Quality Fluctuations Simulation Method by using Multi Agent System in Large Scale Load Setting of Heat Treatment

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Agenda

- ✓ Why use Heat Treatment Simulation
- ✓ Difficulty to Simulate Fluctuation of Heat Treatment
- ✓ What is Multi Agent Simulation
- ✓ Result and Future Development

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DX in Car Manufucturing

Needs for simulation to replace experiments

Assist by CAD/CAE for drawings and strength design

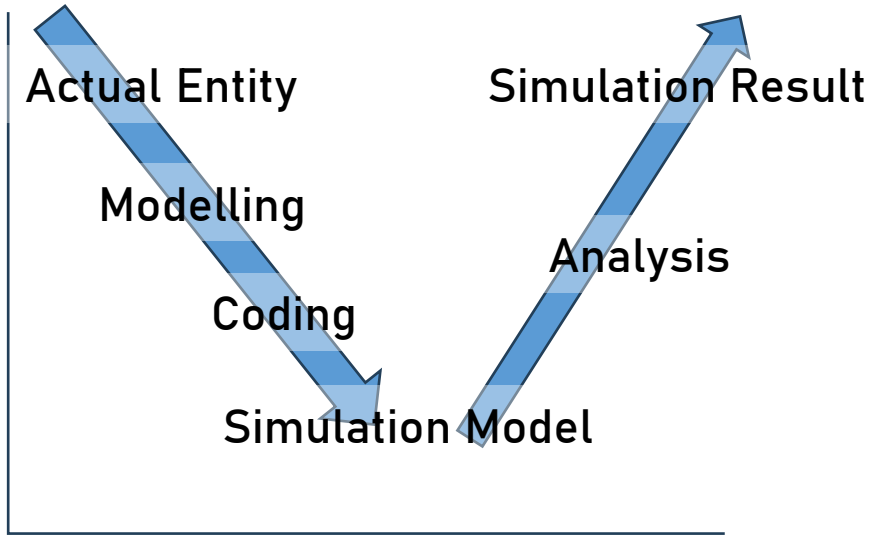
Auonomus Driving etc…

MBD (Model Based Development) is the core technology of development to thoroughly verify all risks.

Total products development is shifting to MBD (Model Based Development)

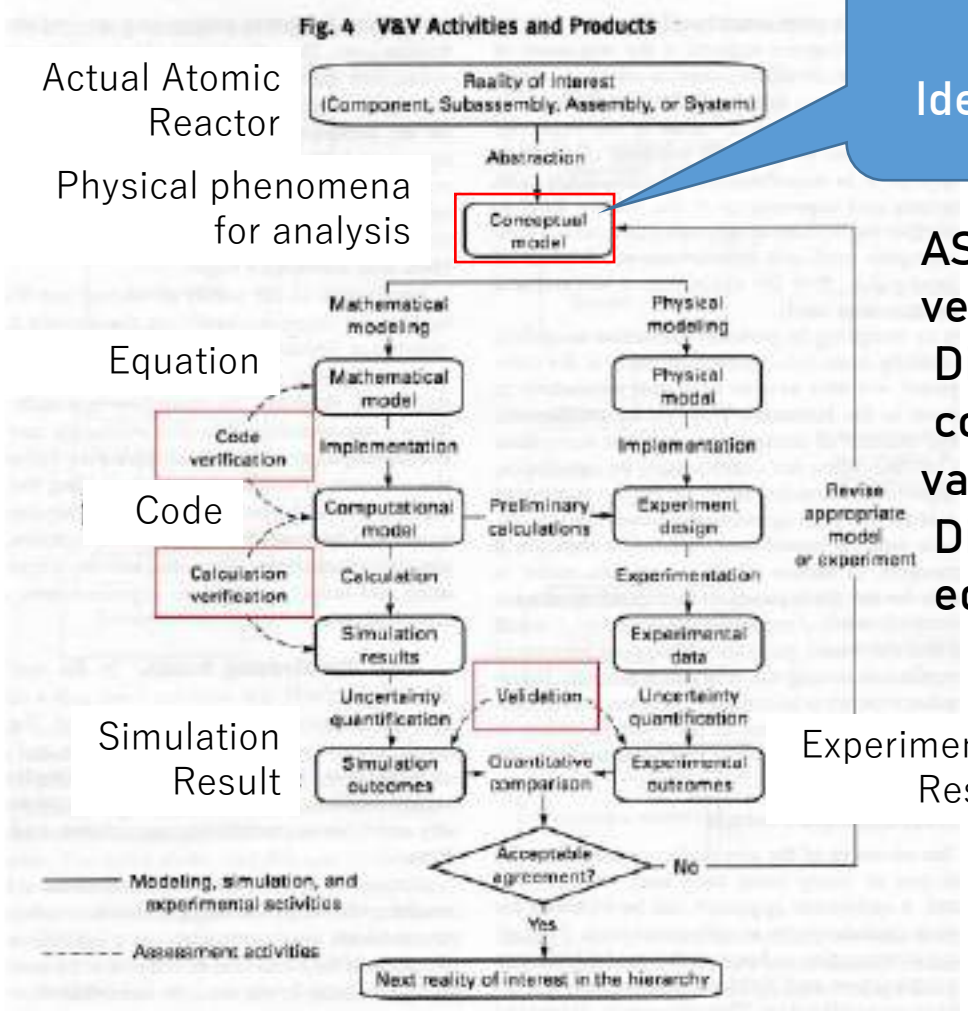
Material and Process development is needed to shift for MBD

What is MBD (Model Based Development)



Development through modelling and simulation

Model Based Development, MBD

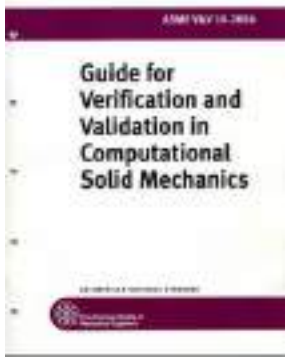


PIRT (Phenomena Identification Ranking Table)

ASME V&V 10-2006

verification:
Did you solve the equation correctly?

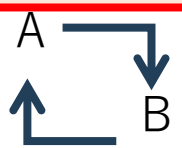
validation:
Did you solve the right equation?



