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Force and temperature feedback

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Challenge with 3D FSW

- Constant FSW parameters and 3D joints:
  - Constant heat input
  - variable heat dissipation
- Material may overheat > Defects

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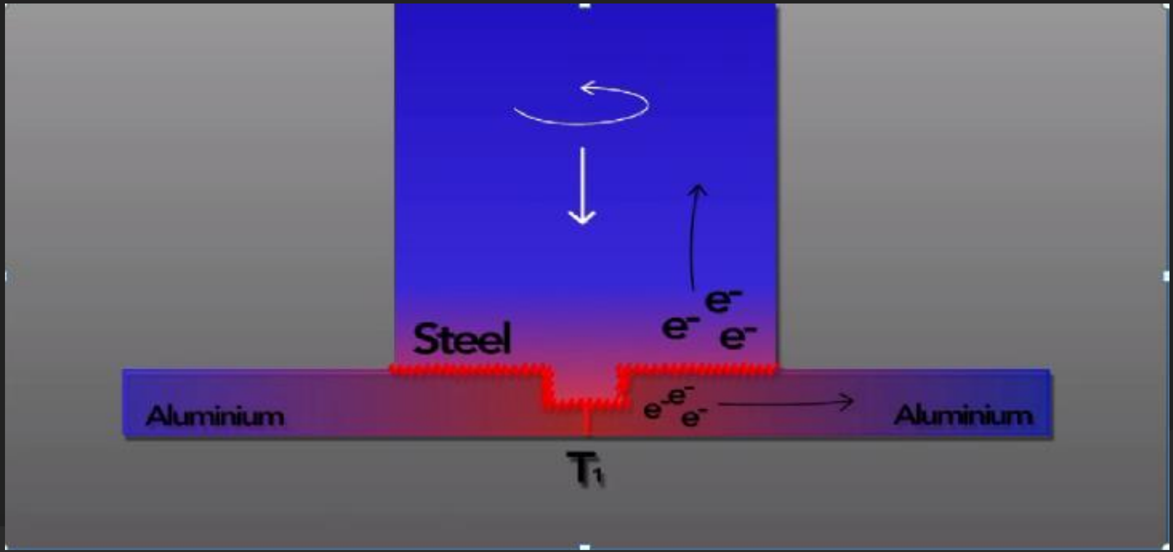
How to measure temperature?
Tool-Workpiece Thermocouple

- Novel method for temperature measurement
- Avoiding sensors inside tool or workpiece
- Easy to implement in production
- Patent Pending



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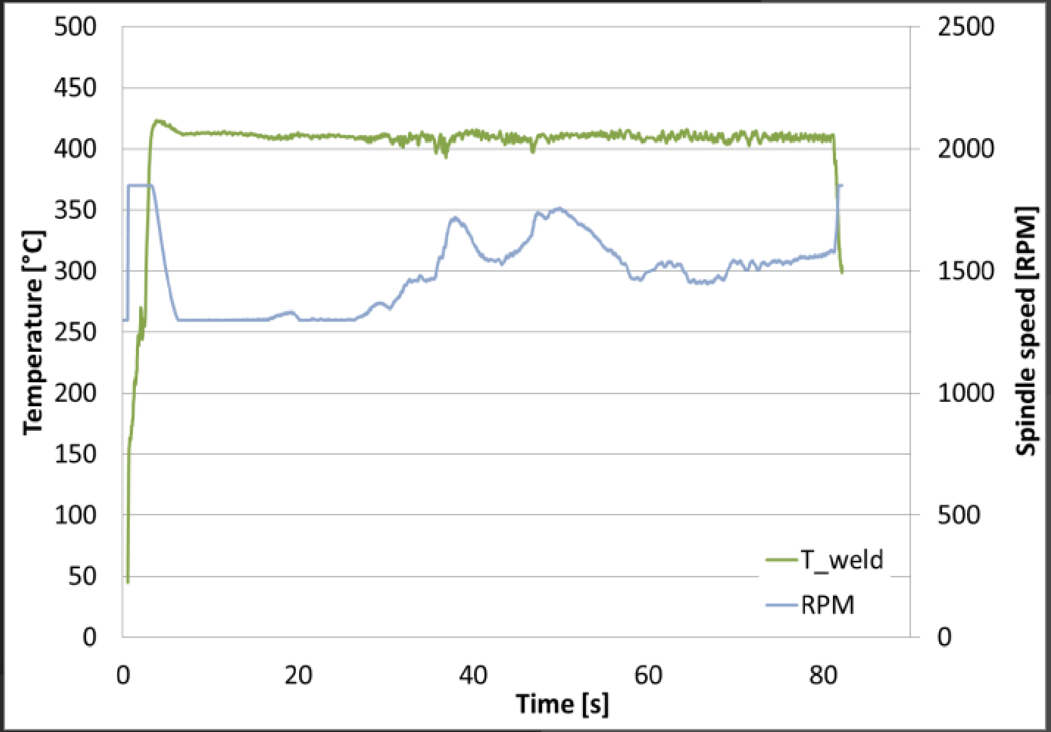
Controller – Phase 1: Adapt RPM

