Optimization of the Process Parameters for Controlling Residual Stress and Distortion in Friction Stir Welding

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Overview

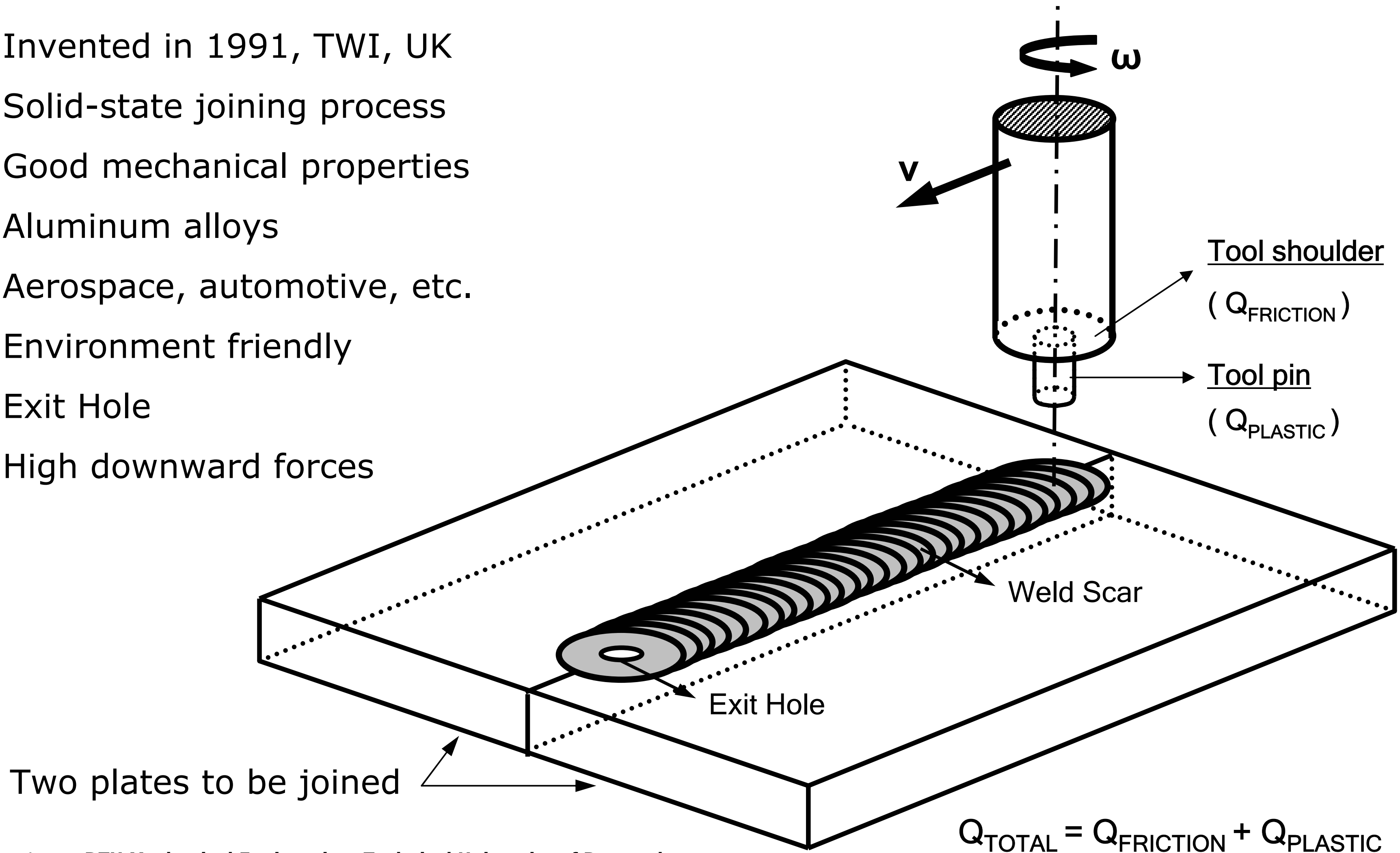
- Objectives of the study
- Friction Stir Welding (FSW) Process
- Thermo-Mechanical Model
  - Thermal-Pseudo-Mechanical (TPM) Model
  - Mechanical Model
- Optimization Procedure
- Results and Discussion
- Conclusion

Objectives of the study

- Simulation of the residual stresses and distortion in (FS)Welding
  - How do they evolve?
- Investigation of the process parameters, i.e. rotational speed, welding speed
  - What are their effect?
- Optimization procedure
  - What is the problem?
  - How can it be solved?
  - How can the best solution(s) be decided?

Friction Stir Welding (FSW) Process

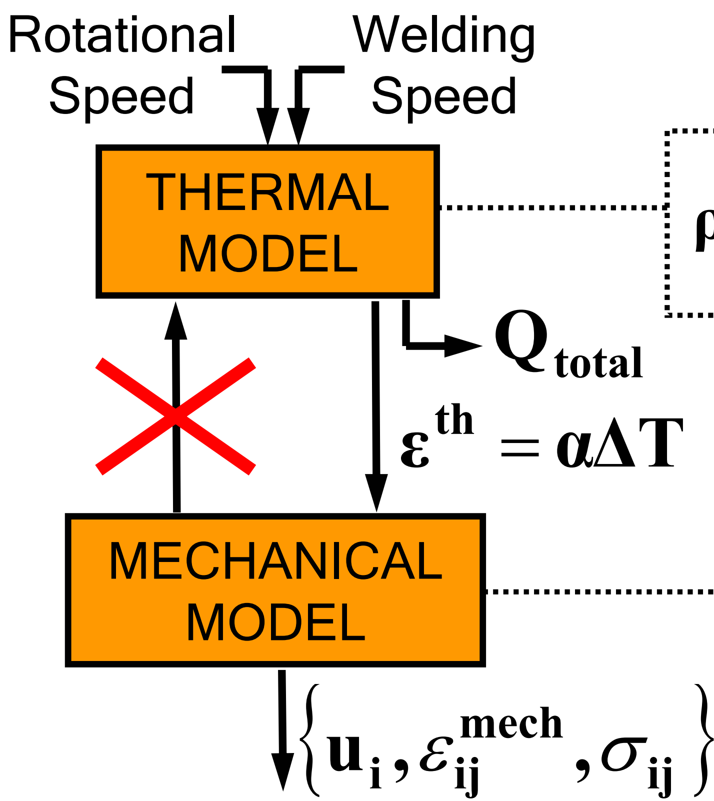
- Invented in 1991, TWI, UK
- Solid-state joining process
- Good mechanical properties
- Aluminum alloys
- Aerospace, automotive, etc.
- Environment friendly
- Exit Hole
- High downward forces



$$Q_{TOTAL} = Q_{FRICTION} + Q_{PLASTIC}$$

Thermo-Mechanical Model

- Coupling Frame & Governing Equations



Heat Conduction Equation:

