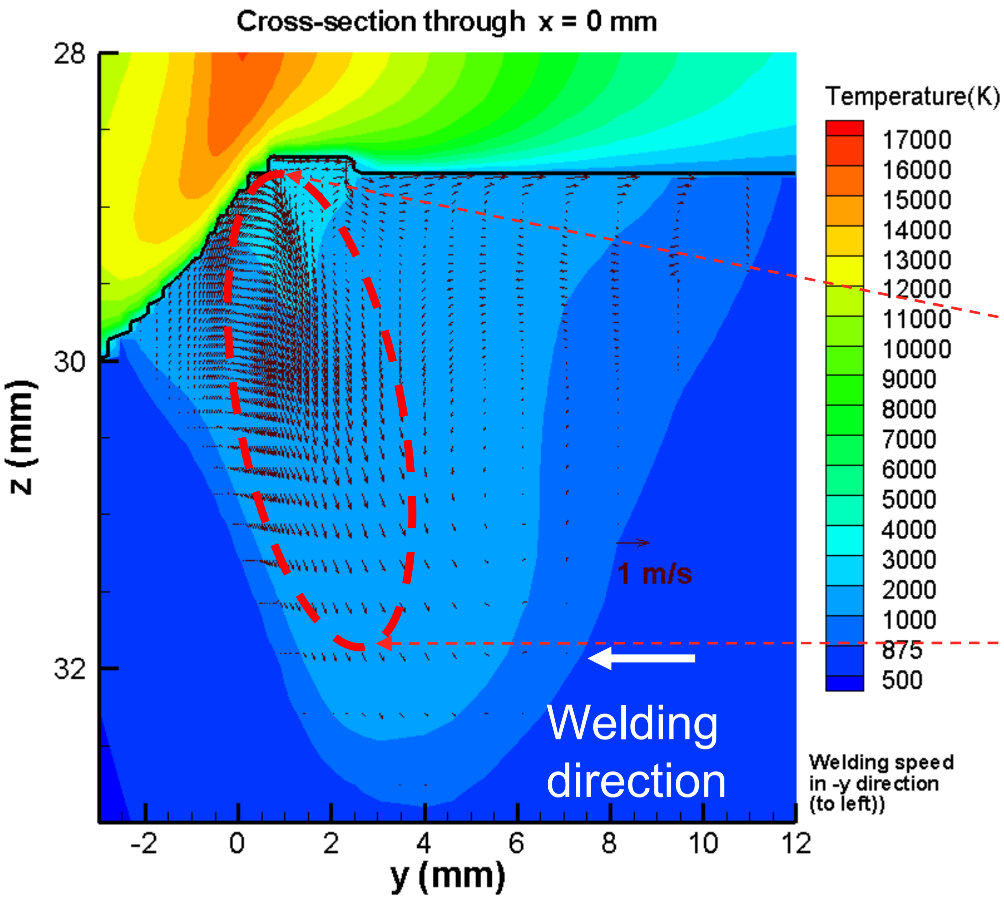


Temperature of Weld Pool is Greatest in the Raised Region where the Current Density is Highest