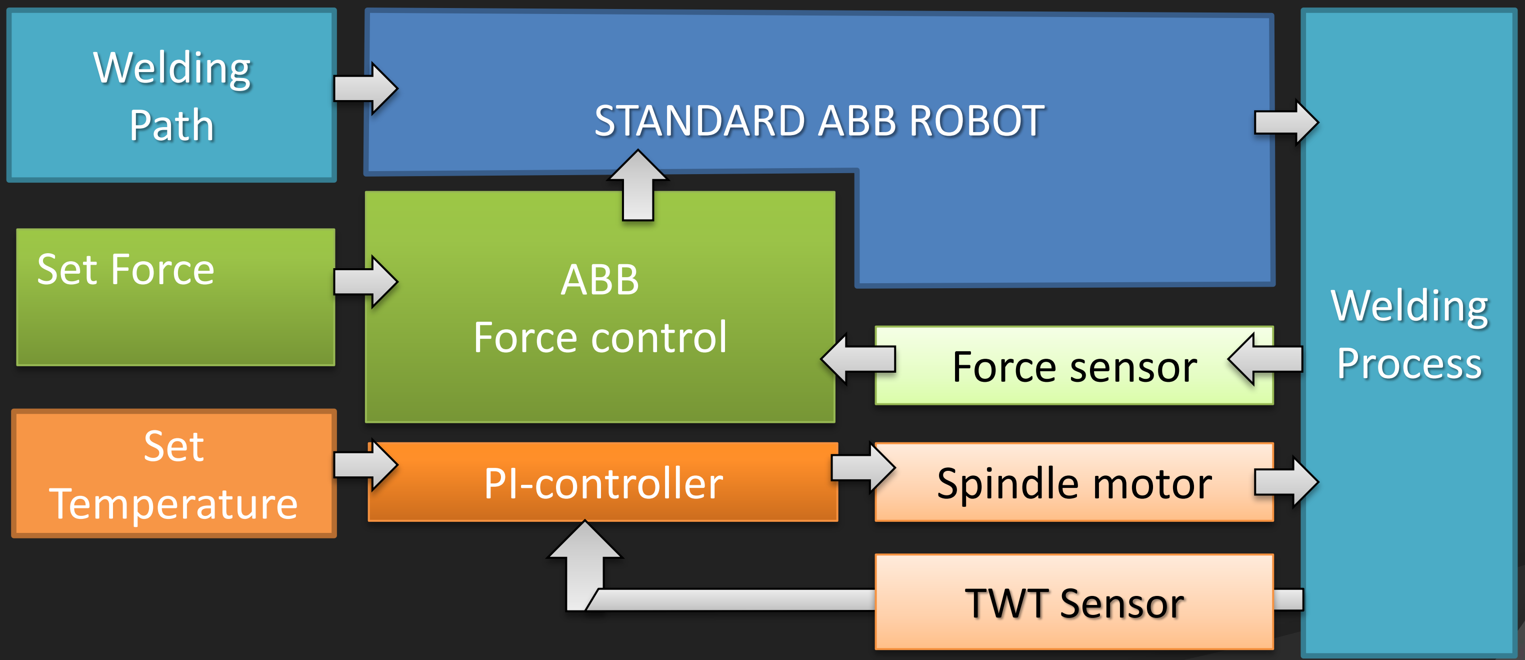
- Aim: Maintain constant temperature through modification of heat input
  - $Q \approx \boldsymbol{\omega} \cdot r \cdot \mu \cdot \boldsymbol{F_z}$
- PI-Controller