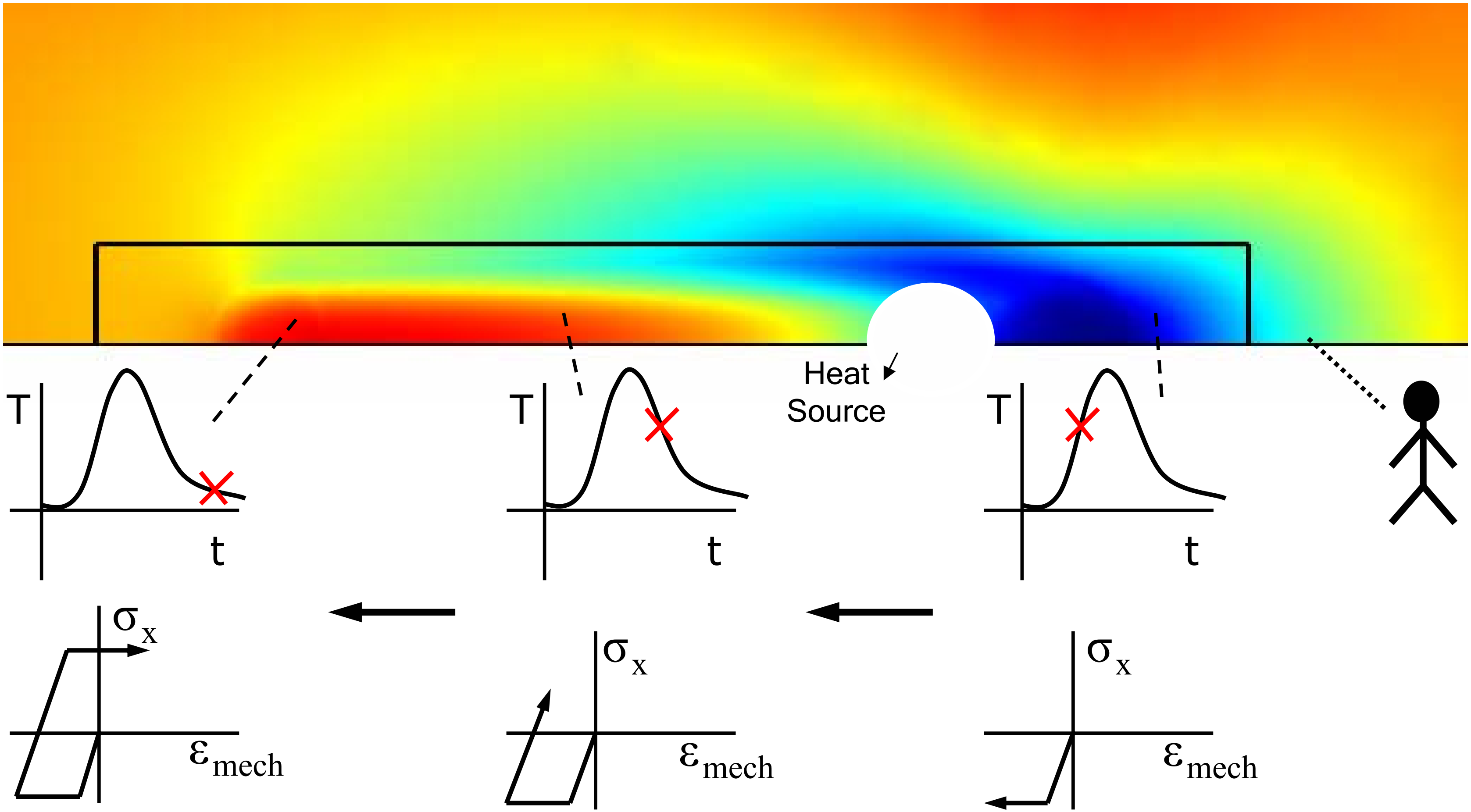
$$\rho c_p \dot{T} + u_i \rho c_p T_{,i} = (k T_{,i})_{,i} + \frac{Q_{gen}}{V}$$

(Quasi)Static Equilibrium Equation:

$$\sigma_{ji,j} + p_i = 0$$

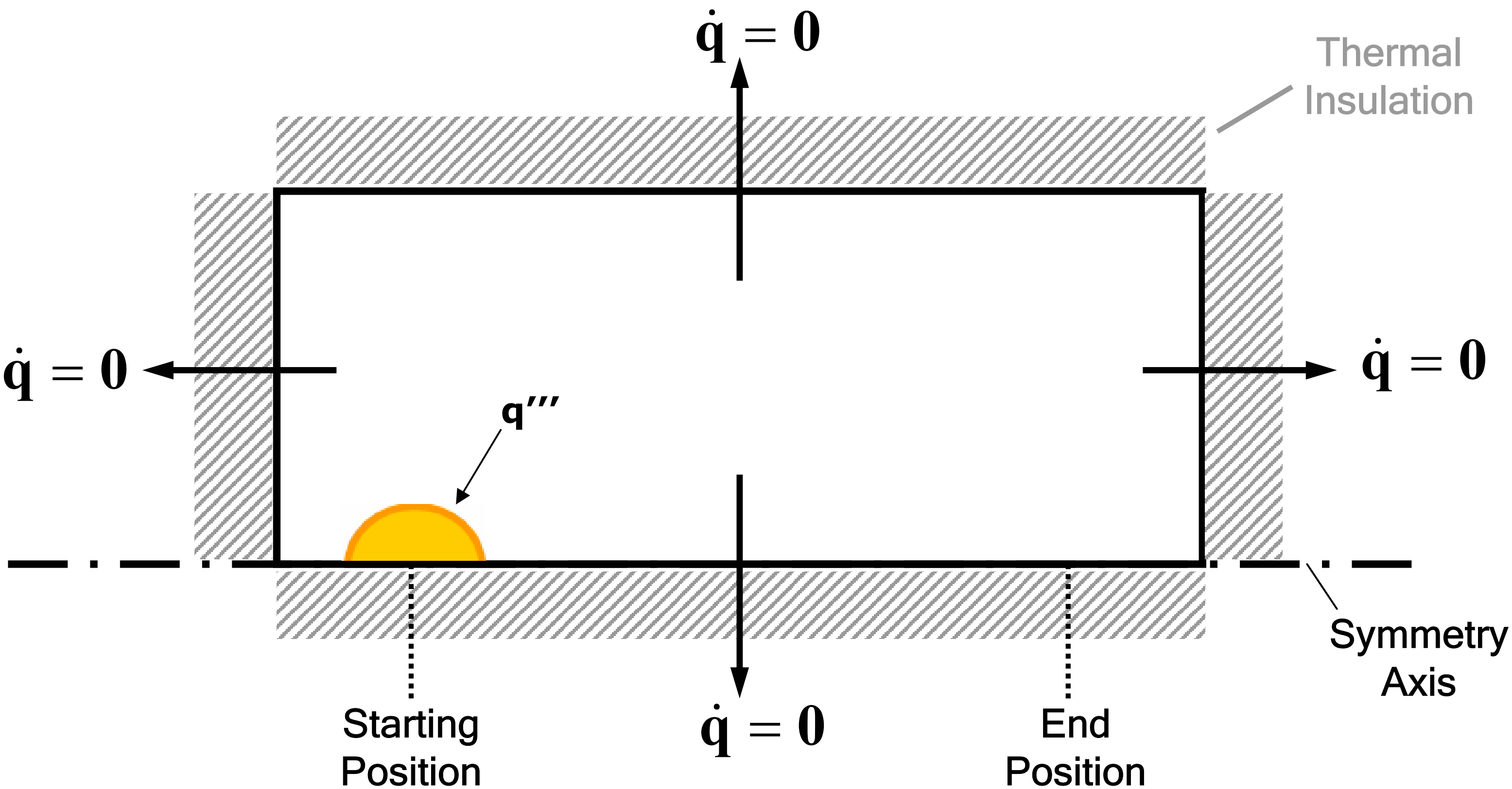
Thermo-Mechanical Model

- Evolution of the residual stresses in welding



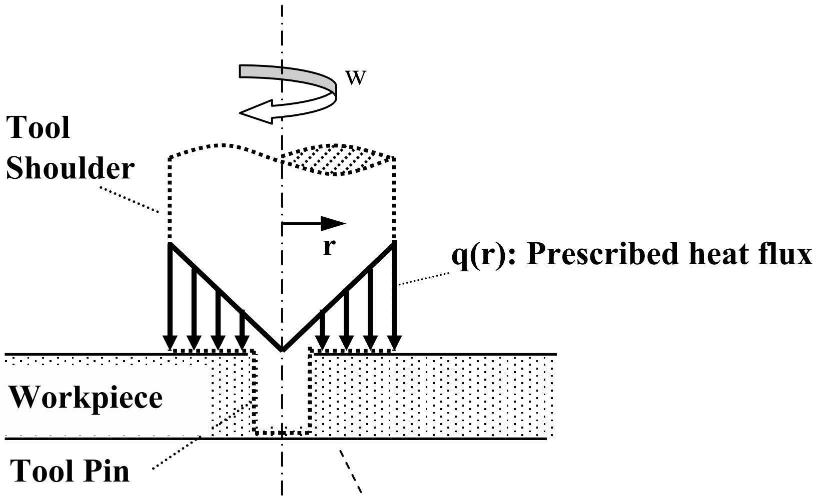
Thermo-Mechanical Model

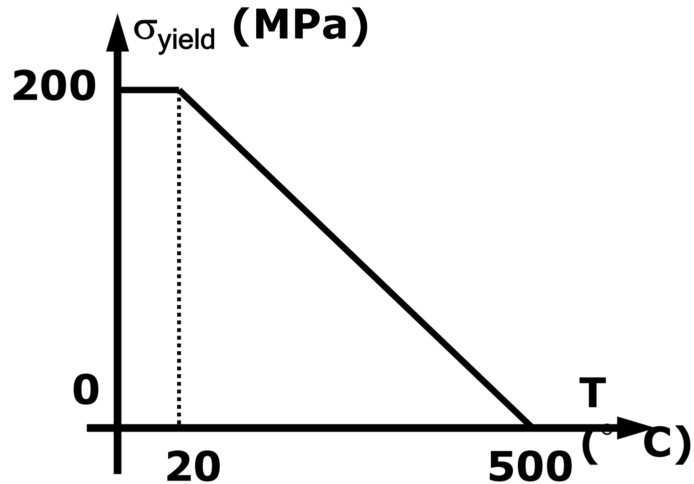
- Thermal-Pseudo-Mechanical (TPM) Model

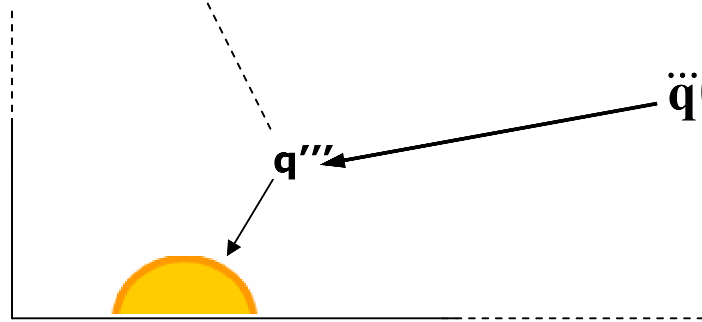


Thermo-Mechanical Model