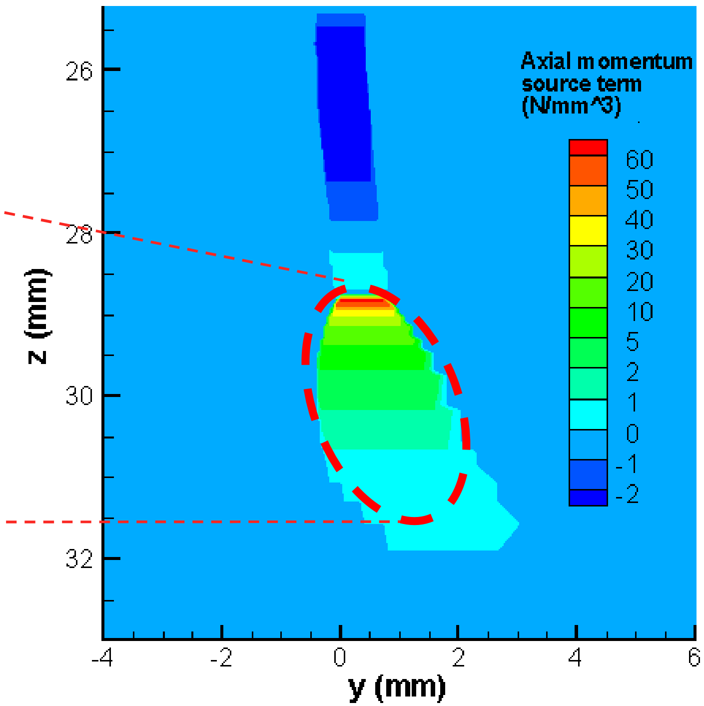


The Flow in the Weld Pool is Driven Downwards by Droplet Momentum

Temperature (K)

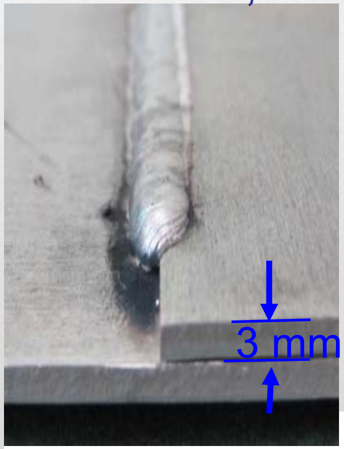


Rate of momentum transfer to arc and weld pool from droplet (N/mm^3)

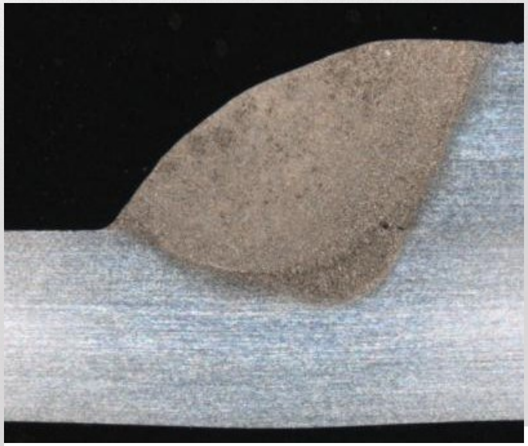


The Model Has Been Adapted to Fillet Weld Geometry

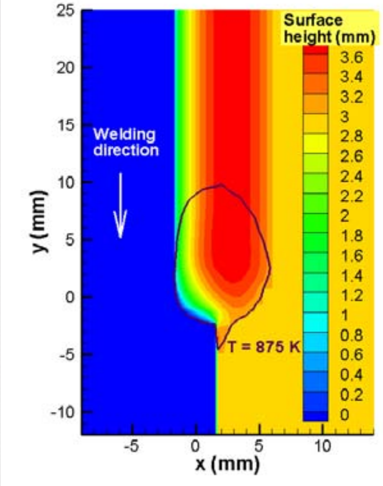
104 A arc, 10 mm/s welding speed, Al alloy (AA 5754) workpiece



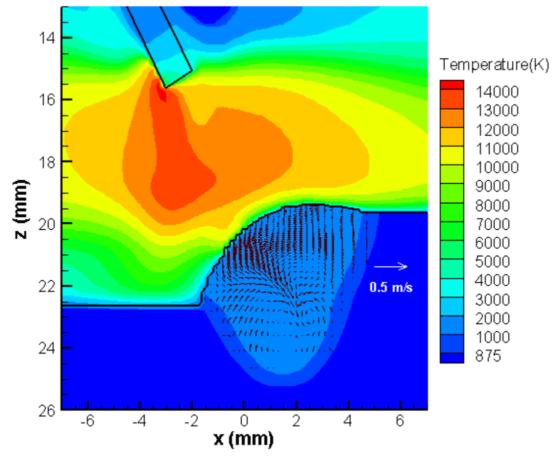
View from above



Weld cross-section



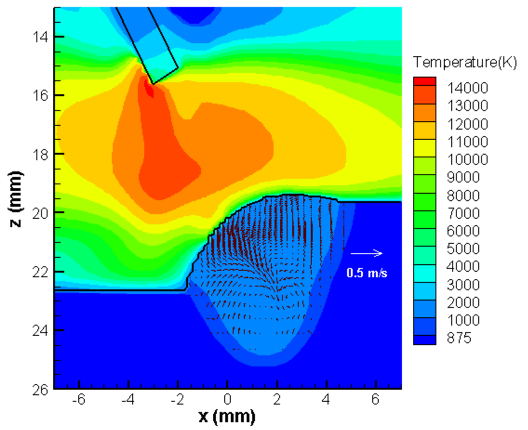
Height of weld pool surface (mm)