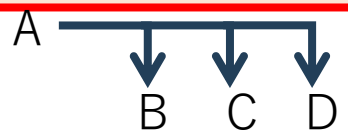
Changes in the DX environment in manufacturing

	Adjustment type (Vertical dividing of tasks)	Assembly type (Horizontal dividing of tasks)
Common sense in Manufucturing	Optimization for Overall Product (Adding Culture, Mutual Complementation)	Combination of Standarized Modules (Multiplication culture, Single Defect is System Defect)
For Designer	Commu… Achieve… Perform…	…rocess is decided in
For Production Engineer	Coordin… Flexibili…	
Company Culture	Inter department negotiation	Achievement with outside world
Marketing	Technology driven, Hardware driven	Software driven, Maret driven

Performance contract-based manufacturing
→ Simulation and Prediction



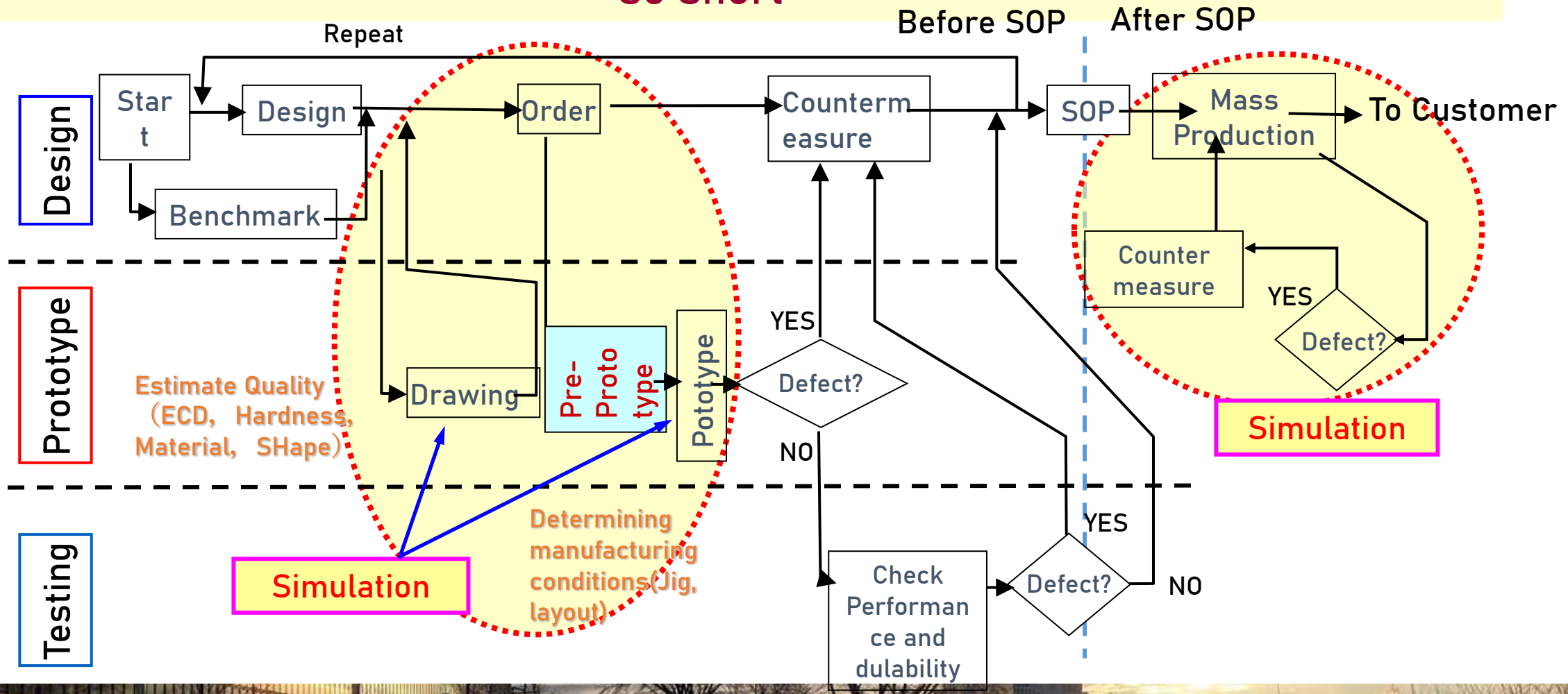
Negotiation



Contract

How to use the simulation

Simulations are used before and after SOP, the time to respond to requests is so short



✓ The simulation that contain complex phenomena include interactions between processes and jig layouts of mass production with short solving time are required.

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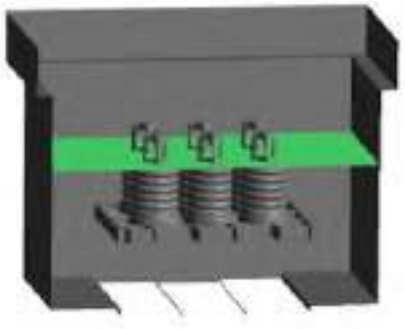
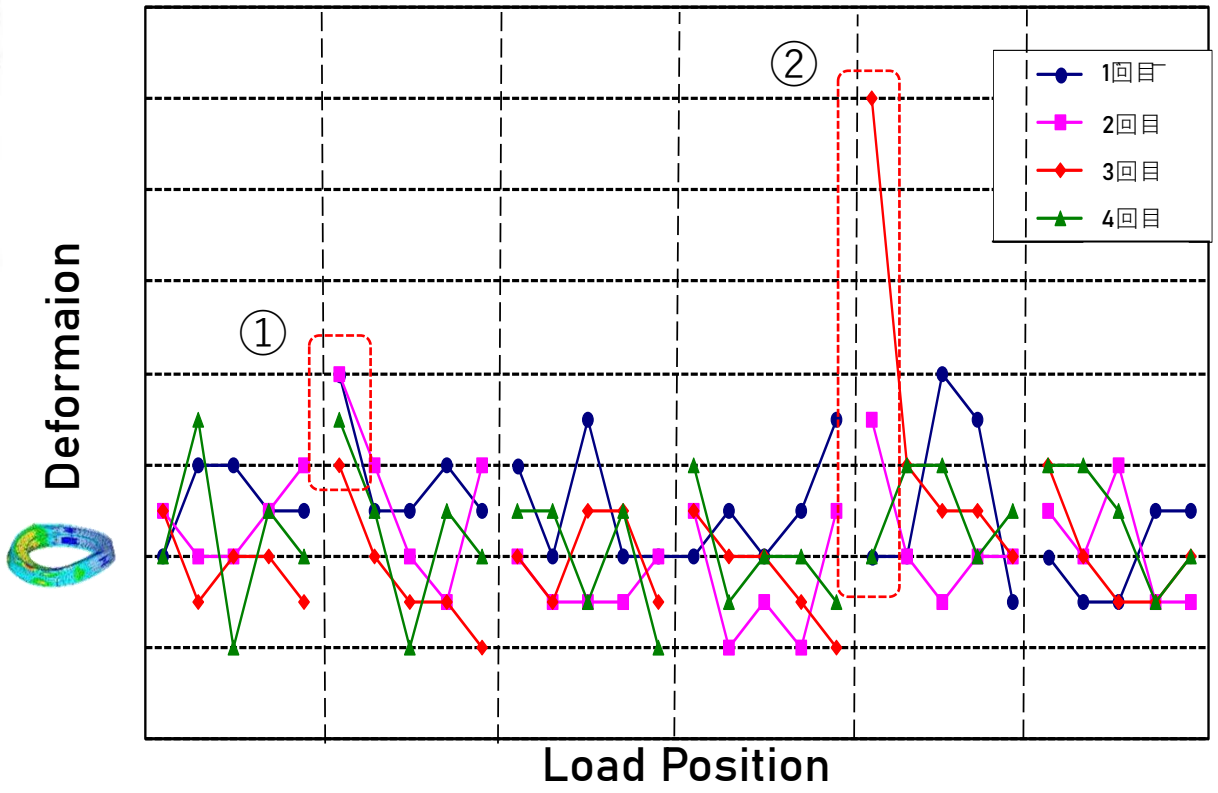
Heat Treatment Deformation Fluctuation in Actual Process



