Centre for
Advanced
Composite
Materials

Applying Bi-level Multi-Objective Evolutionary Algorithms for Optimizing Composites Manufacturing Processes

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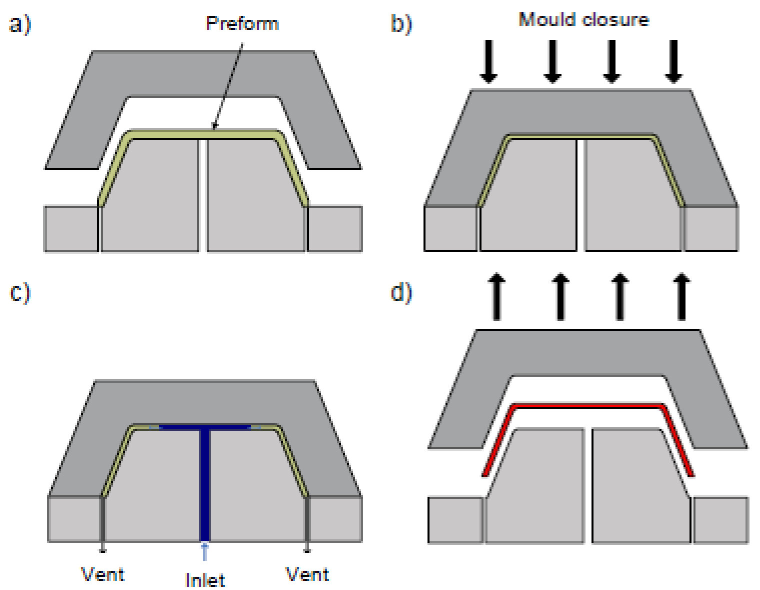
Outline

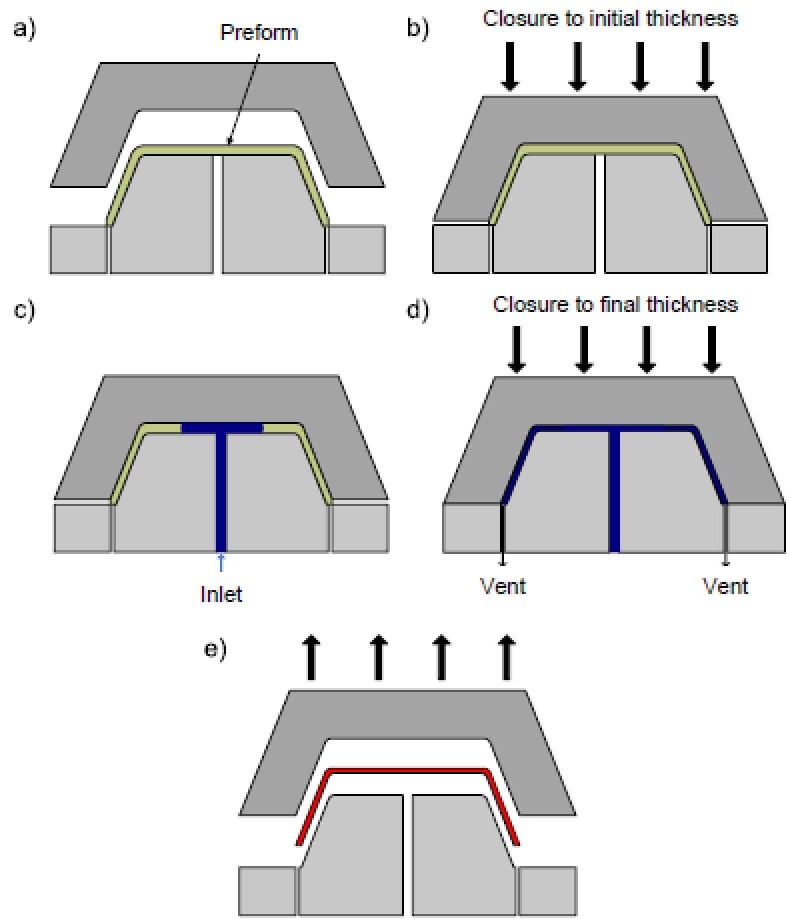
- Introduction to Composite Manufacturing processes – Resin Transfer Moulding (RTM) and Compression RTM (CRTM) .
- Objectives under consideration.
- Non-intuitive consequences of certain process variables.
- Structure of the manufacturing cycle optimization problem.
- Solution approach.
- Results from a test case.

RTM and CRTM

RTM



CRTM



Objectives under consideration

Filling phase:

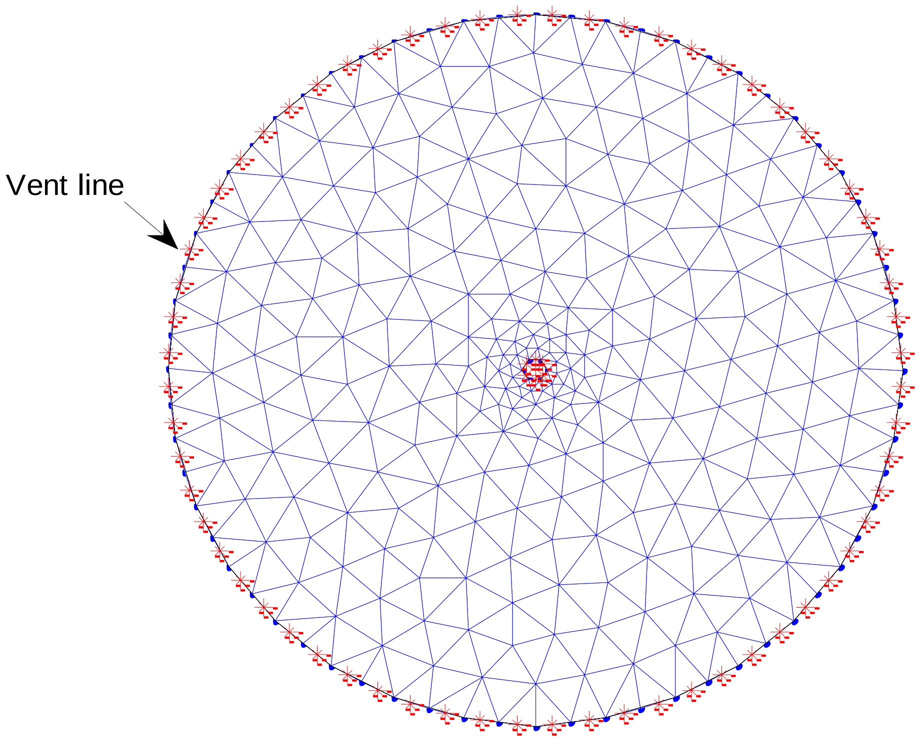
- Fill time - Minimize
- Tooling forces - Minimize

Curing (Solidification) phase:

- Curing time - Minimize
- Part Quality – Maximize (Through thickness temperature gradients within the part – Minimize)

Fill phase simulation example - RTM, CRTM force evolution

Axisymmetric part centrally injected with a reactive epoxy resin.



Process variables:

Injection Pressure

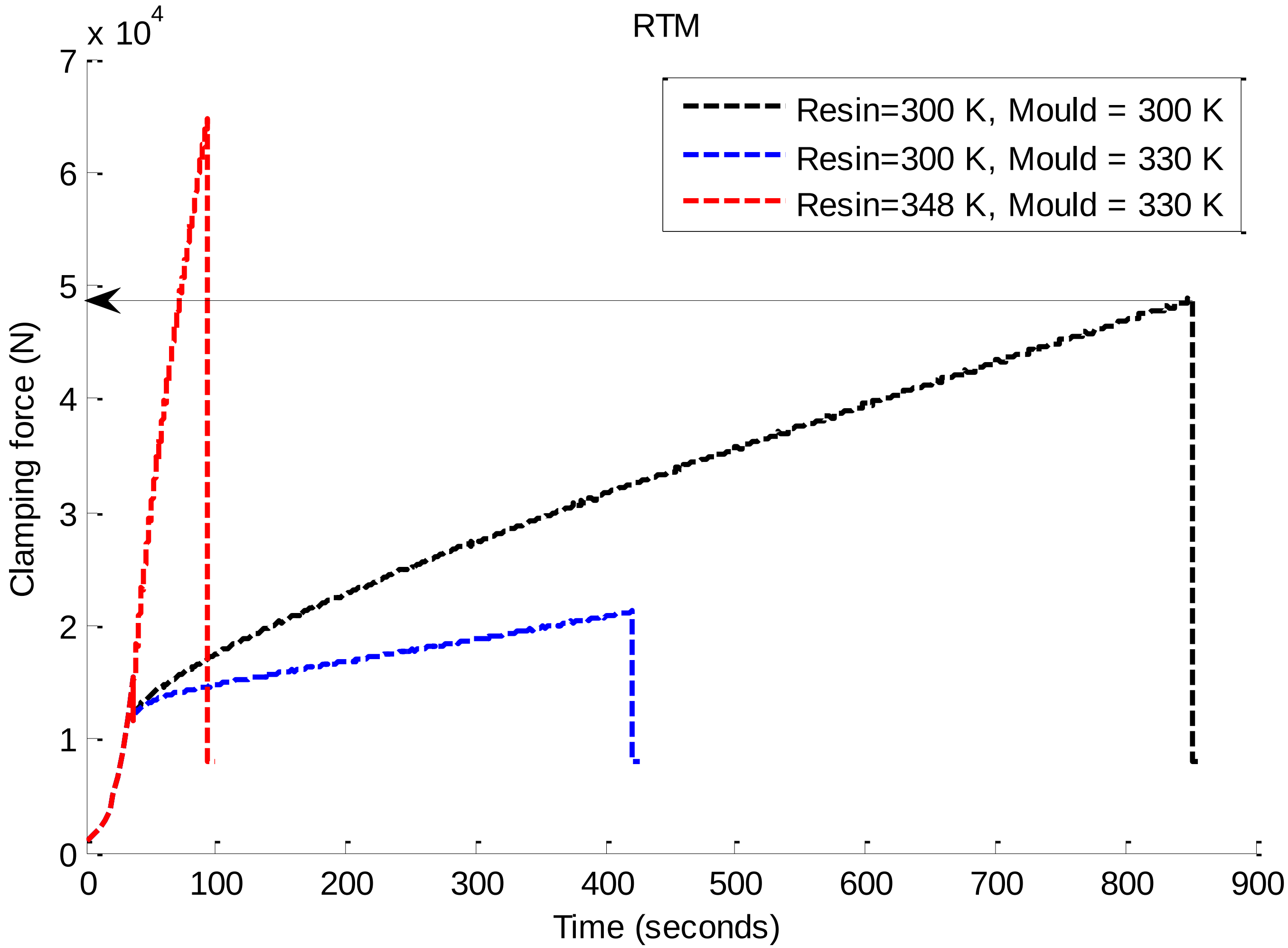
Injection height

Mould closure velocity

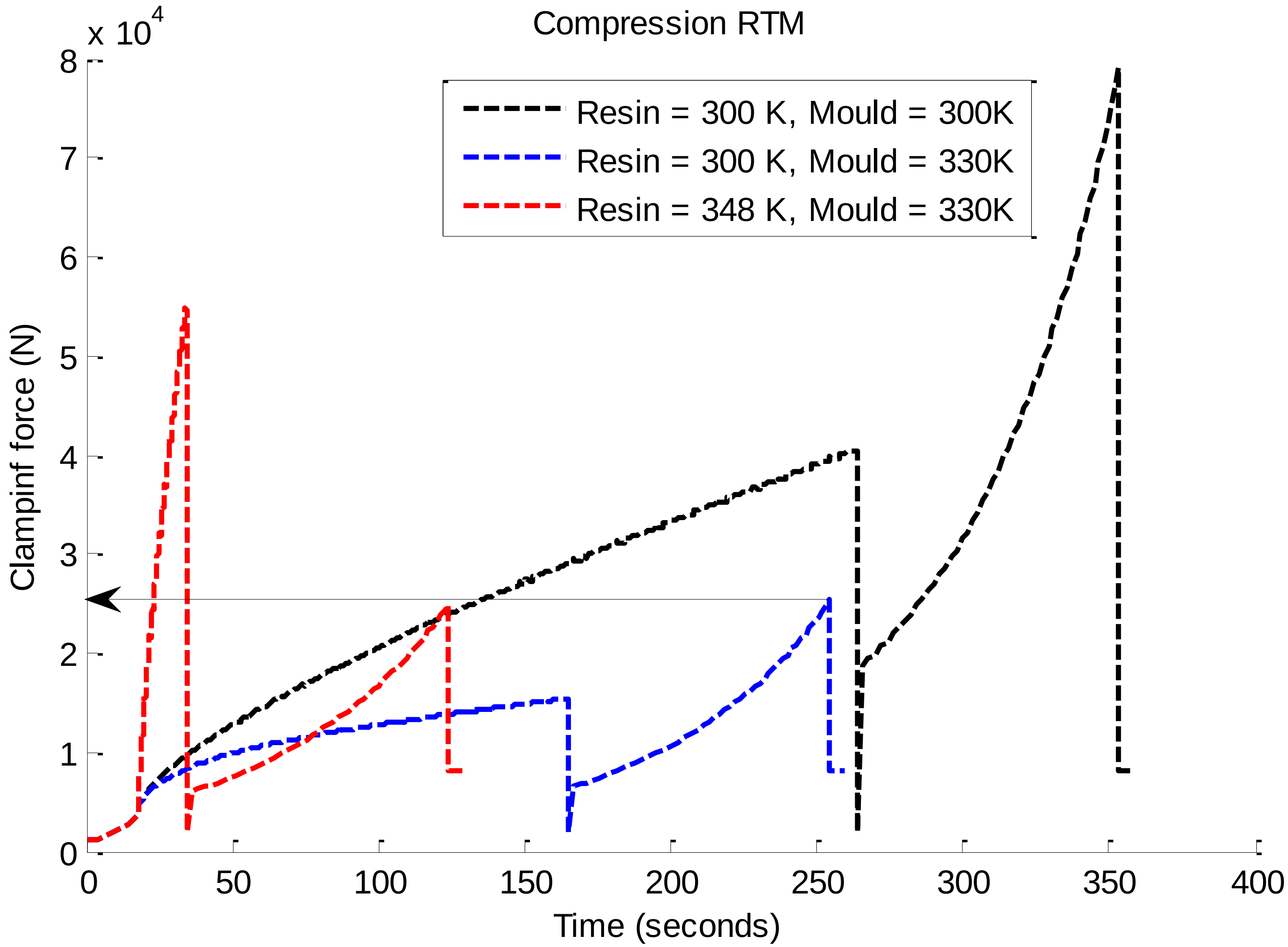
Preheated resin temperature

Mould temperature

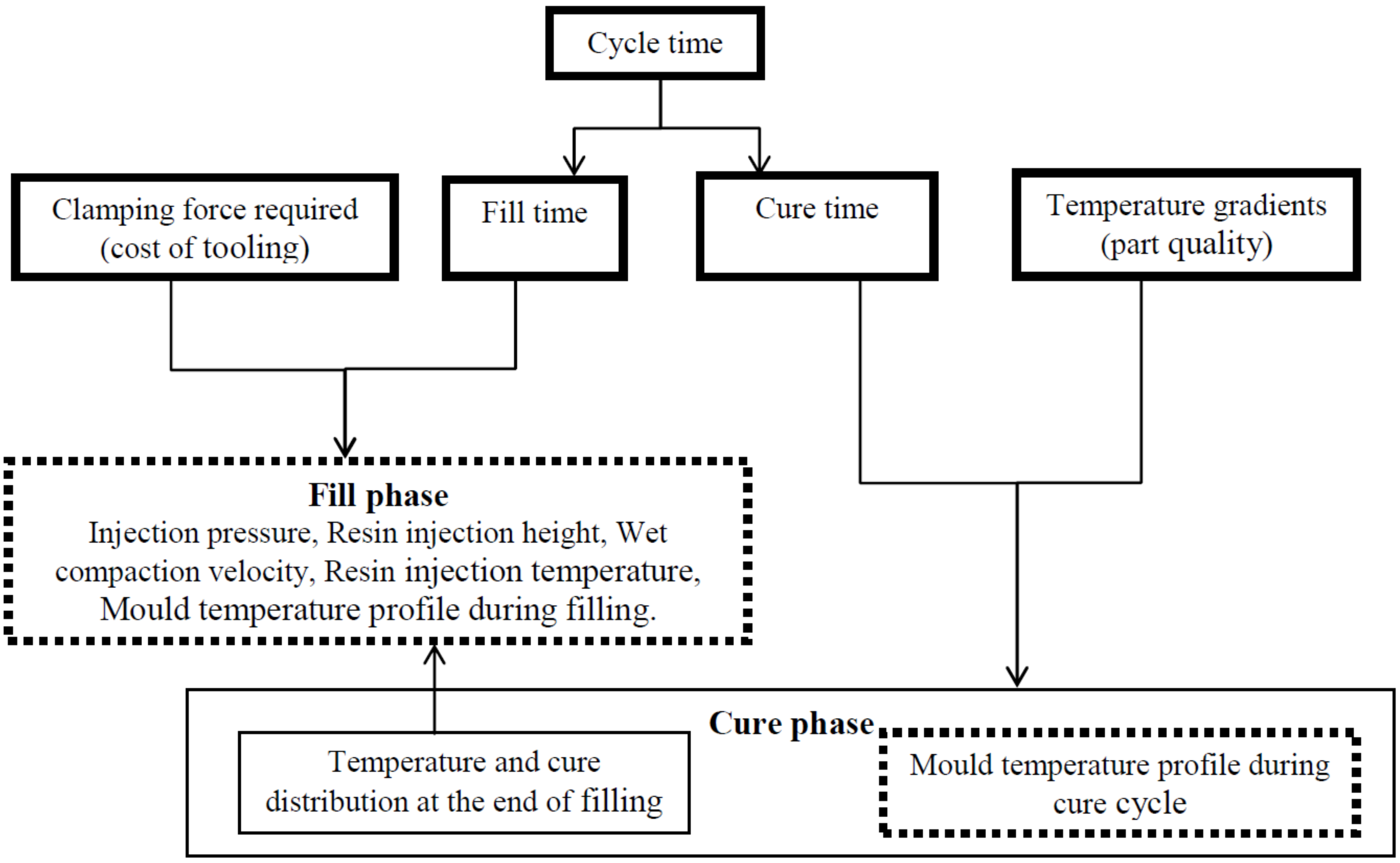
Simulation example 1 - RTM