- Thermal-Pseudo-Mechanical (TPM) Model







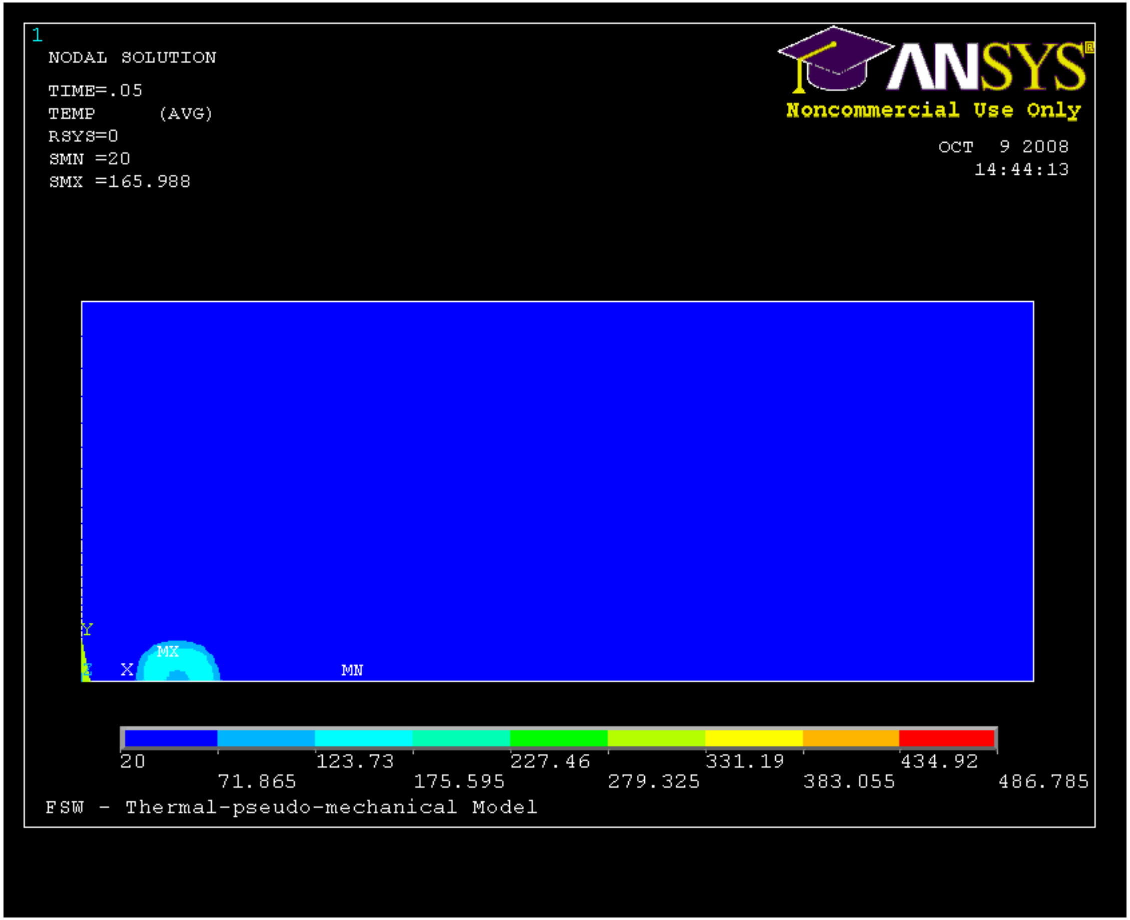
$$\dddot{q}(r,T) = \left(\frac{RPM\,2\pi}{60}\right)\left(\frac{r}{thk}\right)\frac{\sigma_{yield}(T)}{\sqrt{3}}$$

$$\sigma_{yield}(T) = \sigma_{yield,ref}\left(1 - \frac{T - T_{ref}}{T_{melt} - T_{ref}}\right)$$

(Schmidt, H. and Hattel, J. et al.)