Mass Production

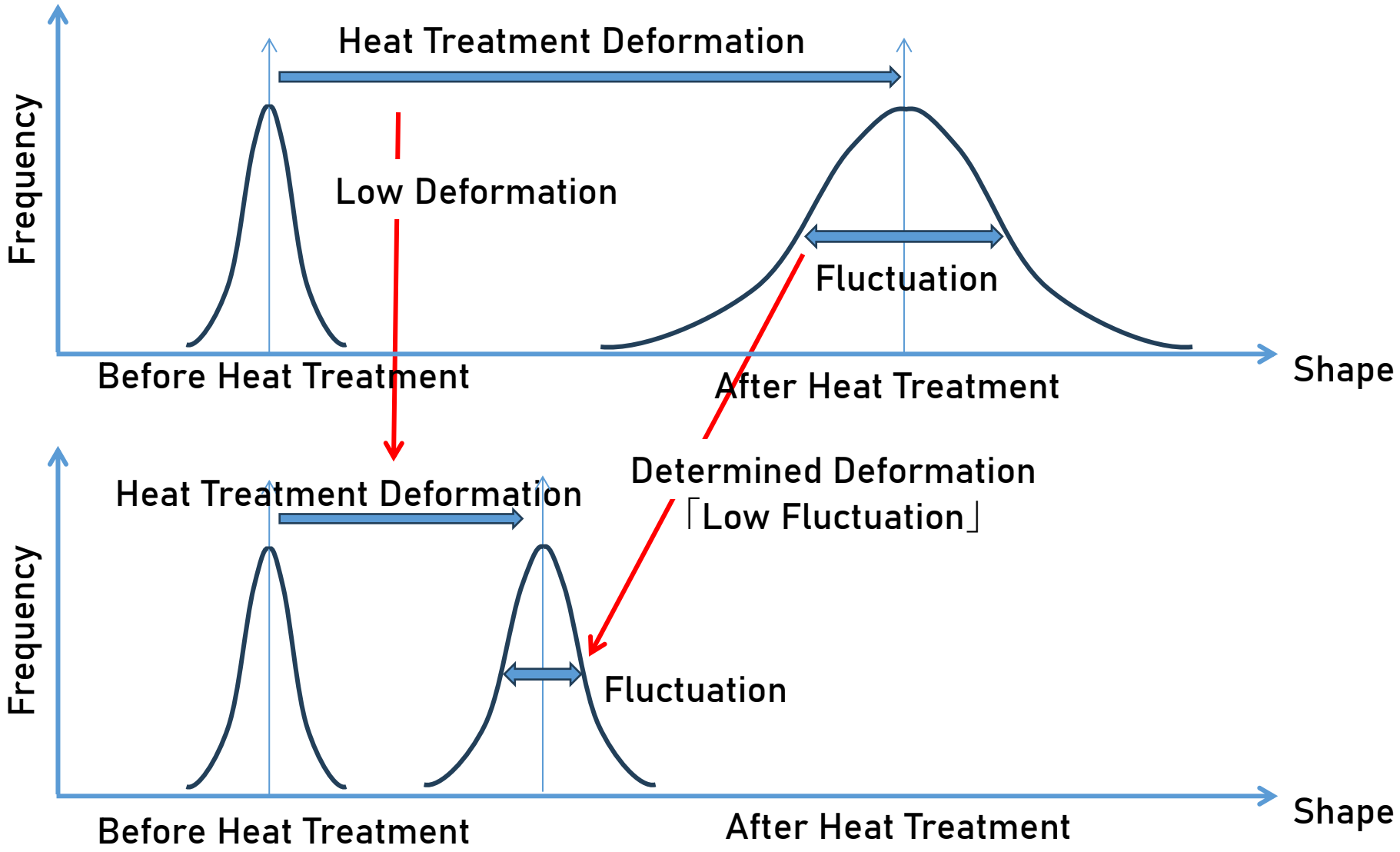


Change of Heat Treatment Deformation in Actual Process

① Constantly Large Deformation

② Large Fluctuation

Occurrence of Fluctuation in Heat Treatment Deformation



Purpose of this research

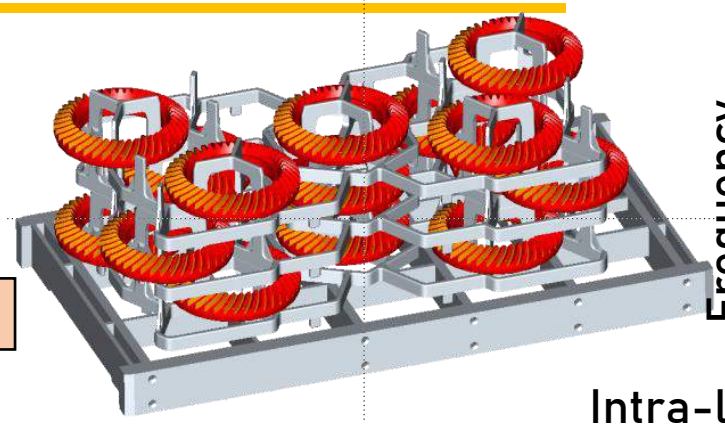
How can heat treatment simulation be made more widely applicable?

