Adhesive bonding process optimization via Gaussian Process models

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Adhesive bonding used in wide variety of applications

https://www.dupont.co.uk/products/betaseal.html

https://blog.paryleneconformalcoating.com/whats-the-difference-between-potting-and-conformal-coating/

https://www.livios.be/nl/bouwinformatie/ruwbouw/muren/verlijmen-versus-dun-metselen/

Quality of the final bond should be guaranteed during the production process

Finding + controlling optimal process parameters is critical for final quality of adhesive bond

Problem

Large number of process parameters which (might) influence final bond quality

Costly experiments: too expensive to optimize by testing them all

Traditional approach: expert knowledge + trial & error

- Settle for suboptimal solution
- Depends largely on experience + knowledge process designer

Use Design of Experiments together with Gaussian process models for optimization

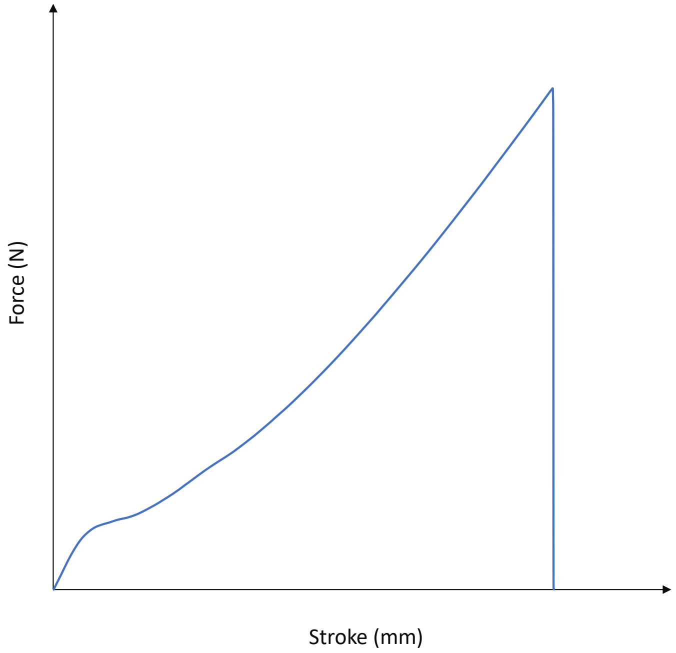
Content

- Adhesive bonding process
- Traditional approach
- Gaussian process models
- Results
- Conclusions