  $\boldsymbol{\omega}$ → Q → T



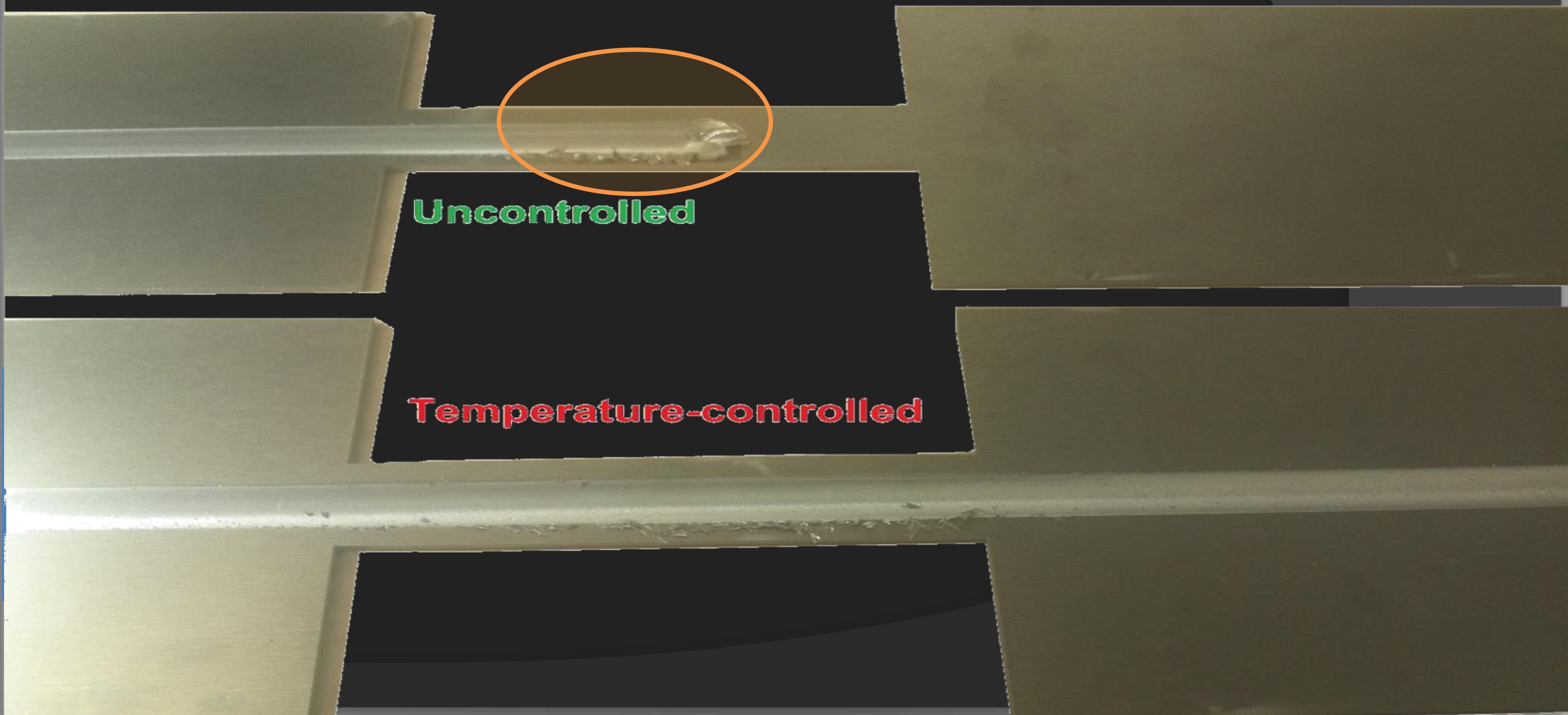
Controller – Phase 1: RPM variation

- Model based compensation for path deviations
- Control of heat input by temperature measurement



Controller – Phase 1: RPM variation

- Succesful implementation of PI controller