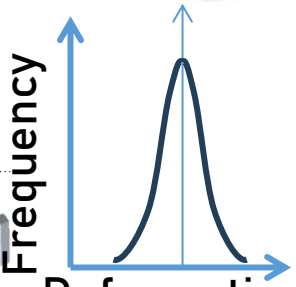
- Easy to use. Simulation model preparation:
  Heat treatment contractors ⇔ Designers
  ⇔ End users Materials and coolant database

- Fluctuation must be addressed.

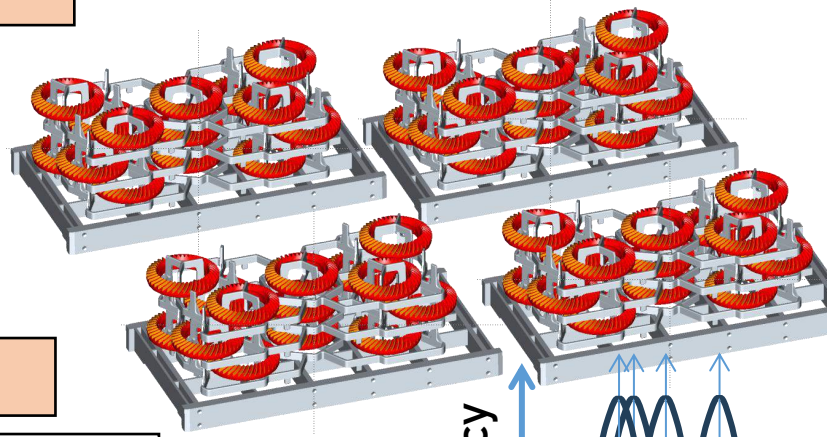
Why does Fluctuation Occur?

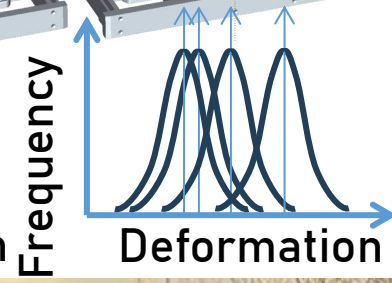
- **Fluctuation of Heat Treatment Deformation**
  - Design
    - Shape
  - Material
    - Segmentation
    - Materila Fluctuation
    - Contents
  - Cutting
    - Residual Stress, Metal Structure
    - Roughness
  - Carburizing
    - Carburizing depth Fluctuation
    - Surfase c% Fluctuation
  - Quenching
    - Oil Temperature Fluctuation
    - Quenching Temperature Fluctation
    - Coolig Speed Fluctuation





Intra-lot Fluctuation

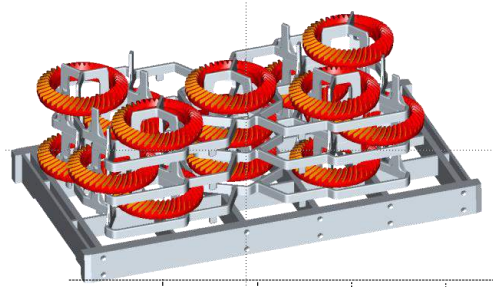


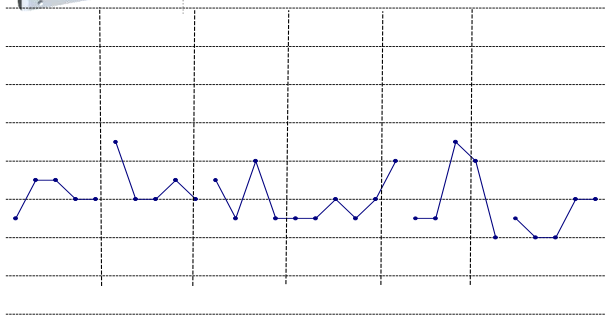


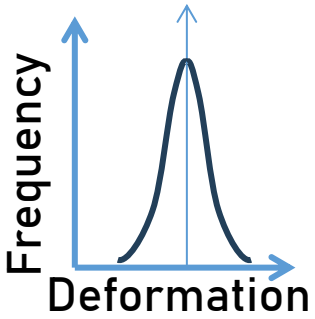
Inter-Lot Fluctuation

Important Factor

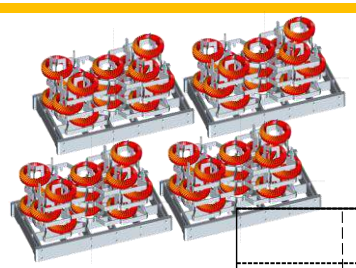
Two type Fluctuations

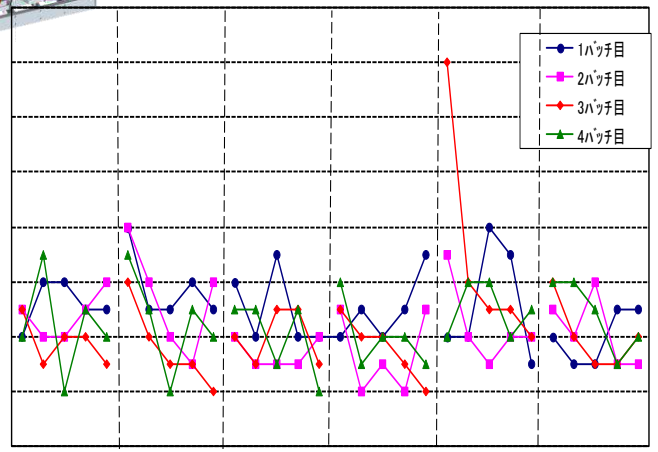


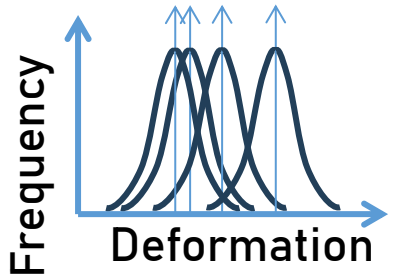




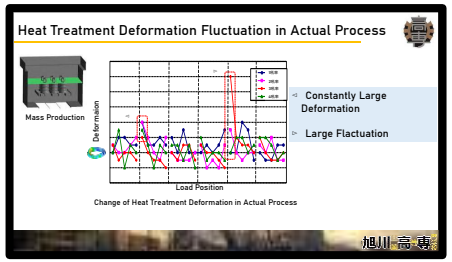
Intra-lot Fluctuation (Space Dependent Fluctuation)