Thermo-Mechanical Model

➢ Thermal-Pseudo-Mechanical (TPM) Model

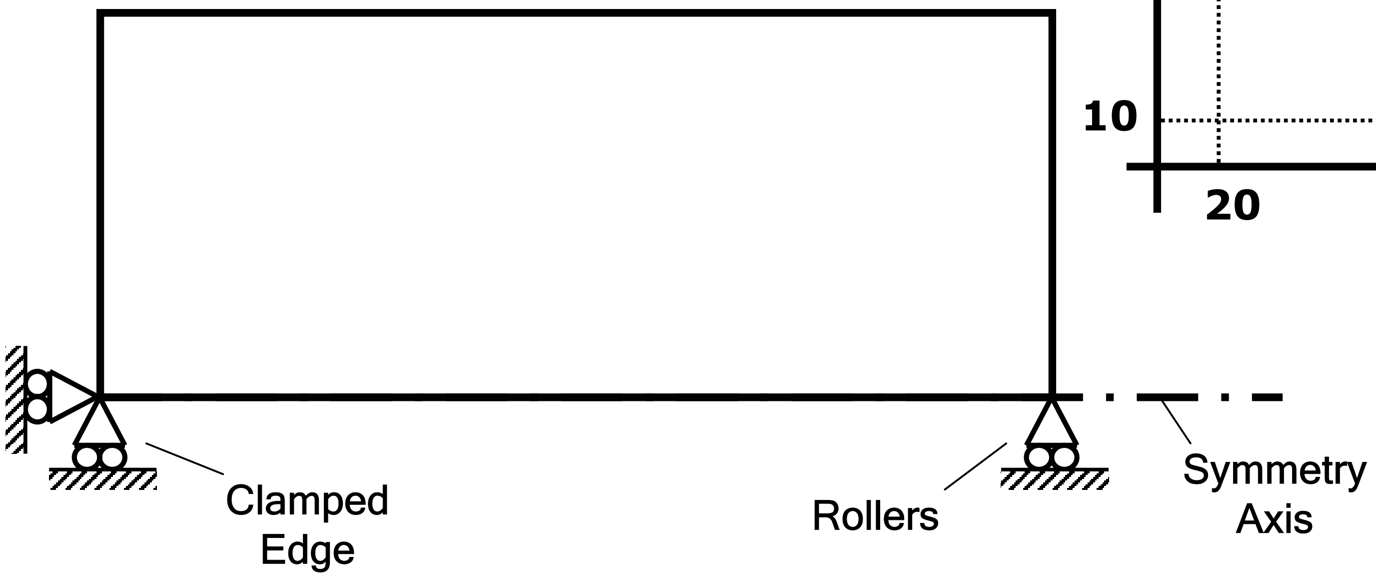


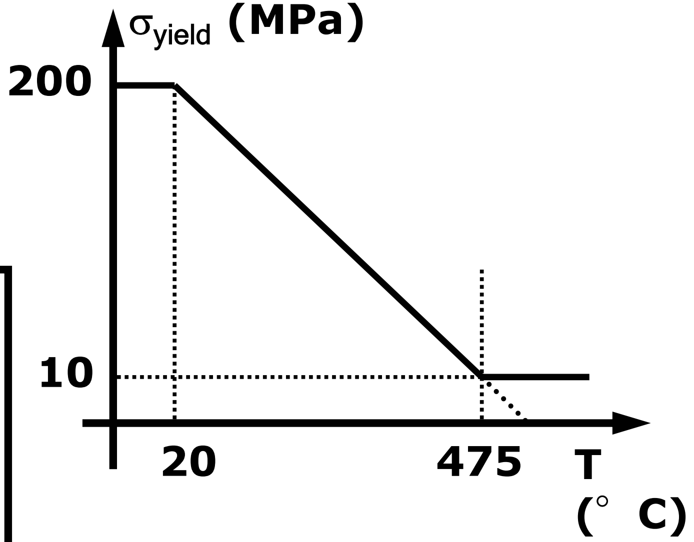
Solution Time ≈

15-20 min

Thermo-Mechanical Model

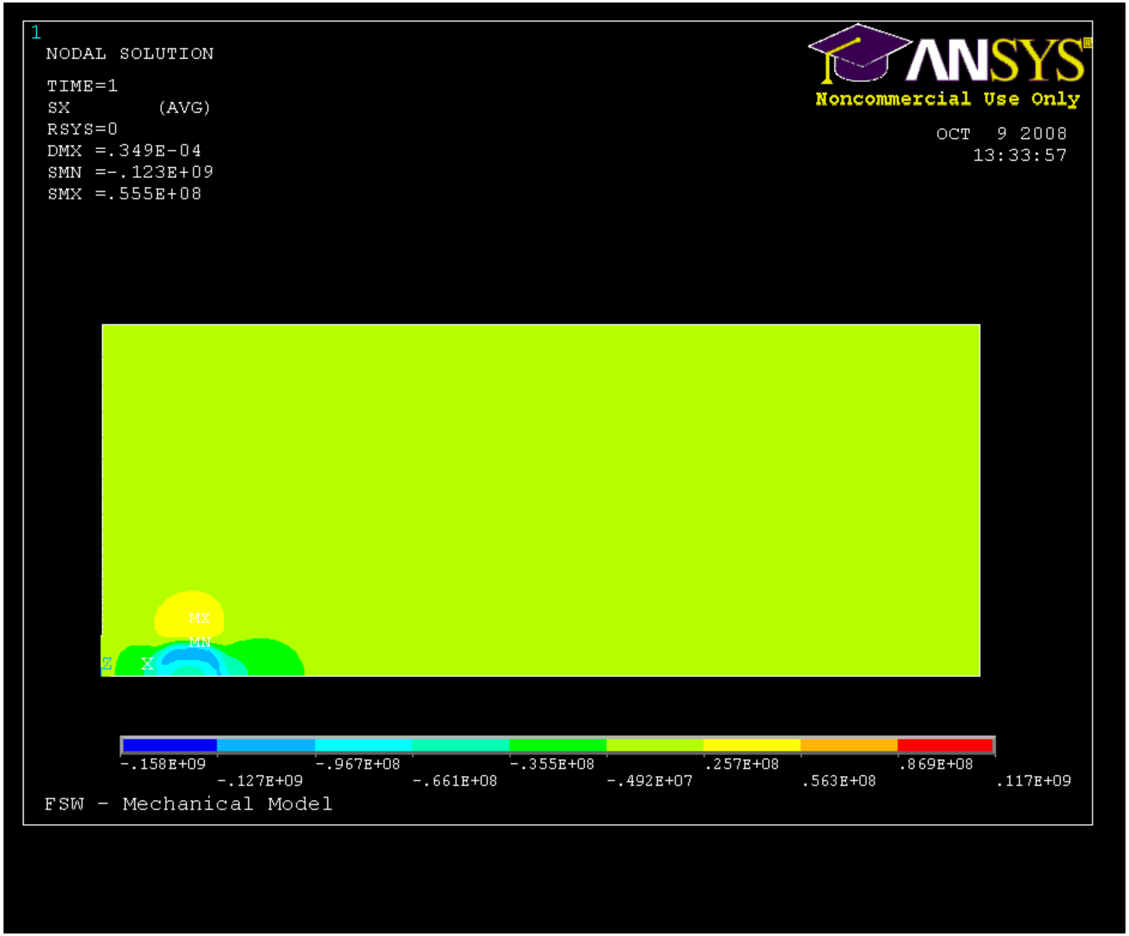
- Mechanical Model





Thermo-Mechanical Model

- Mechanical Model

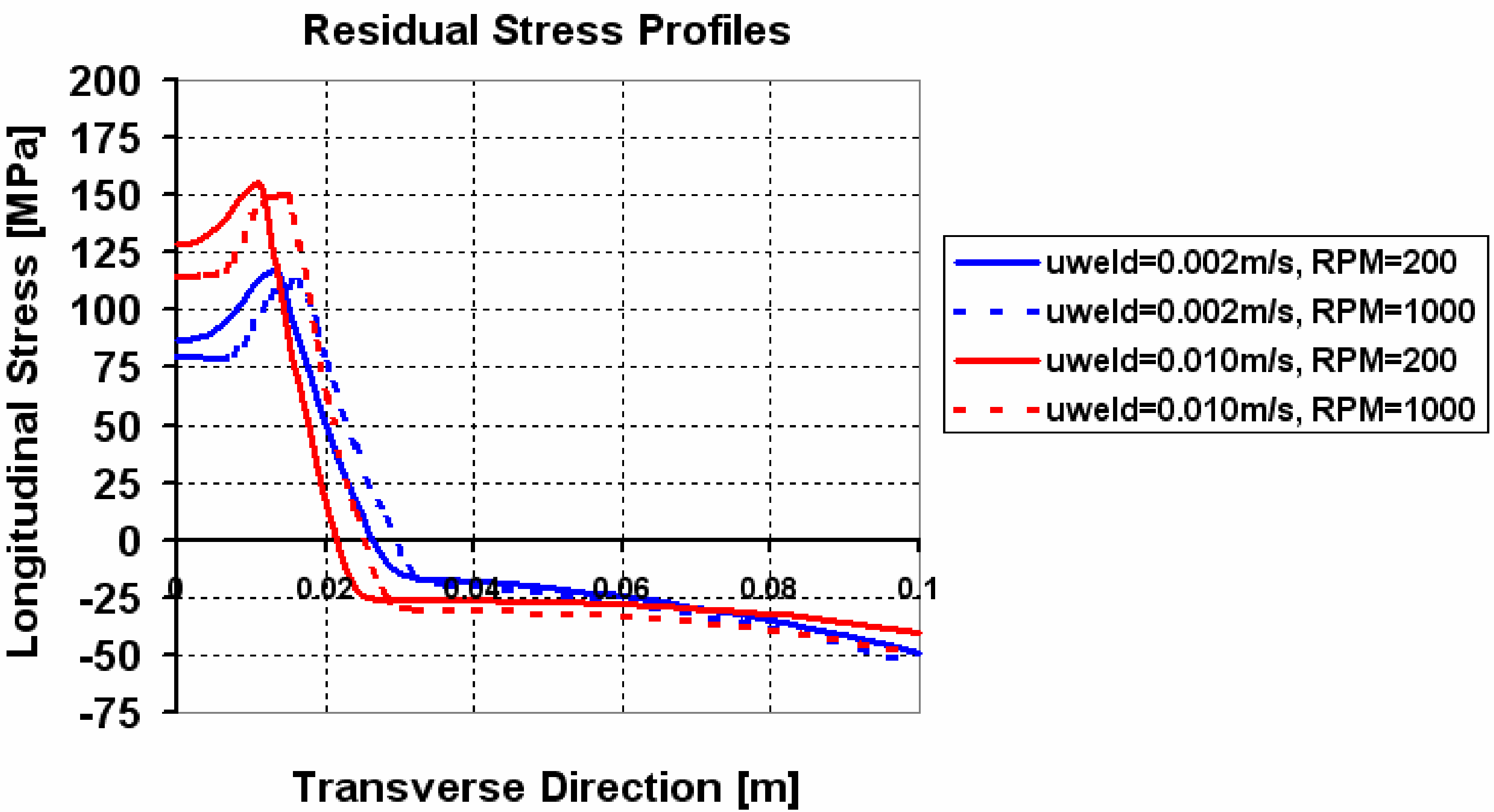


Solution Time ≈

45-50 min

Thermo-Mechanical Model

- Effects of the FSW Parameters (w_{rot}, v_{weld}) on σ_x