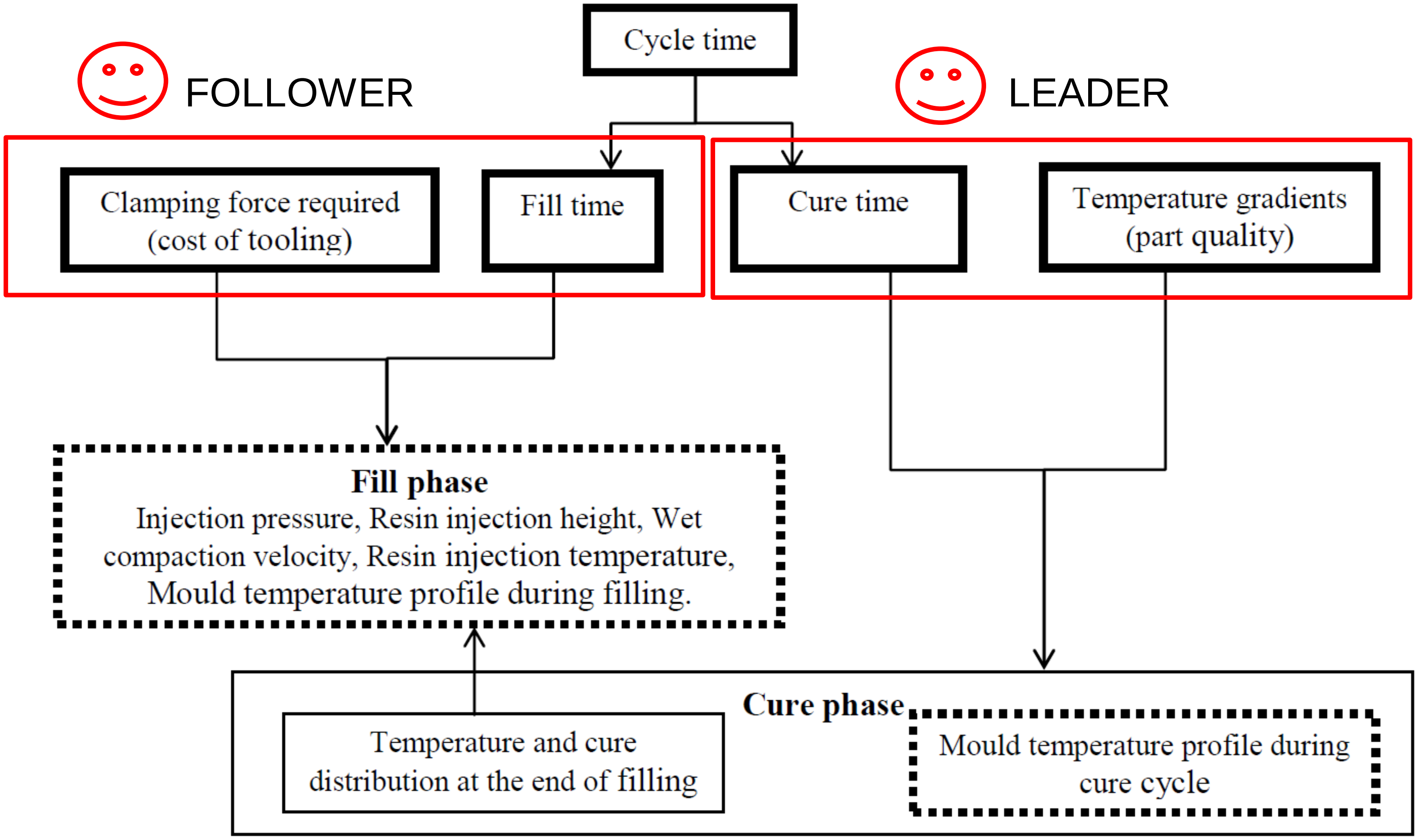
Simulation example 2 - CRTM



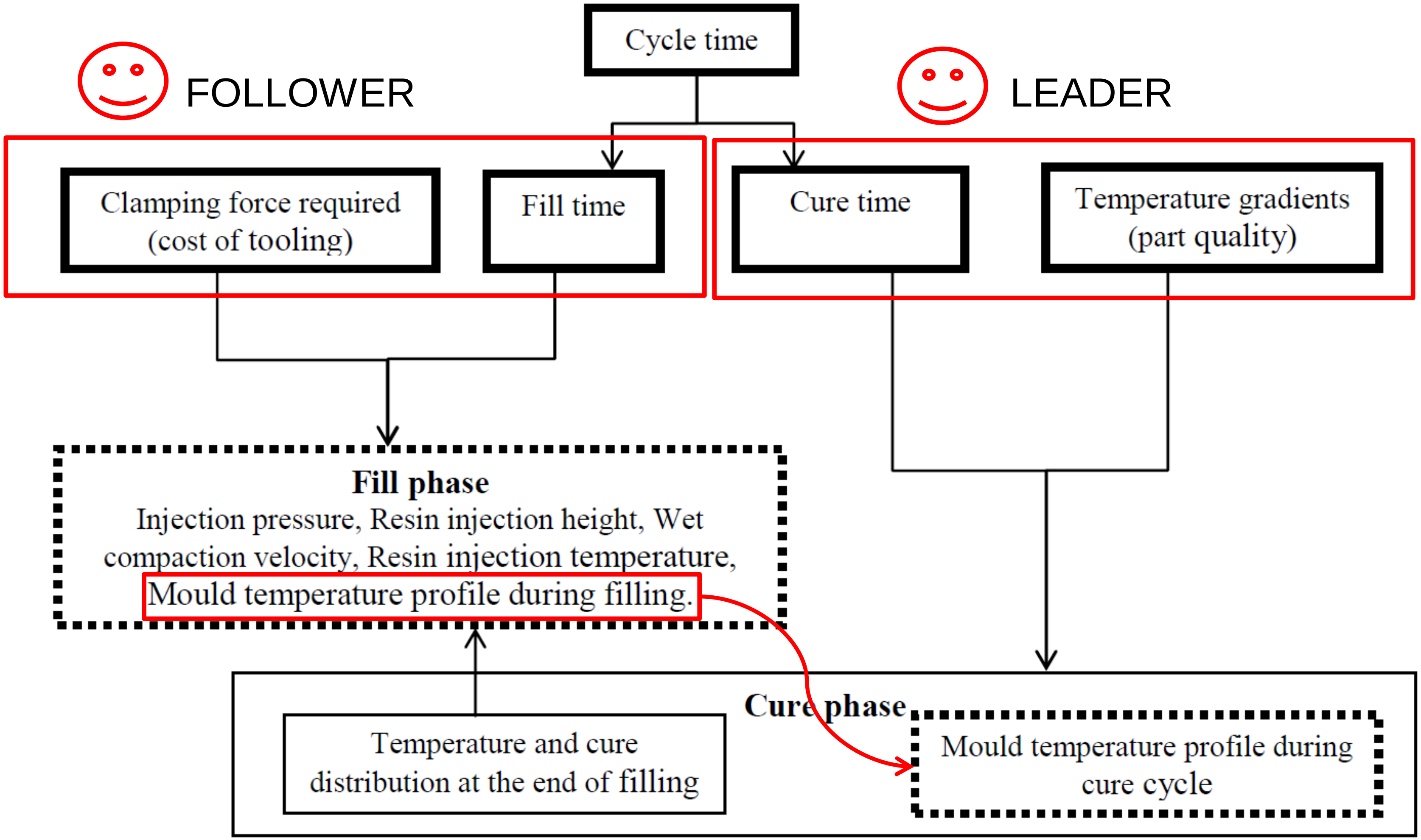
The complete optimization problem



The complete optimization problem



The complete optimization problem



A multi-objective Stackelberg game