Controller – Phase 1: RPM variation

- Problem:
  - Physical limits to spindle speed
  - Still risk of meltdown at minimum RPM

$\omega = \omega_{min}$

$\omega < \omega_{min}$

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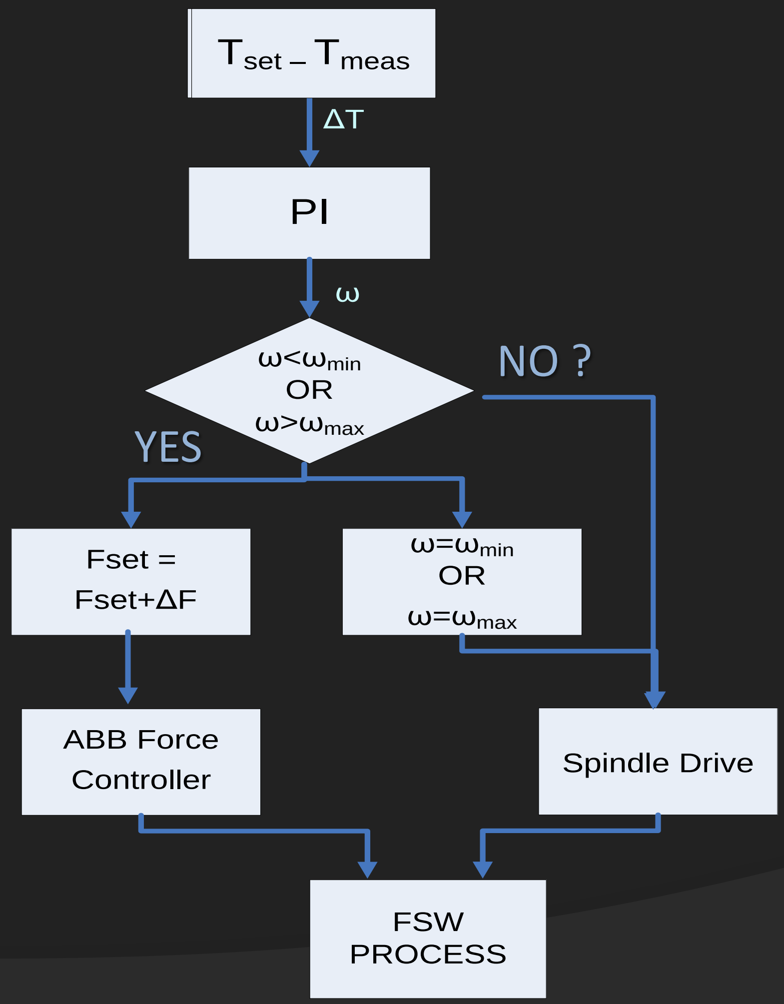
Controller – Phase 2: RPM + Down-force Principle