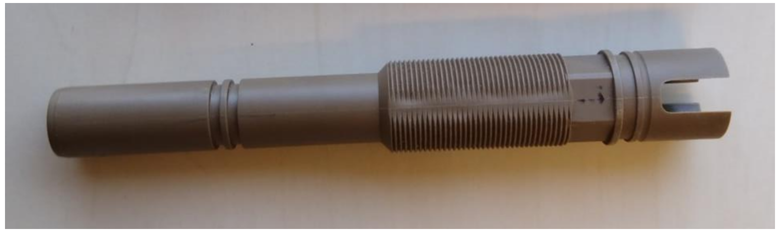
Adhesive bonding process

Adhesive bonding process

Destructuve testing



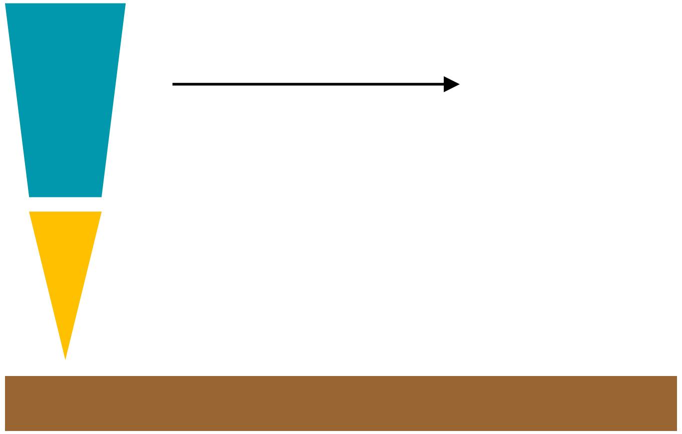
Potting of sensor in PPS housing

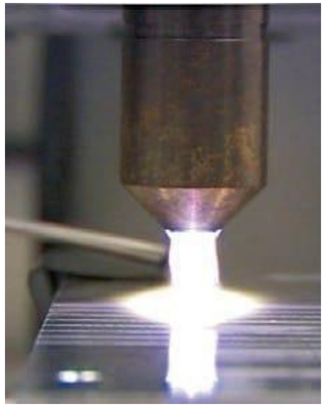


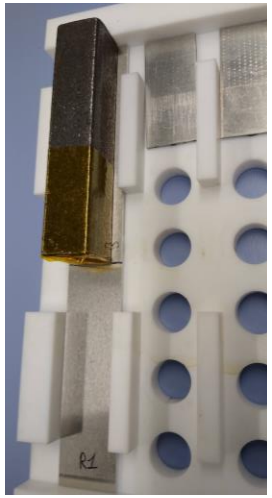
- Break stress
- Failure mode

Bond quality

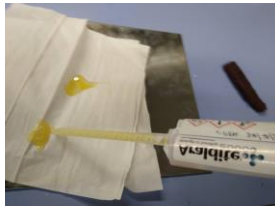
Adhesive bonding process







- Part preparation
- Cleaning
- Plasma treatment
- Adhesive preparation
- Adhesive application
- Part assembly
- Curing