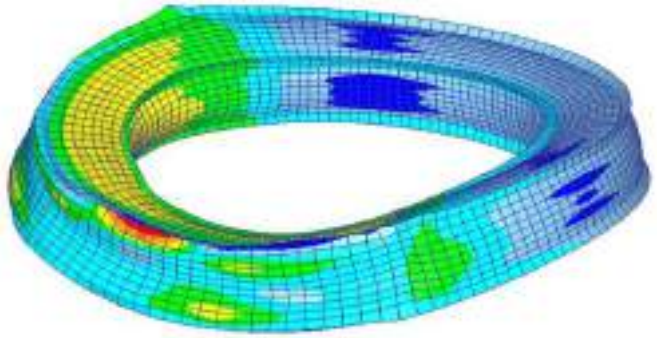




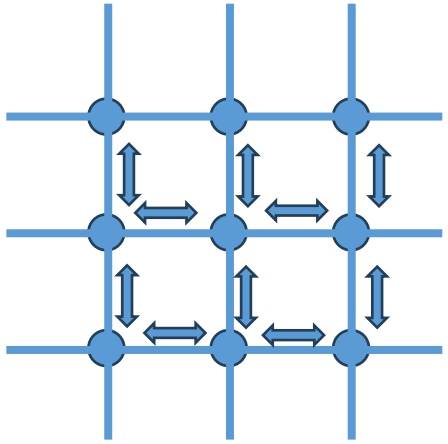
Inter-lot Fluctuation (Time Dependent Fluctuation)