General mathematical description (Optimistic approach) -

$$Minimize\ F(x_u, x_l),$$

$$subject\ to\ x_l \ \in\ argmin\,\{f(x_l) \mid g(x_l) \geq 0, h(x_l) = 0\},$$

$$G(x_u, x_l) \geq 0, H(x_u, x_l) = 0,$$

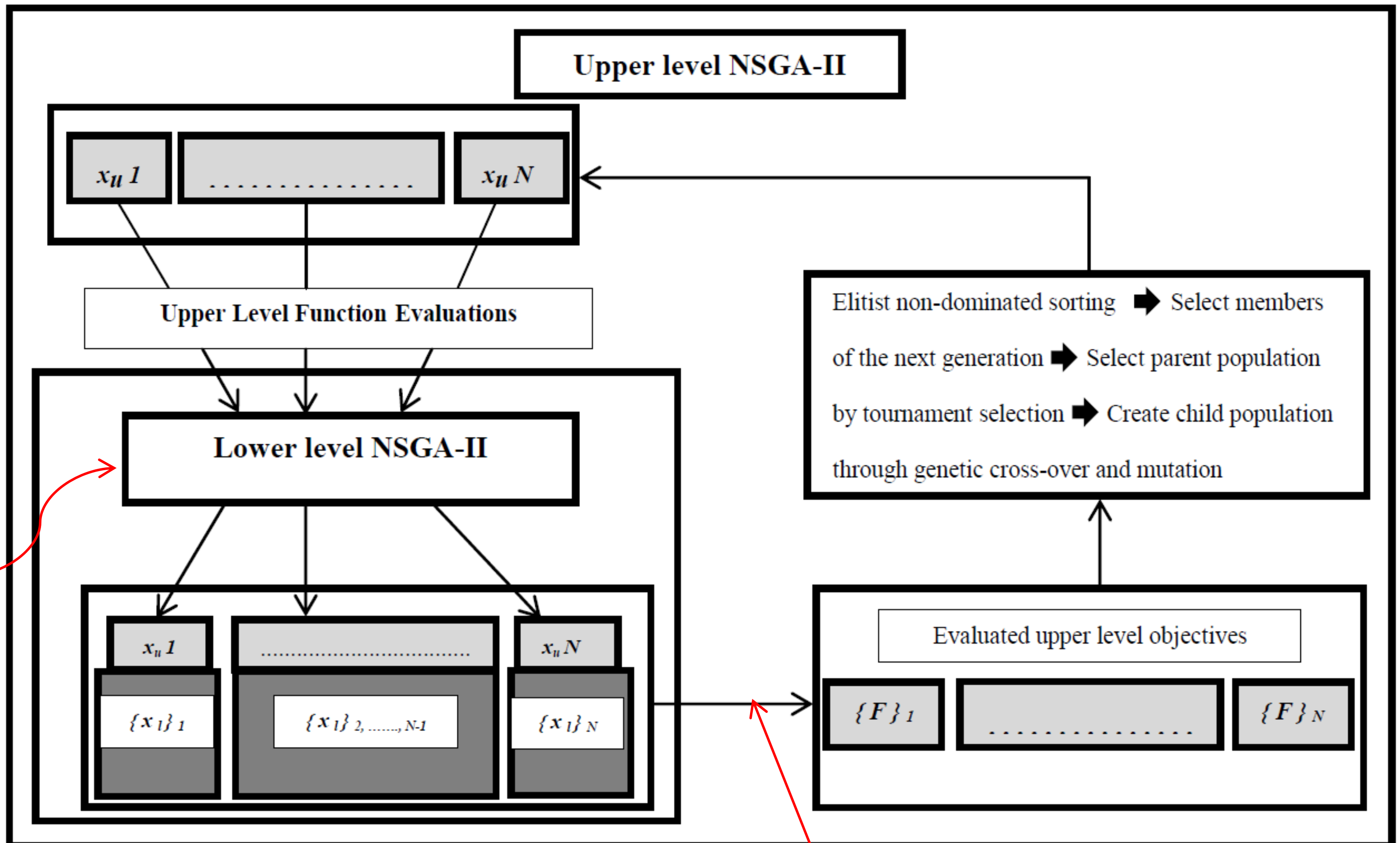
$$x_u = (x_1, \ldots, x_r);\ x_l = (x_{r+1}, \ldots, x_n),$$

$$x_i^{(L)} \leq\ x_i\ \leq\ x_i^{(U)}, i = 1, \ldots, n.$$

A slight modification (Subdued Optimism) -

$$x_l\ \in\ \{argmin\,\{f(x_l) \mid g(x_l) \geq 0, h(x_l) = 0\}\ \cap \{x_l\!: f(x_l) \in RI\}\}$$