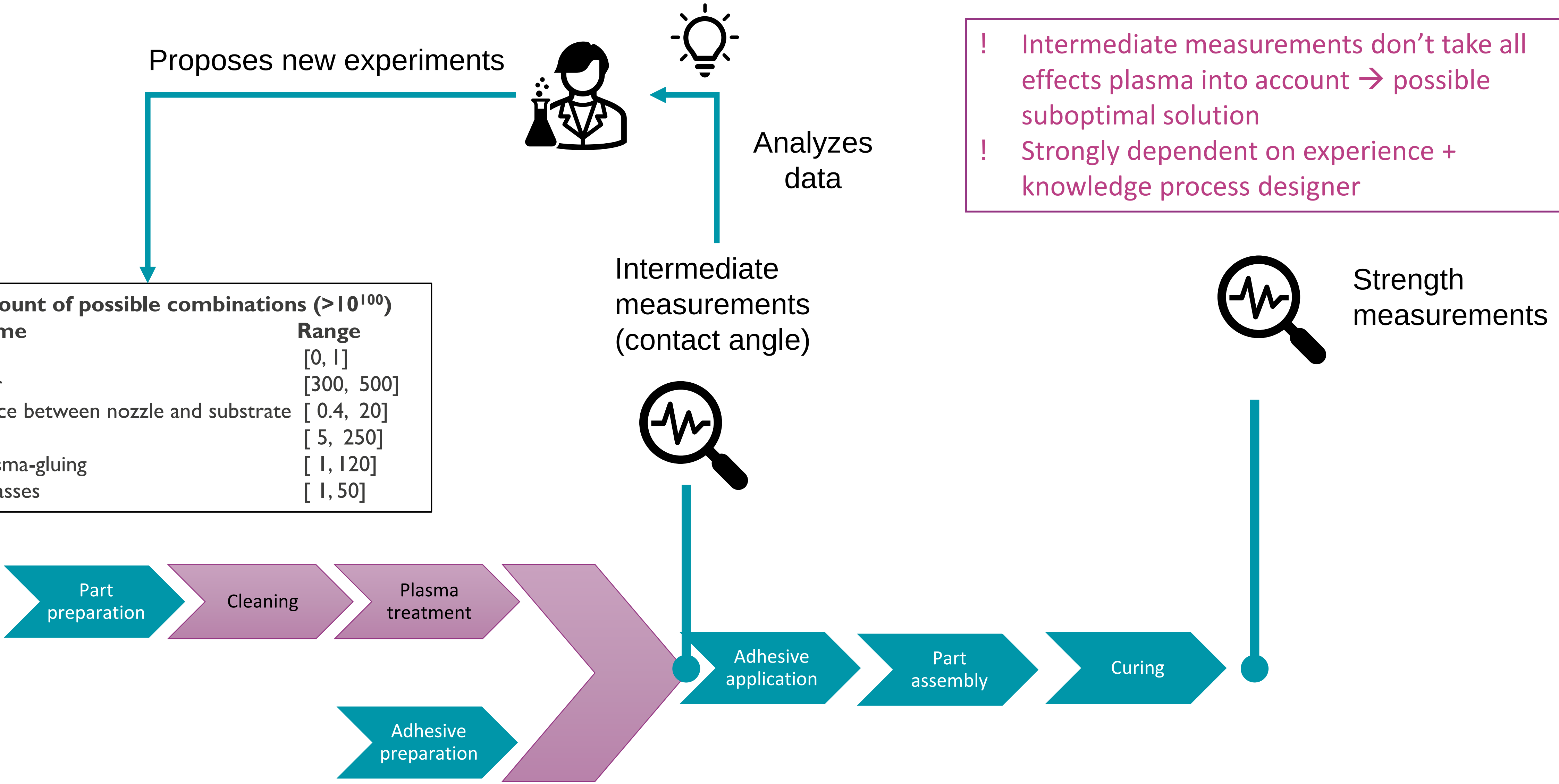


Adhesive bonding process – traditional approach

Huge amount of possible combinations ($>10^{100}$)

Variable name	Range
Cleaning	[0, 1]
Plasma power	[300, 500]
Plasma distance between nozzle and substrate	[0.4, 20]
Plasma speed	[5, 250]
Real time plasma-gluing	[1, 120]
Number of passes	[1, 50]

Adhesive bonding process – traditional approach



Huge amount of possible combinations (>10^{100})

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Cleaning	[0, 1]
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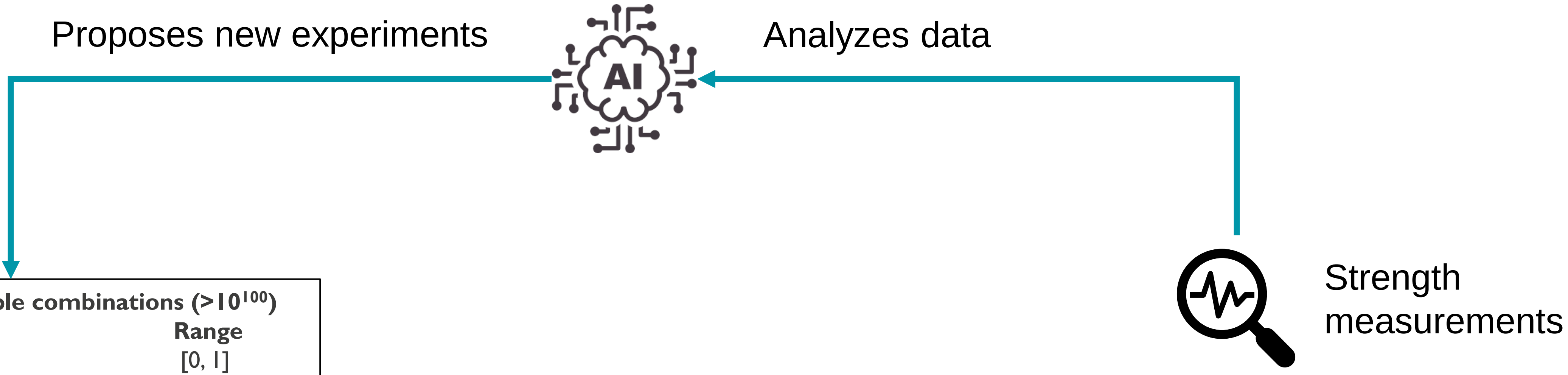
Plasma speed	[5, 250]
Real time plasma-gluing	[1, 120]
Number of passes	[1, 50]

- ! Intermediate measurements don't take all effects plasma into account → possible suboptimal solution
- ! Strongly dependent on experience + knowledge process designer