Optimization Procedure

$$\textbf{Minimize : Max}(\sigma_x)\ \&\ \textbf{Maximize : } v_{weld}$$

$$\textbf{subject to :}\quad 420^\circ C \le \text{Max}(T) \le 490^\circ C$$

$$100 \le w_{rot} \le 1000\ \text{rpm (10 – steps)}$$

$$1 \le v_{weld} \le 10\ \text{m/s (10 – steps)}$$

Optimization Algorithm: MOGA-II in modeFRONTIER

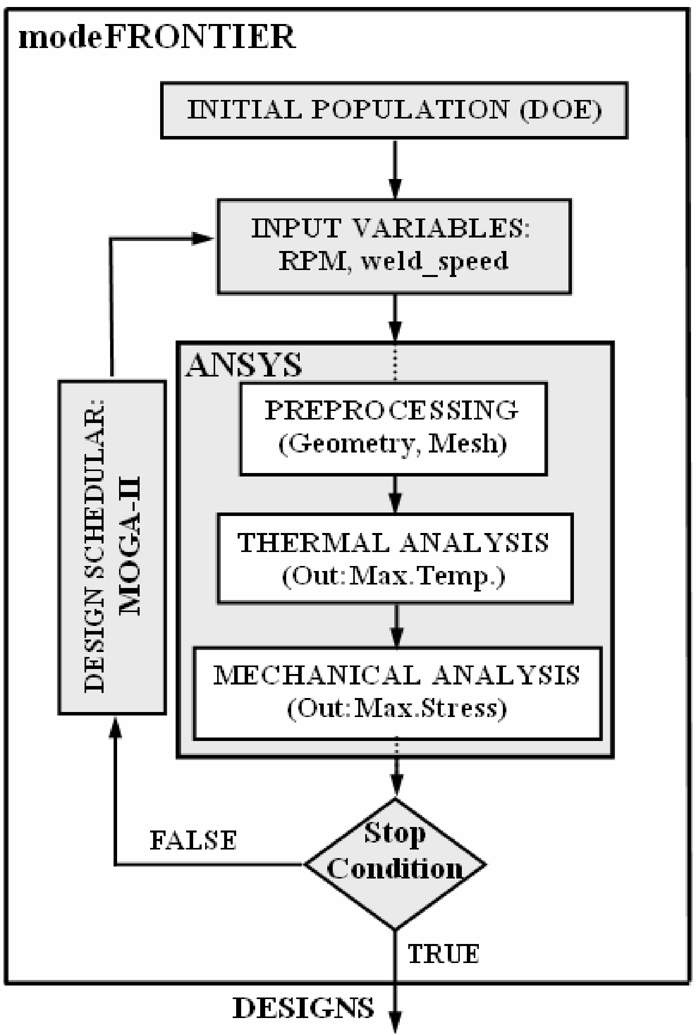
Algorithm Type: MOGA - Adaptive Evolution