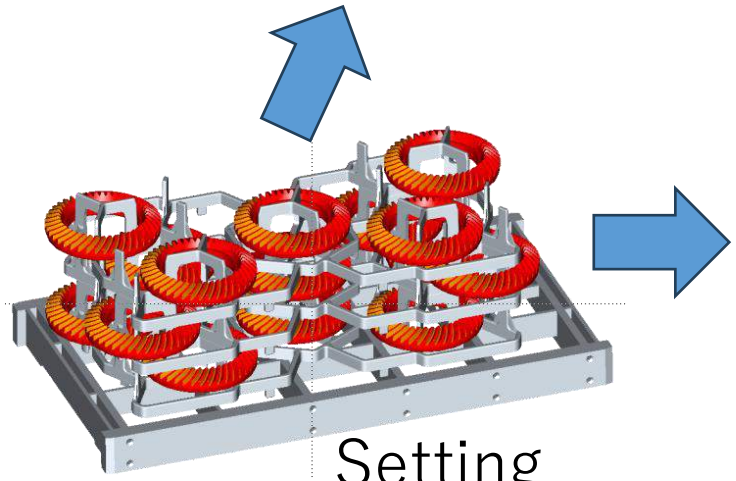


Computational Load to Calculate Fluctuations in FEM

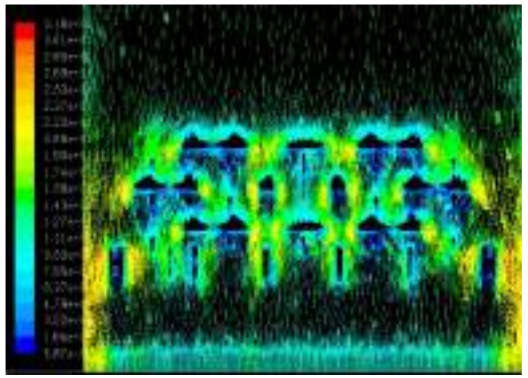


Inside Phenomena





Setting



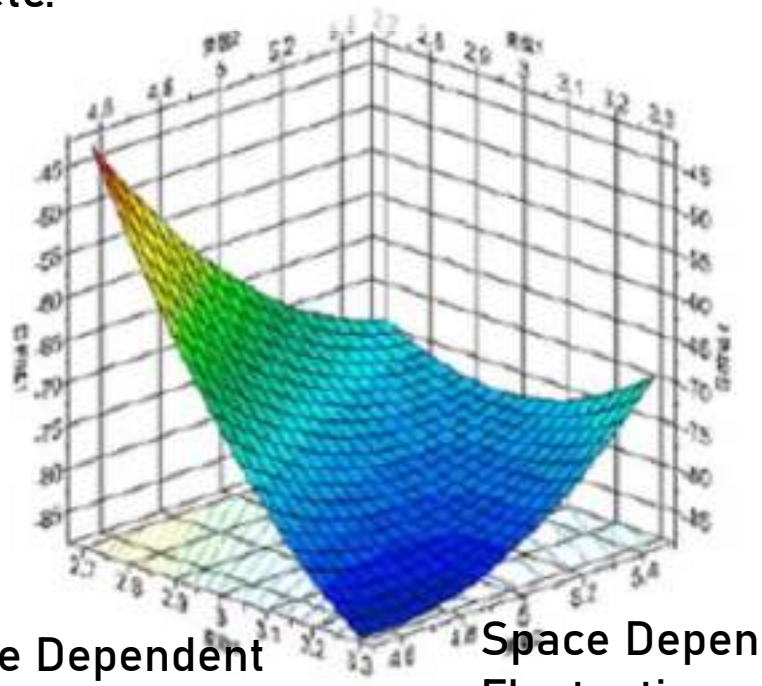
Outside Phenomena

The computational load is proportional to the cube of the analysis size

Fluctuation simulation by FEM is Difficult

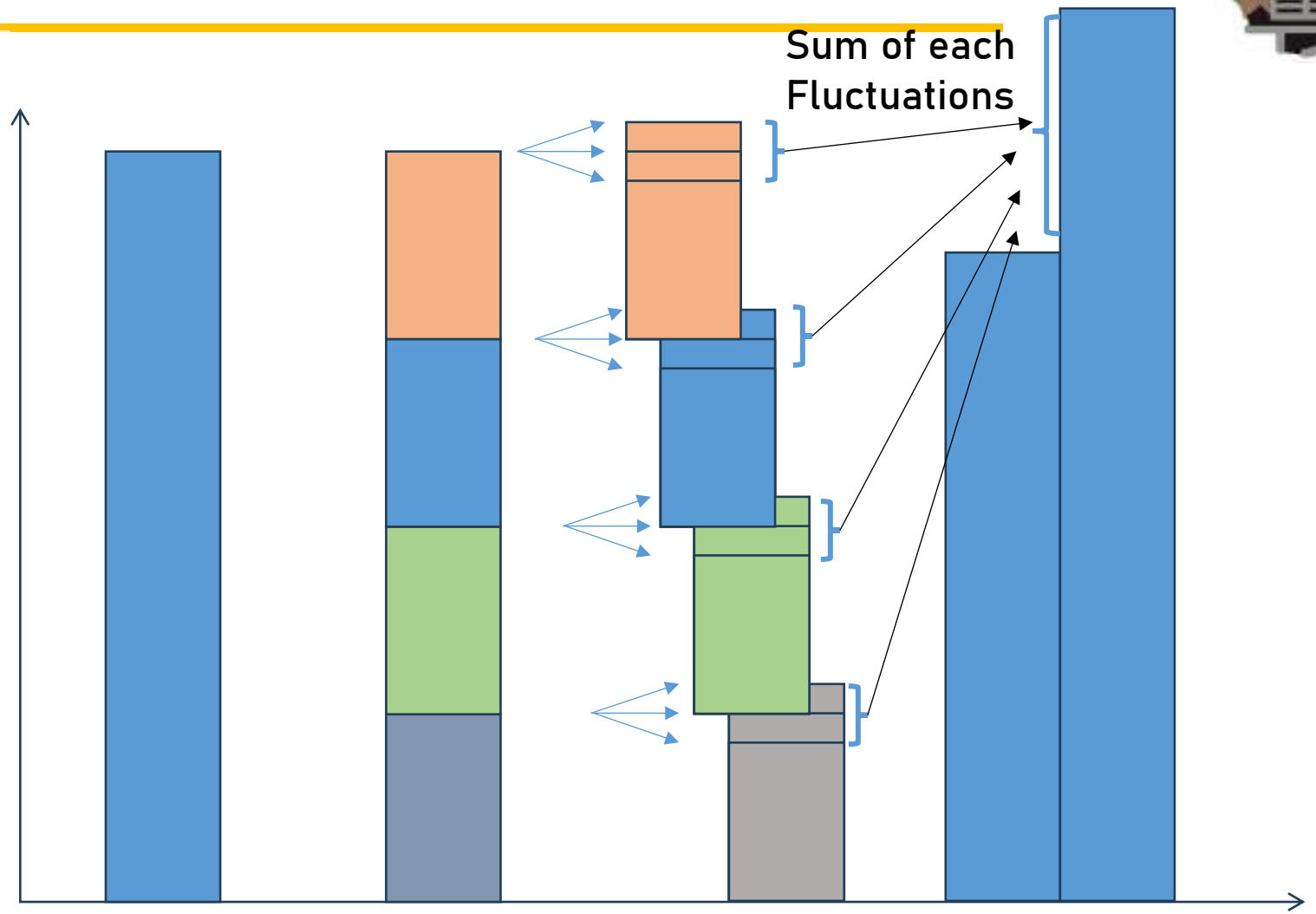
Calculation Method for Fluctuations

- ✓ Accumulate variation for each factor at each process.
- ✓ Monte Carlo simulation method and the system moment method.
- ✓ At each process, materials, process conditions, pre-processing conditions, etc.



Time Dependent Fluctuation

Space Dependent Fluctuation



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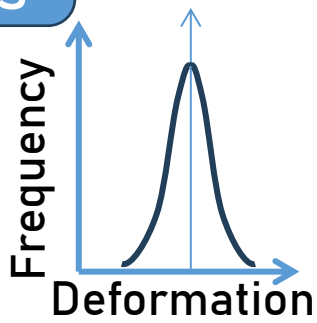
Quality calculation using multi-agents simulation