Adhesive bonding process – Gaussian process models



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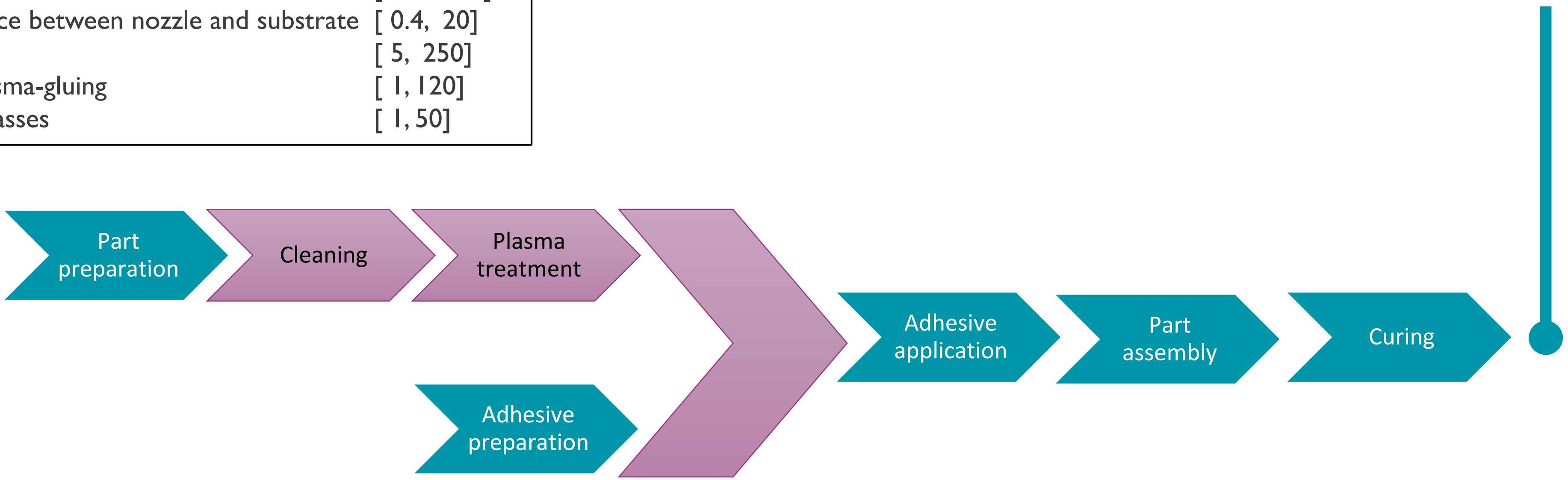
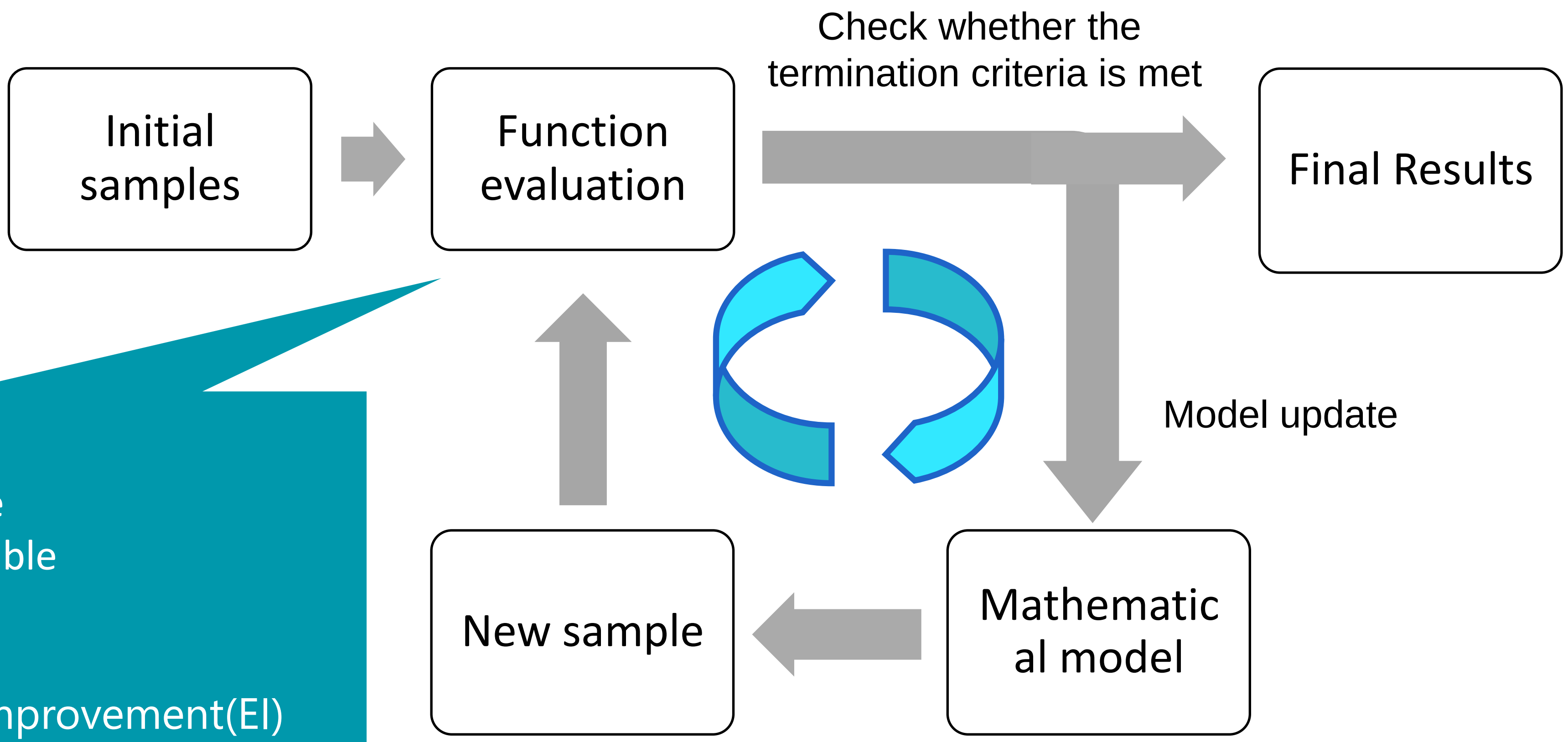