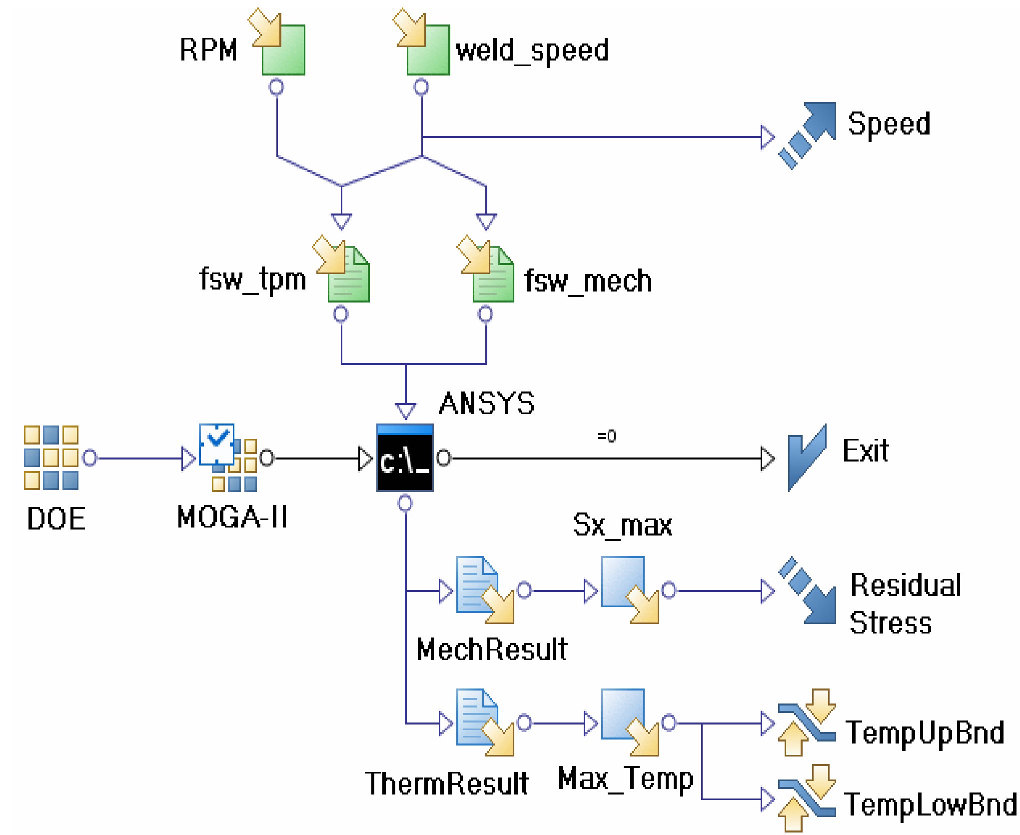
Initial Population: Full Factorial DOE with 4-levels

[(w_{rot}=100,400,700,1000rpm) x (v_{weld}=1,4,7,10mm/s)]=16 designs)