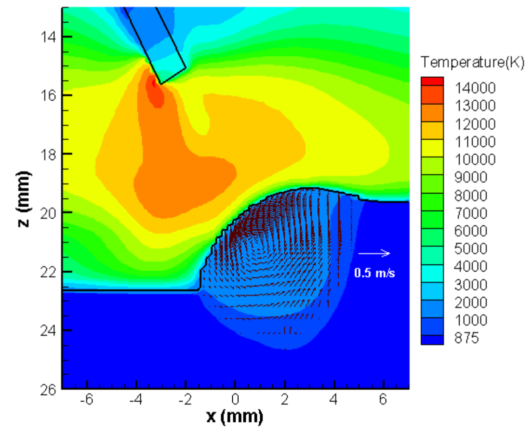
Temperature in a cross-section

For Decreasing Arc Current and Welding Speed: the Arc Cools and the Weld Pool Shrinks with Time

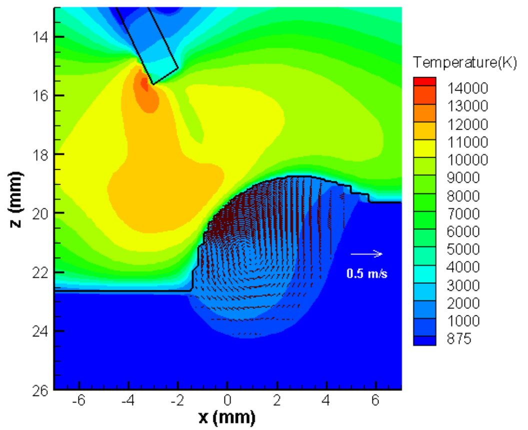
t = 0.0 s
I = 104 A
V_w= 10 mm/s



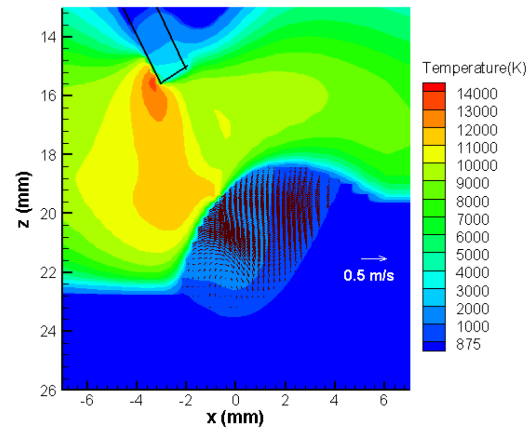
t = 0.2 s