Methodology adhesive bonding process – Gaussian process models

DoE:
Latin Hypercube

Budget for finding final solution consumed



Adapted from (Ivo, 2019)

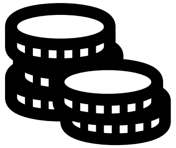
Optimization criteria:

- Break stress as high as possible
- Production cost as low as possible

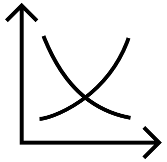
Bayesian Optimization using

- Single objective: Expected Improvement(EI) acquisition function
- Multi-objective : Hypervolume expected improvement (HVEI) acquisition function

Termination criteria



Budget 3000 EUR for finding optimal solution



Cost model made about how much it would cost to search for optimal settings in traditional + Gaussian Process Bayesian Optimization
+ cost model for calculating production cost with selected solution

Traditional approach

Contact angle tests: 6 x 30 samples
Strength test: 1 x 30 samples

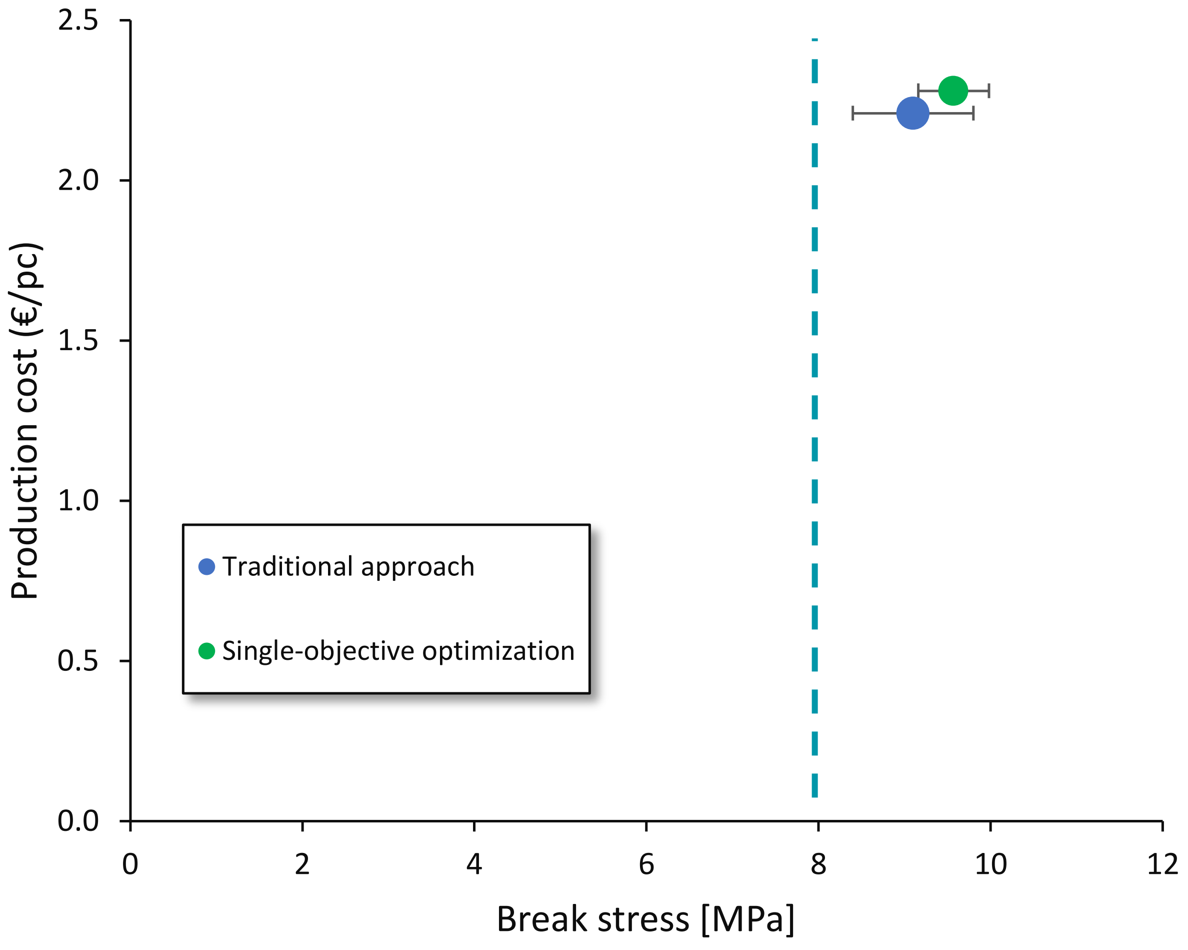
Gaussian processes

Strength test: 9 x 30 samples

Consume budget of 3000 EUR for each approach + compare both final solutions

Results

	Cleaning	Power (W)	Distance (mm)	Speed (mm/s)	Number of passes (-)	Time after plasma (min)	Break stress (Mpa)	StDev
Traditional approach	TRUE	450	10	20	4	30	9.10	8%



1) Define optimal solution with **traditional approach**
   → perform contact angle measurements
   → Select interesting points for full test cycle
   → Select only feasible solutions
2) Start with **single objective optimization**

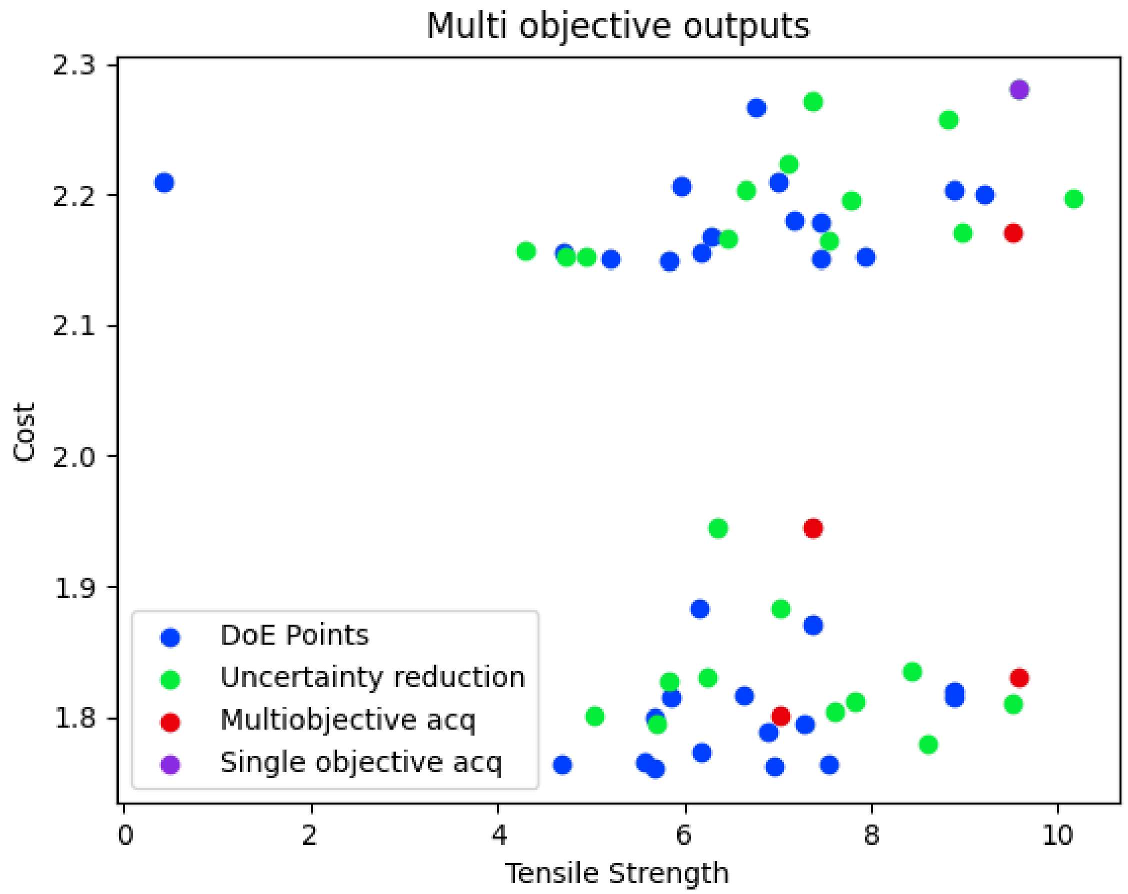
Optimization criteria: Break stress as high as possible