Solving the bilevel multi-objective problem



Based on Fill simulation

Based on cure simulation

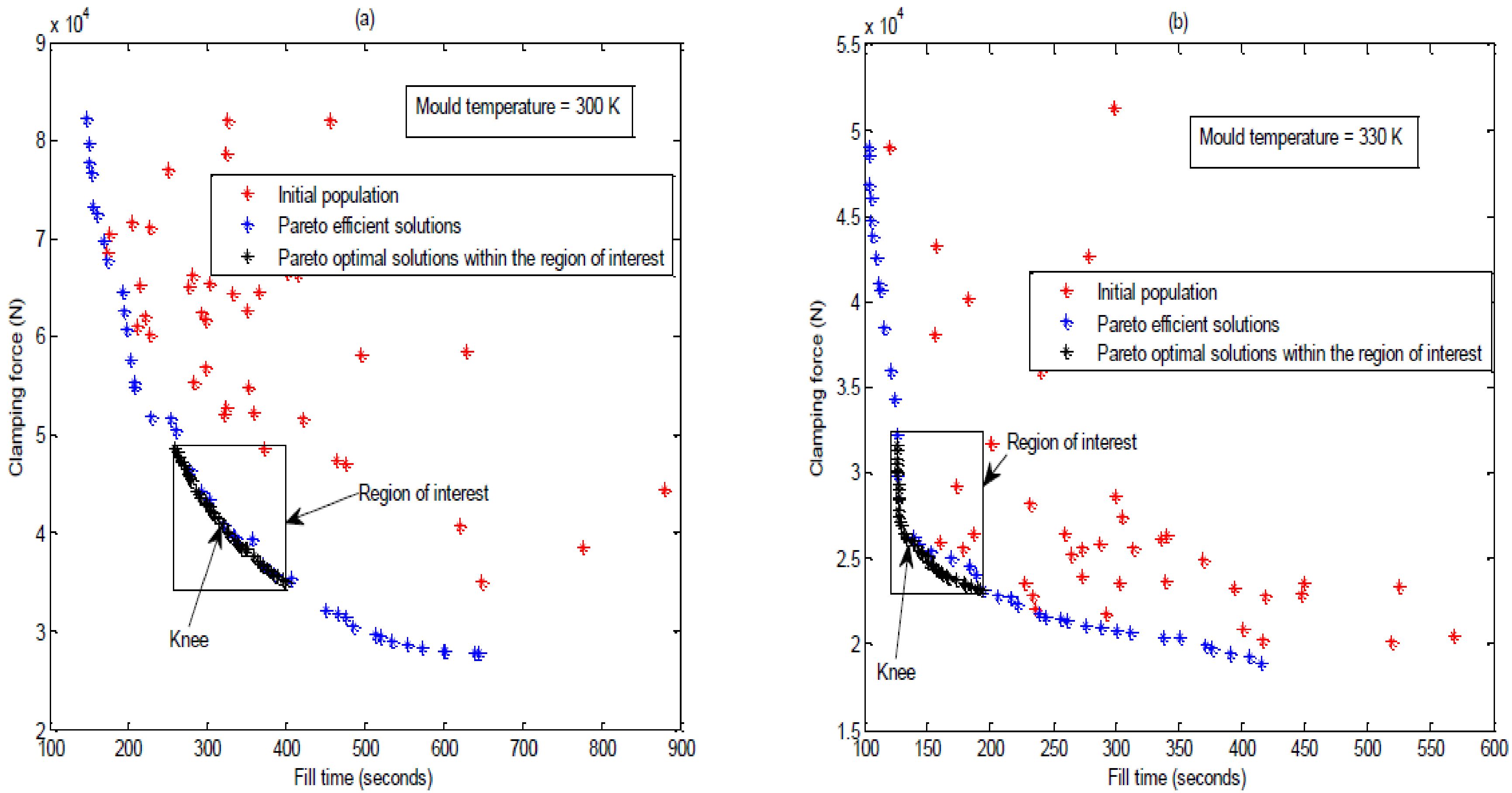
Surrogate Model

- Simulation code is too expensive to carry out millions of lower level (fill phase) simulations.

- Few hundred simulations at the lower level are carried out to train a Cascade Correlation Learning Architecture neural network for subsequent function evaluations.

- For this a Latin Hypercube Sampling technique is used to create the reference set of points in the process variable space.