20 Generations (16x20=320 designs)

Optimization Procedure

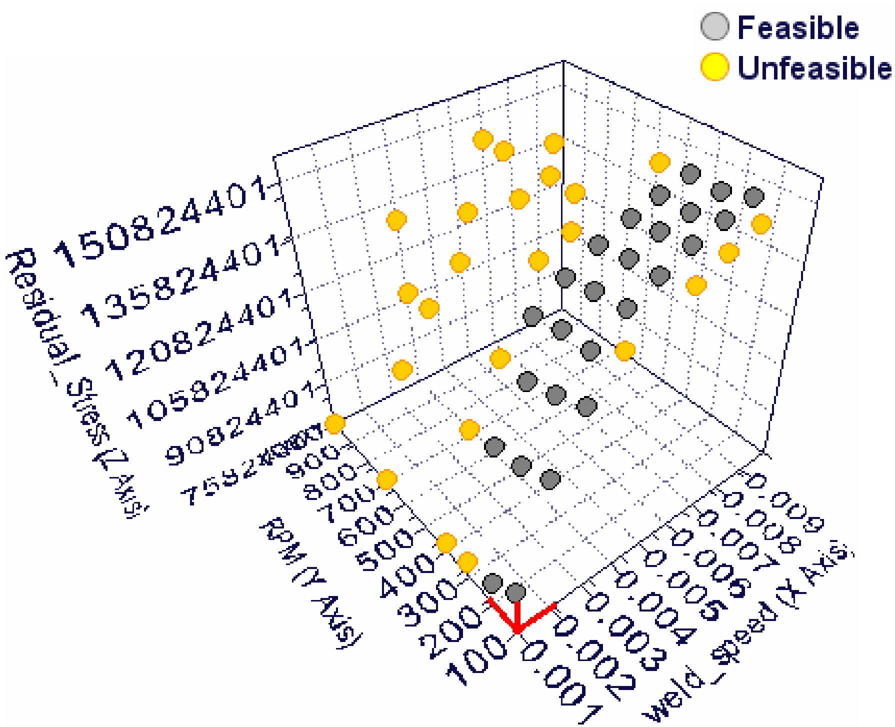


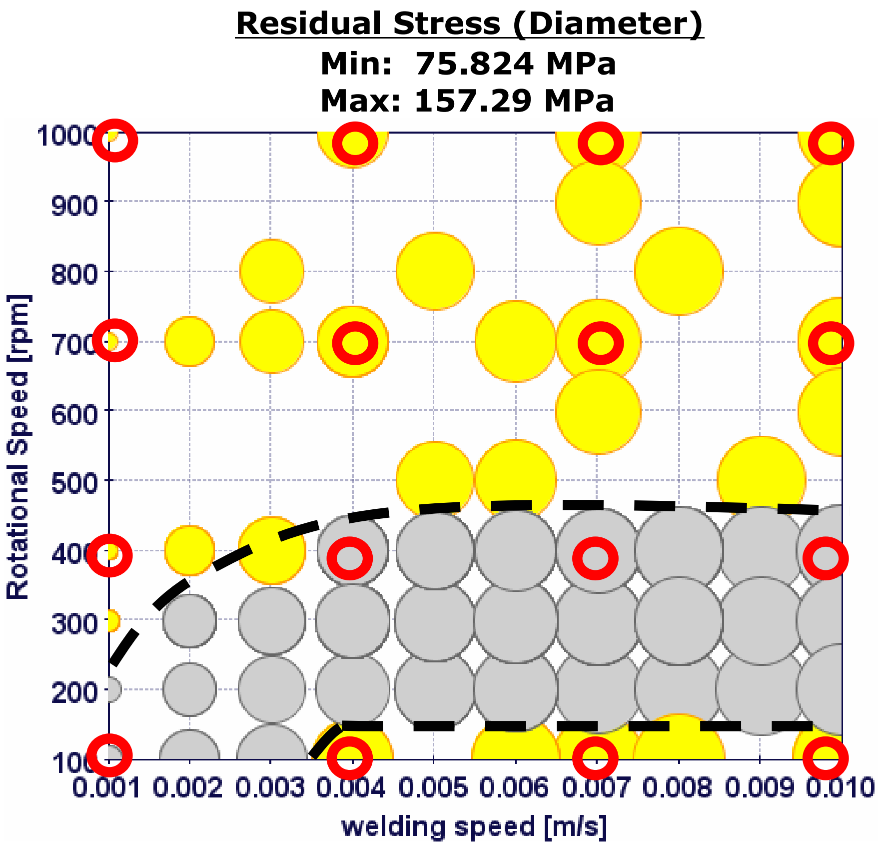


modeFRONTIER workflow

Results and Discussion

DESIGN SPACE

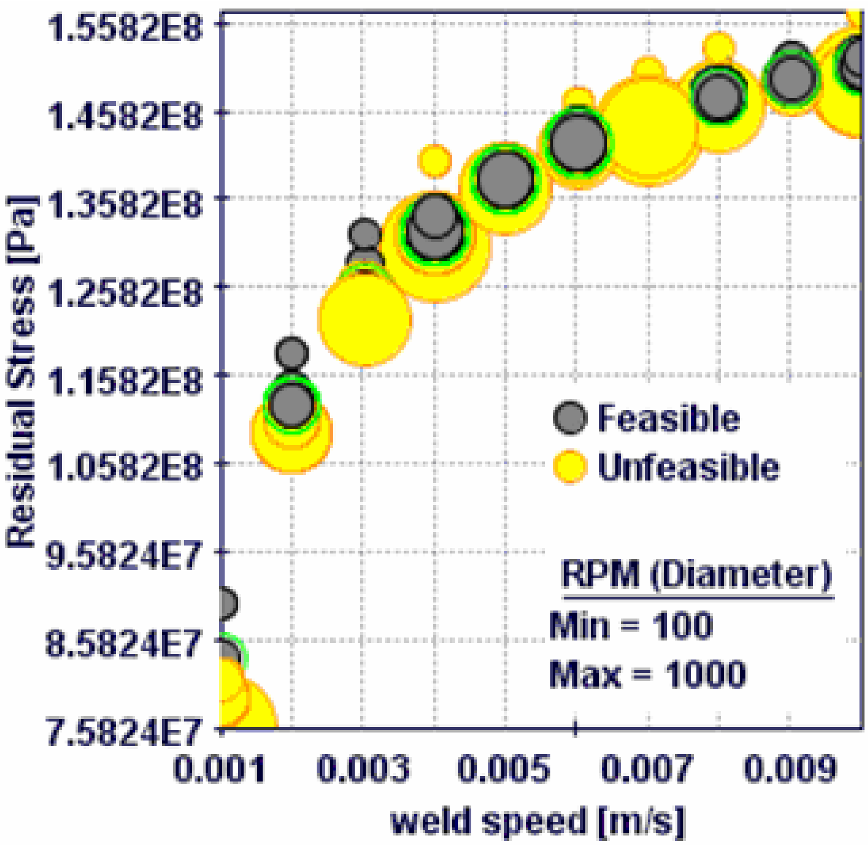


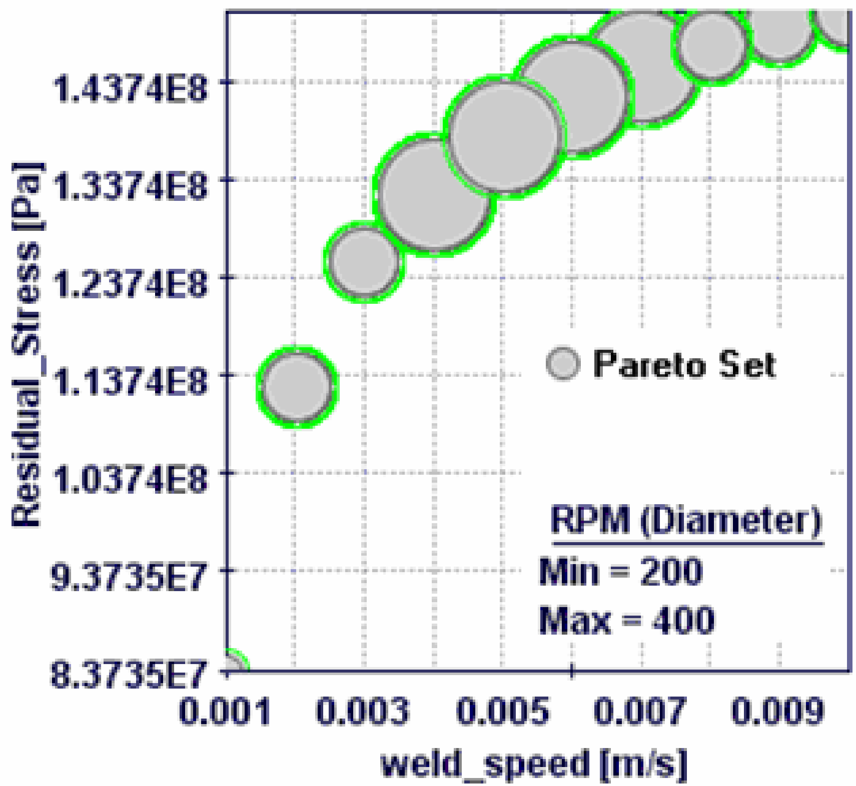


Initial Population (DOE)

Results and Discussion

CRITERION (OBJ.) SPACE





Conclusion

✓A MOOP application of FSW is presented.

✓Min($\sigma_{residual}$) and Max(v_{weld}), simultaneously
→ rotational speed and the welding speed.

✓Process-specific thermal limitations, i.e. $T^{(L)}<T_{peak}<T^{(U)}$
→ tool loads and tool life issues taken into account.

✓Feasible and unfeasible solutions are discussed and the Pareto-optimal solutions are presented.

✓A tool rotational speed of 200 to 400 rpm can be considered as robust working conditions for almost all v_{weld}.

✓Trade-off design alternatives from a manufacturer viewpoint.

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THANK YOU FOR YOUR ATTENTION...