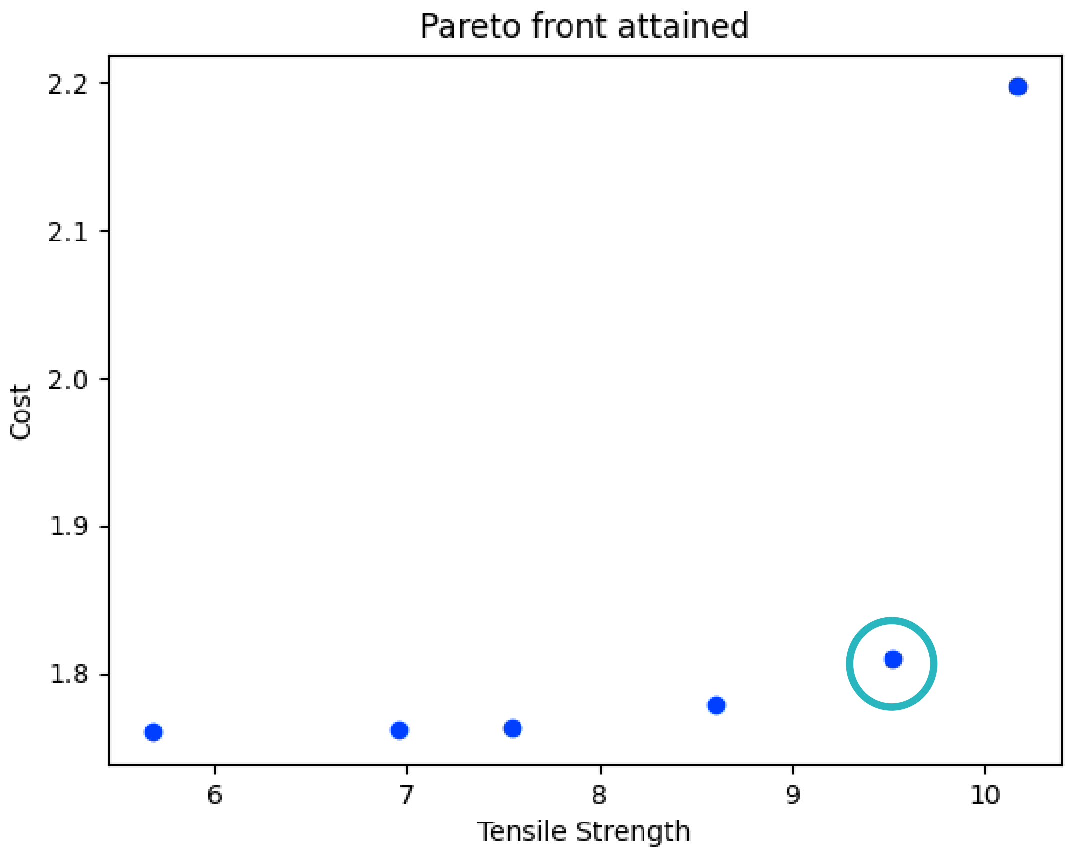
Criteria for feasible solution:

- Break stress above 8MPa
- No adhesion failure
- No visual damage due to plasma
- StDev < 15% of break stress

After initial DoE +1 single objective optimization (67% of budget used)
→ break stress + cost comparable with traditional approach
→ Can we reduce production cost further?