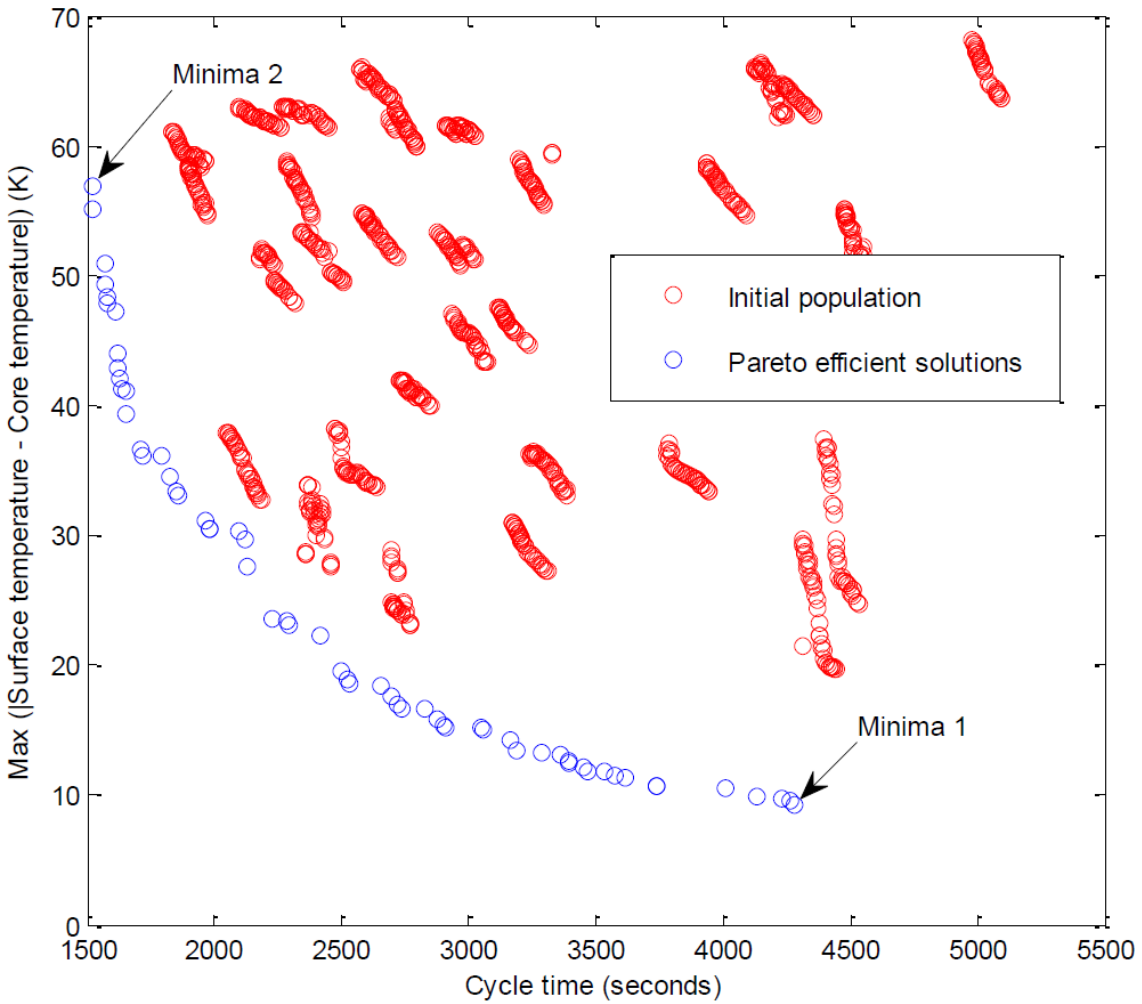
Lower-level NSGA-2 simulation



(a) Pareto frontier (blue) for a mould temperature of 300 K
(b) Pareto frontier (blue) for a mould temperature of 330 K

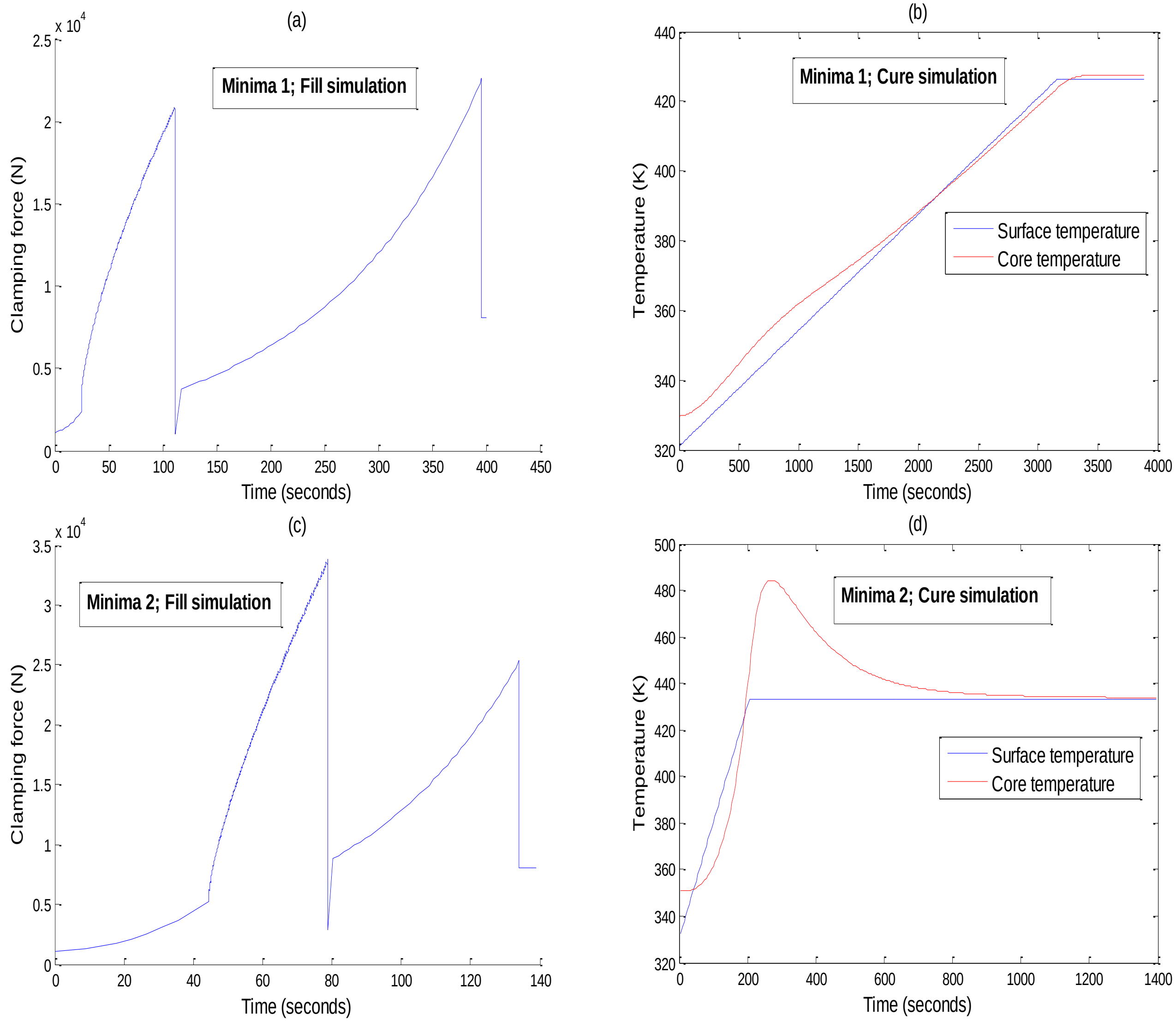
Overall problem solution

Pareto frontier obtained by the Upper Level decision maker.



Final result analysis

Filling and cure simulations corresponding to Minima 1 (a, b) and Minima 2 (c, d) in the previous slide



Conclusions

- An integrated framework for optimizing the complete manufacturing cycle has been developed by using an EA based approach to solving bilevel multiobjective optimization problems.

- The method requires minimal interaction with the manufacturer, which is considered desirable for the problem under consideration.

Thank You !