conditions

Multi-agent simulation is a method for investigating **crowd behaviour**

Local Interrelationships

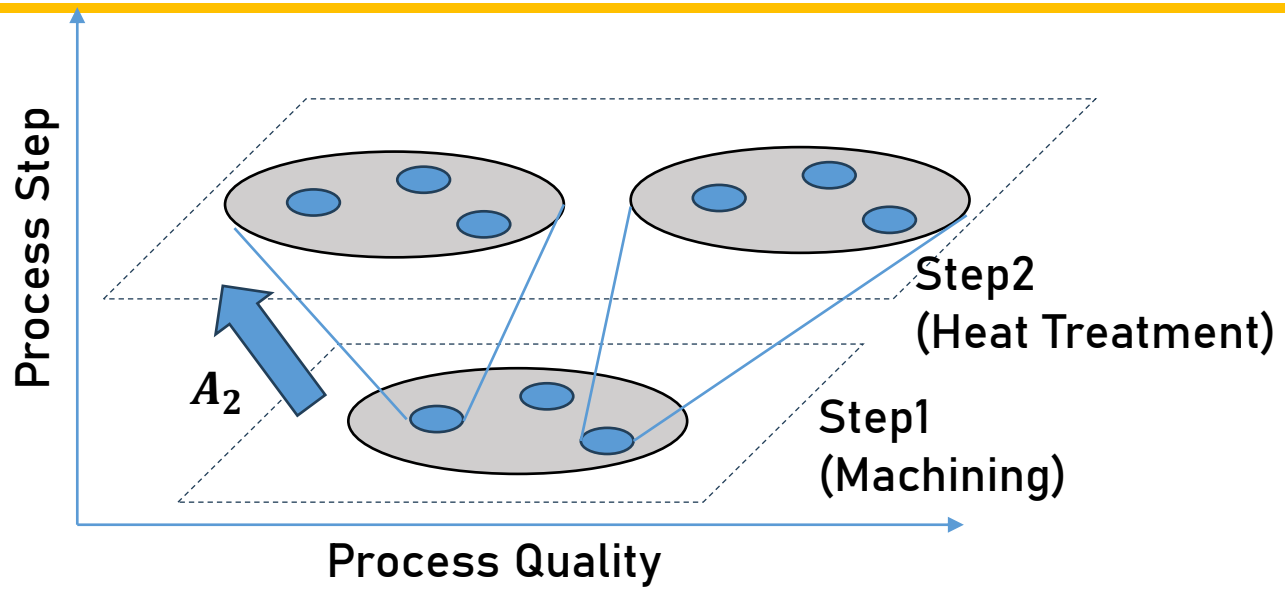
Spontaneous Movement



People → Work Piece

Crowd behavior →Quality Distribution

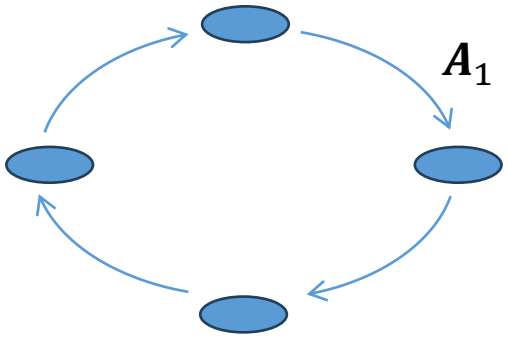
Hierarchical Multi-agent Systems in Multiple Process



$$\dot{x} = (P - I)x \quad (1)$$

The $P - I$ dealing with the cycles within a process is defined as A_1. Similarly, the matrix solving for the dynamics between processes is A_2 and can be expressed as in Eq. (2).

$$A_2 = \begin{pmatrix} A_1 - I & \Delta & 0 \\ 0 & A_1 - I & \Delta \\ \Delta & 0 & A_1 - I \end{pmatrix} \quad (2)$$



When defined as above, a multi-agent that crosses processes when it repeats a process and reaches process l can be defined as in Eq.(3), where Δ is the 'connection matrix' that interconnects the processes. where Δ is the 'connection matrix' interconnecting the processes.

$$A_l = \mathbf{diag}(A_{l-1} - I) + P \otimes \Delta \quad (3)$$

Quality calculation using multi-agents simulation

$$A_2 = \begin{pmatrix} A_1 - I & \Delta & 0 \\ 0 & A_1 - I & \Delta \\ \Delta & 0 & A_1 - I \end{pmatrix}$$

Effect of Pre-Process

Change

No Change

Parts No.

Properties

$$\begin{pmatrix} x_{11} & x_{i+1j} & \cdots & x_{i1} \\ & & & \\ x_{1j} & & & x_{ij} \end{pmatrix} = \begin{pmatrix} a_{11} & \cdots & a_{i1} \\ \vdots & \ddots & \vdots \\ a_{1j} & \cdots & a_{ij} \end{pmatrix} \left(\right) + \left(\right)$$

Process No. N+1

Connection Matric
Process N to N+1

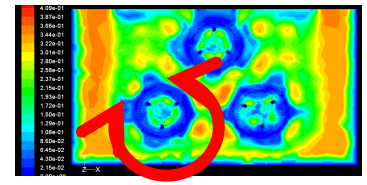
Process No. N

Rocking Parameter

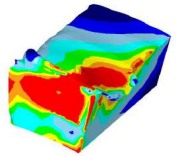
Anisotropic Boundary Conditions

$$a_{ij} = r_{ij}(\cos\theta + i\sin\theta)$$

CFD Result



Process Simulation



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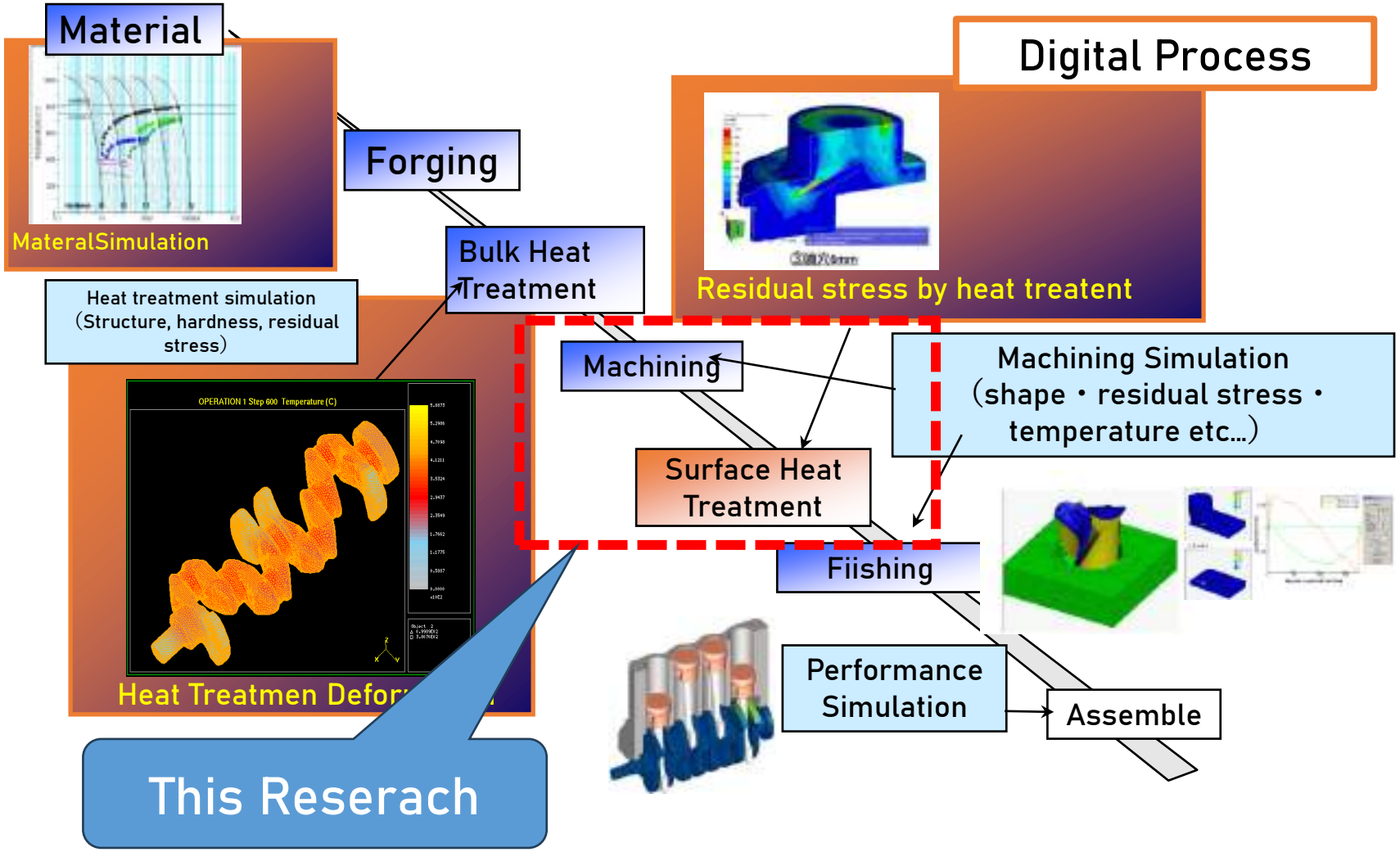
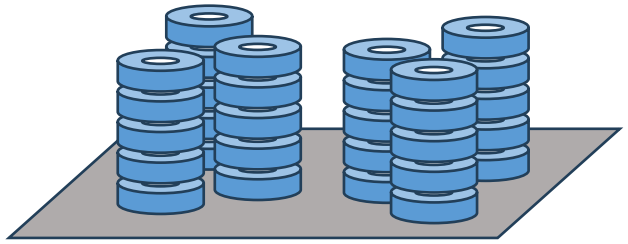
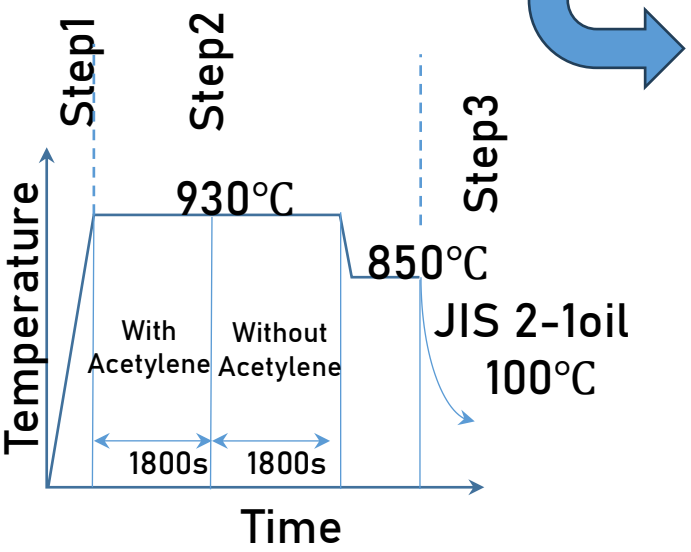
Process Through Simulation