Results multi-objective optimization





Multi-objective optimization + uncertainty reduction for remaining budget

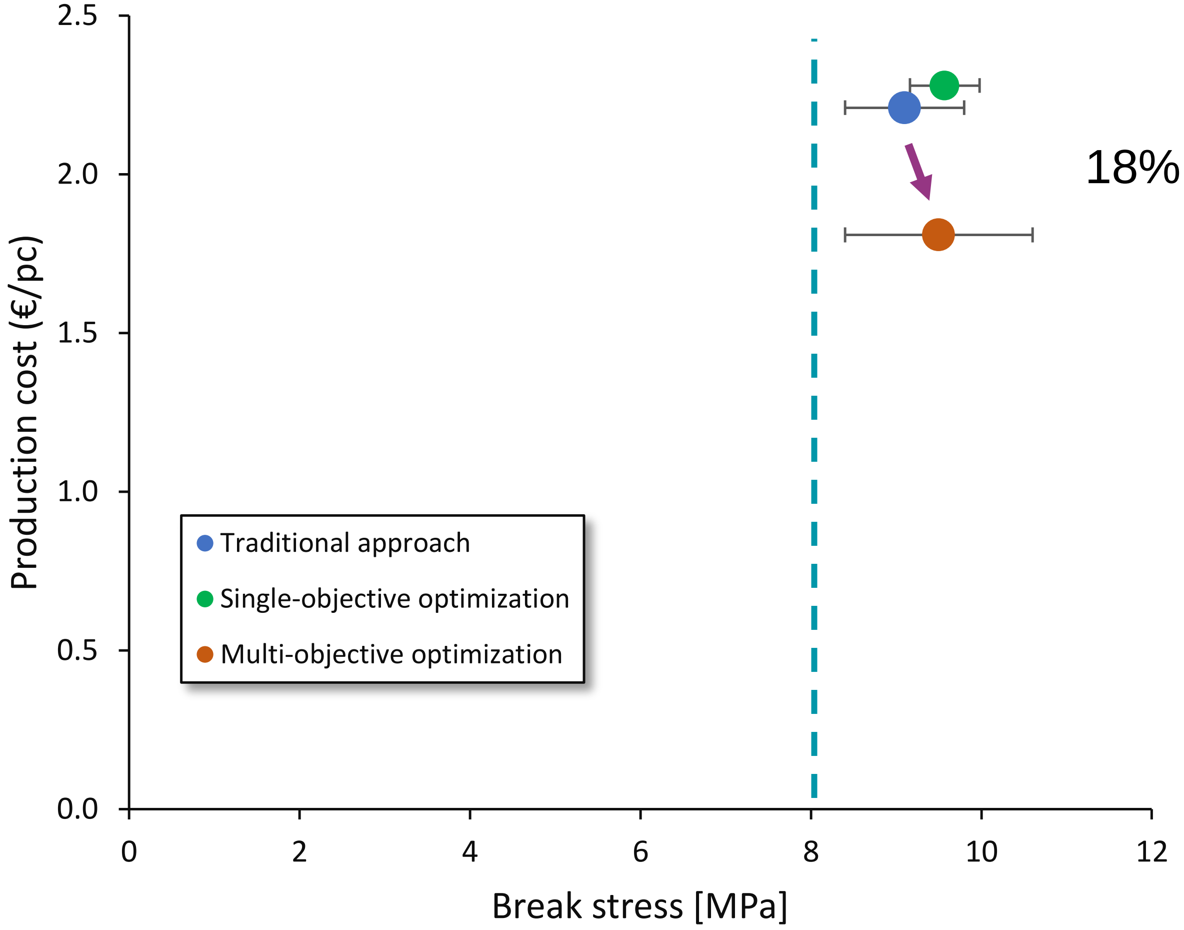
→ Pareto front attained → interesting point selected

Results

	Cleaning	Power (W)	Distance (mm)	Speed (mm/s)	Number of passes (-)	Time after plasma (min)	Break stress (Mpa)	StDev
Traditional approach	TRUE	450	10	20	4	30	9.10	8%
Single objective optimization	TRUE	330	6	115	49	64	9.57	4%
Multi-objective optimization	FALSE	340	6	60	10	10	9.52	12%

Criteria for feasible solution:

- Break stress above 8MPa
- No adhesion failure
- No visual damage due to plasma
- StDev < 15% of break stress



18% reduction in production cost

Conclusions & outline

- Use of DoE & Gaussian process models is valuable approach for optimizing adhesive bonding process parameters
- Bayesian optimization yields similar break stress as traditional approach
- 18% reduction in production cost for final solution obtained via multi-objective optimization
- Trade-off analysis interesting to define when it is no longer beneficial to search for a more optimal solution
- Extend to more process settings (>10 parameters) to cover multiple production steps which mutually influence each other

https://airesearchflanders.be/nl/index.html

Questions

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