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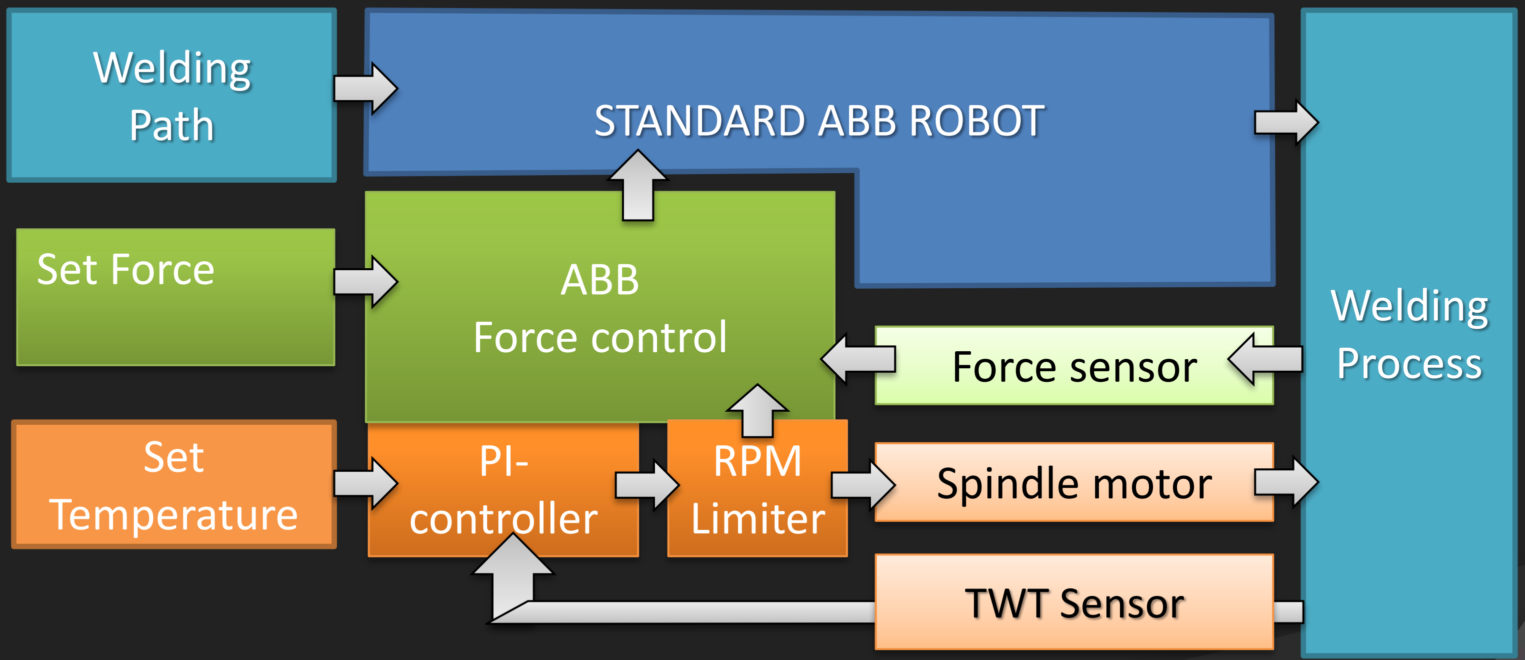
Controller – Phase 2: RPM + Downforce

- Model based compensation for path deviations
- Control of heat input by temperature measurement