I = 99 A
V_w = 8 mm/s



t = 0.5 s
I = 78 A
V_w= 5 mm/s

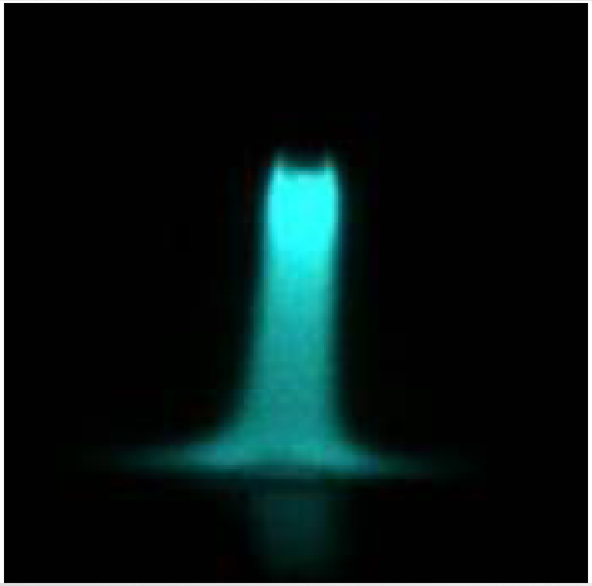


t = 0.7 s
I = 68 A
V_w = 3 mm/s

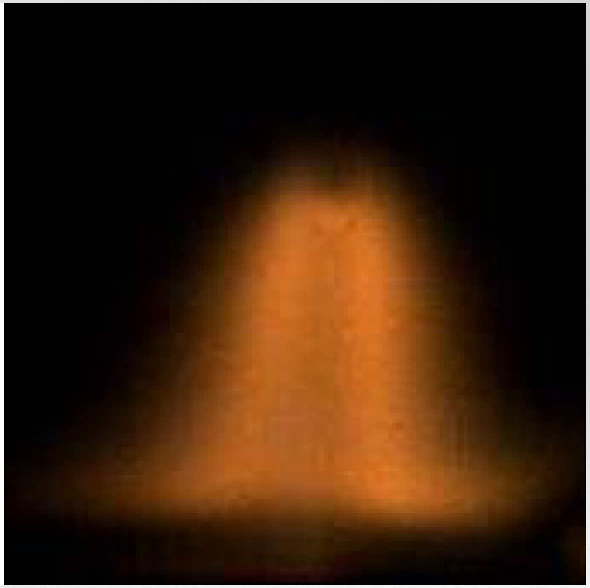


Metal Vapour Is Important In GMA Welding Arcs

All emission

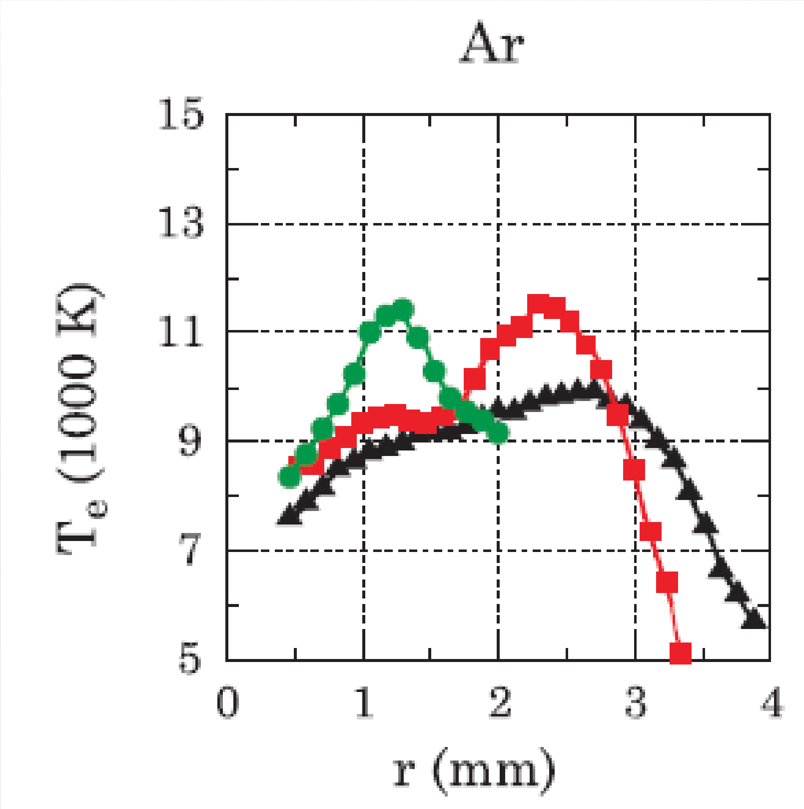