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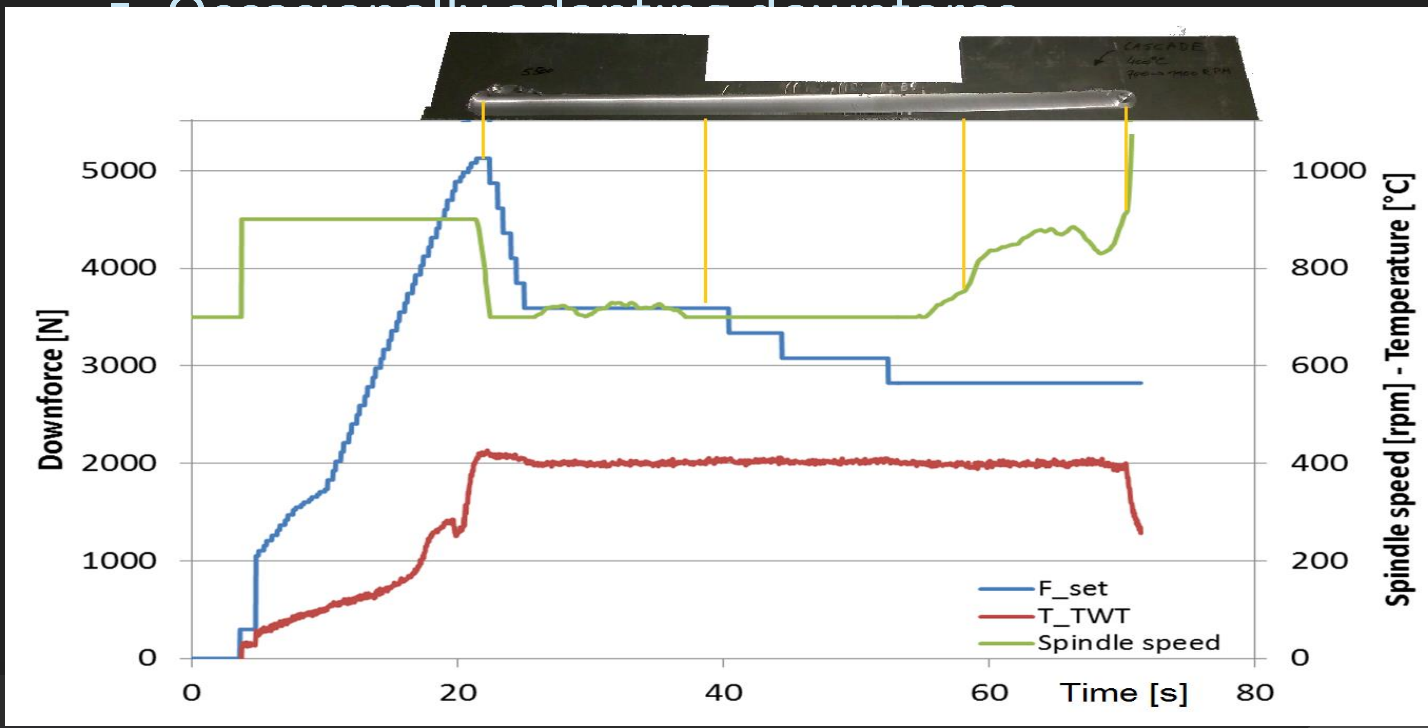
Results

- Cascade controller
  - Primarily adapting RPM
  - Occasionally adapting downforce