Atomic iron line



Atomic argon line

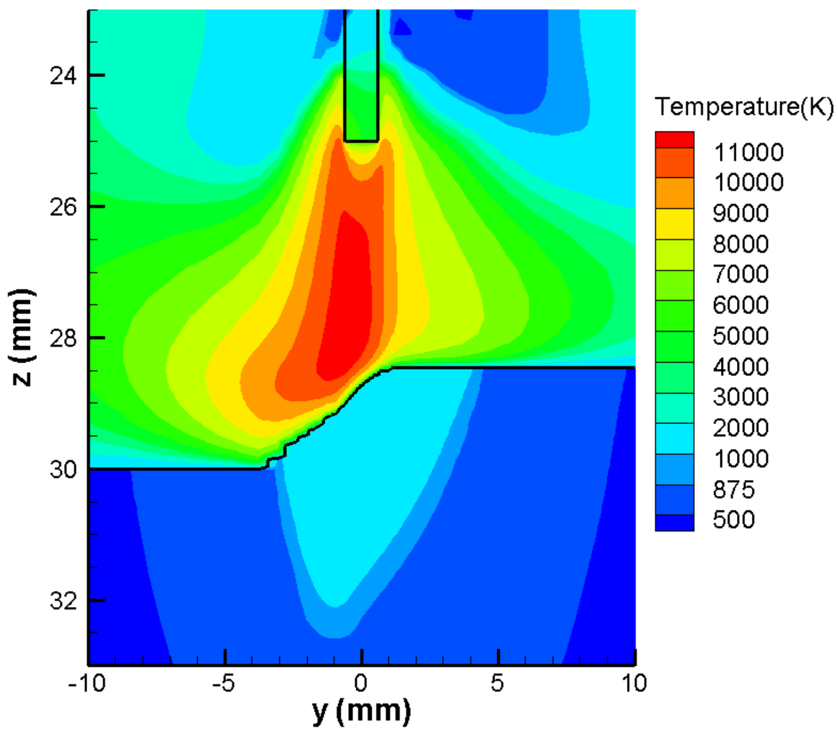
Measurements Show a Temperature Minimum on Axis



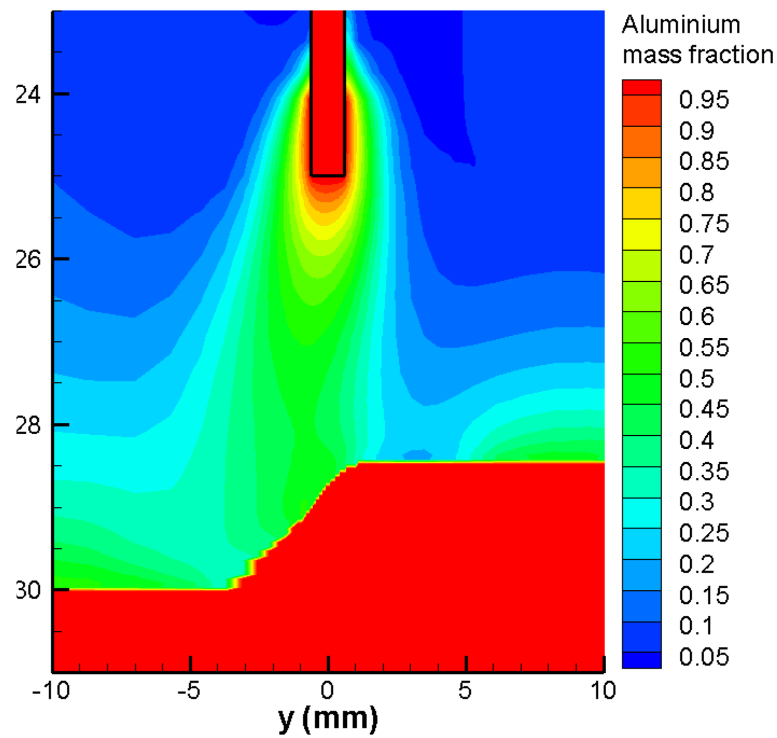
Zielińska S, Musioł K, Dzierżęga K, Pellerin S, Valensi F, de Izarra C & Briand F
Plasma Sources Sci. Technol. **16** 832–8 (2007)