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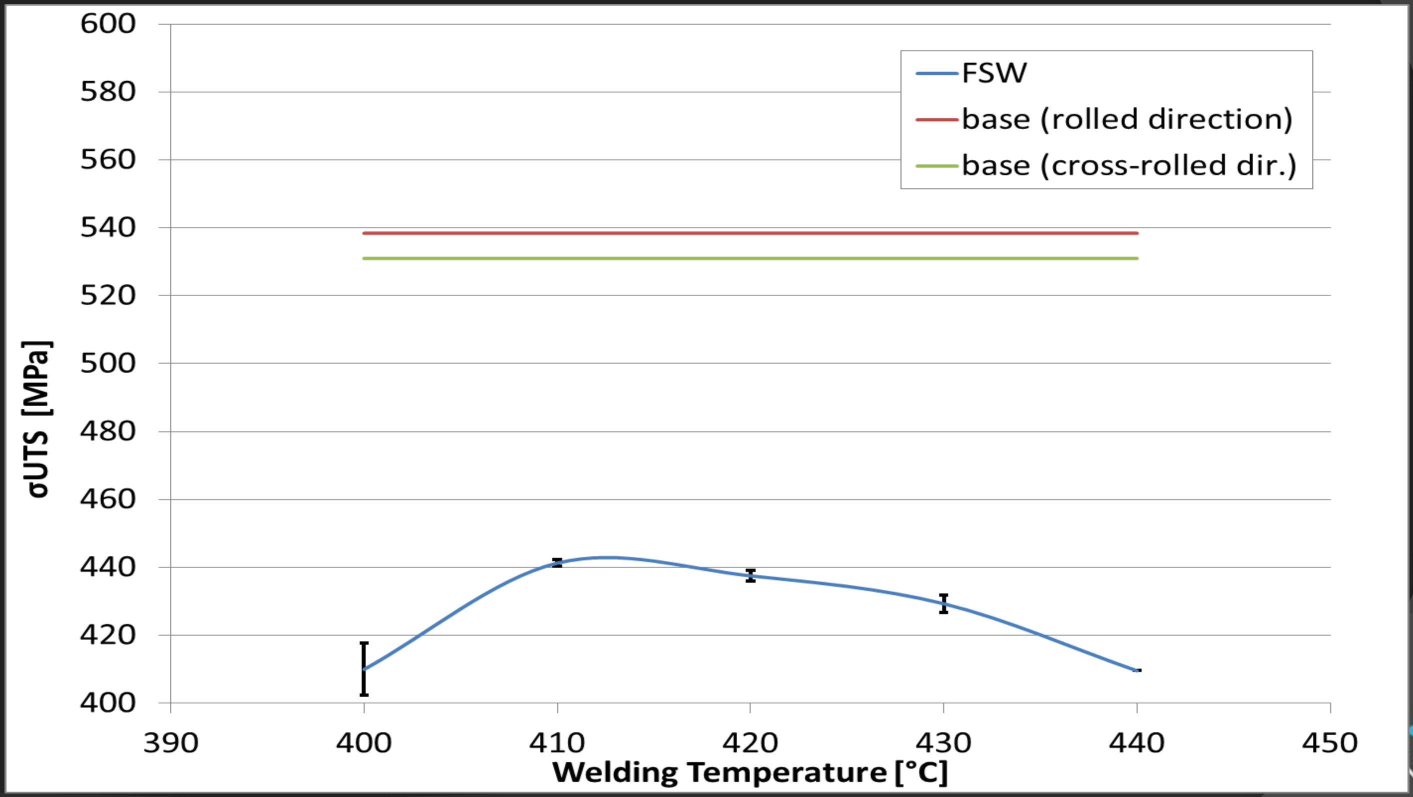
Results

- Temperature in relation to welding quality



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Results

- Maximal joint efficiency: 82%
- ISO 25239 (FSW):
Material type	Temper condition of parent material before welding [a, b]	Post-weld condition [c]	Joint efficiency factor (T)
Pure aluminium	All temper conditions	As welded	1,0[d]
Non heat treatable alloys	All temper conditions	As welded	1,0[d]
Heat treatable alloys	T4	Natural ageing	0,7
	T4	Artificial ageing	0,7[e]
	T5 and T6	Natural ageing	0,6
	T5 and T6	Artificial ageing	0,7[e]
  - Minimum: 0.7*438 Mpa = 306 Mpa
  - All welds (400→440°C) are approved

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Conclusions

- Temperature control of FSW
  - Required in geometrically complex applications
- Sucessfully implemeted cascade controller
  - Primarily adapting RPM
  - Occasionally adapting downforce
- Improved tensile properties
- Fewer manual parameters
  - No need for highly experienced operator
  - Reduced run-in time
  - Reduced implementation costs

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Thank You

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