Metal Vapour Reduces the Arc Temperature

Temperature

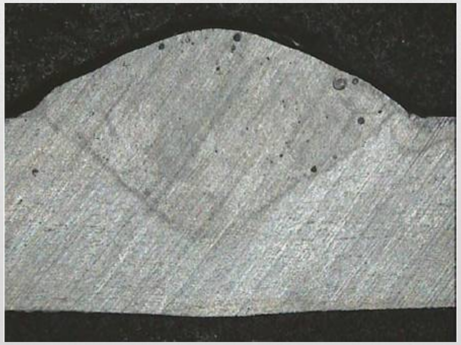


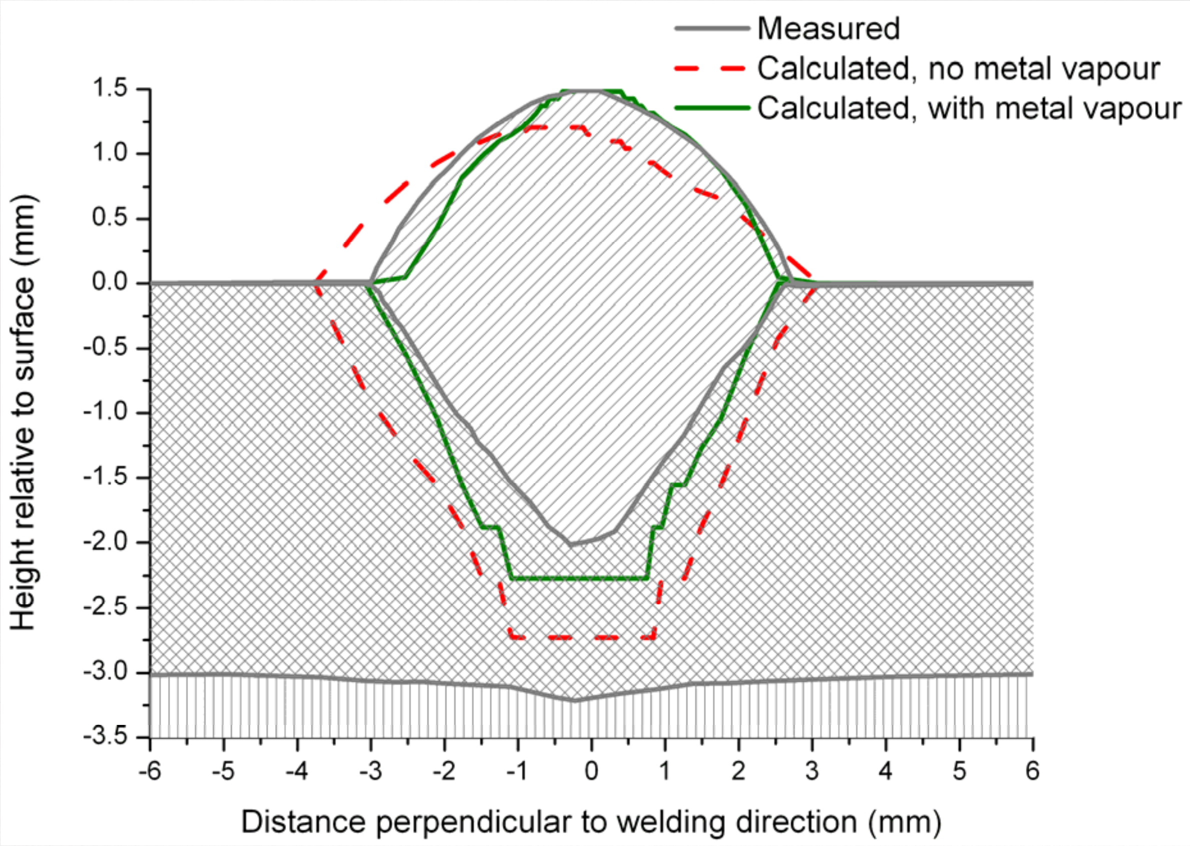
Aluminium concentration



Metal Vapour Reduces the Weld Pool Size, In Agreement with Measured Weld Cross-sections

95 A arc, 15 mm/s welding speed, Al alloy (AA 5754) workpiece





Summary

- We have developed a computational model of metal inert-gas welding of aluminium for the car industry
- The aim was to predict weld pool depth and shape
- We have developed a 3D model that includes:
  - the arc, wire electrode and workpiece,
  - motion of the arc
  - flow in the molten weld pool
  - weld pool surface deformation
  - transfer of mass, energy and momentum from metal droplets
  - fillet weld geometry
  - time-dependence
  - effect of metal vapour
- Good agreement is obtained with measurements of weld pool shape when metal vapour is taken into account

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Reference:

A. B. Murphy, ‘A self-consistent three-dimensional model of the arc, electrode and weld pool in gas-metal arc welding’, *J. Phys. D: Appl. Phys.* **44** 194009 (2011).