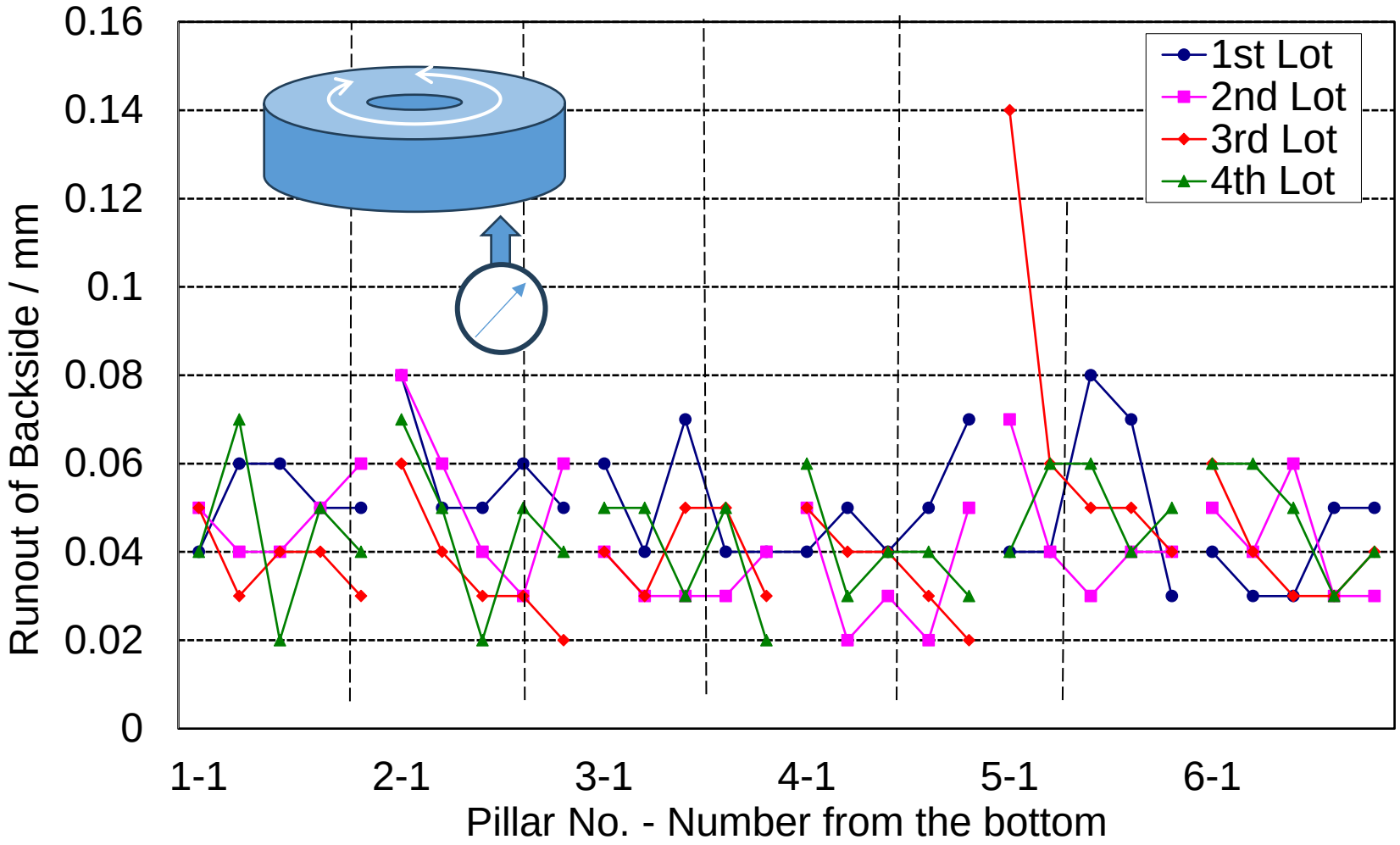


Result of Actual Experiment

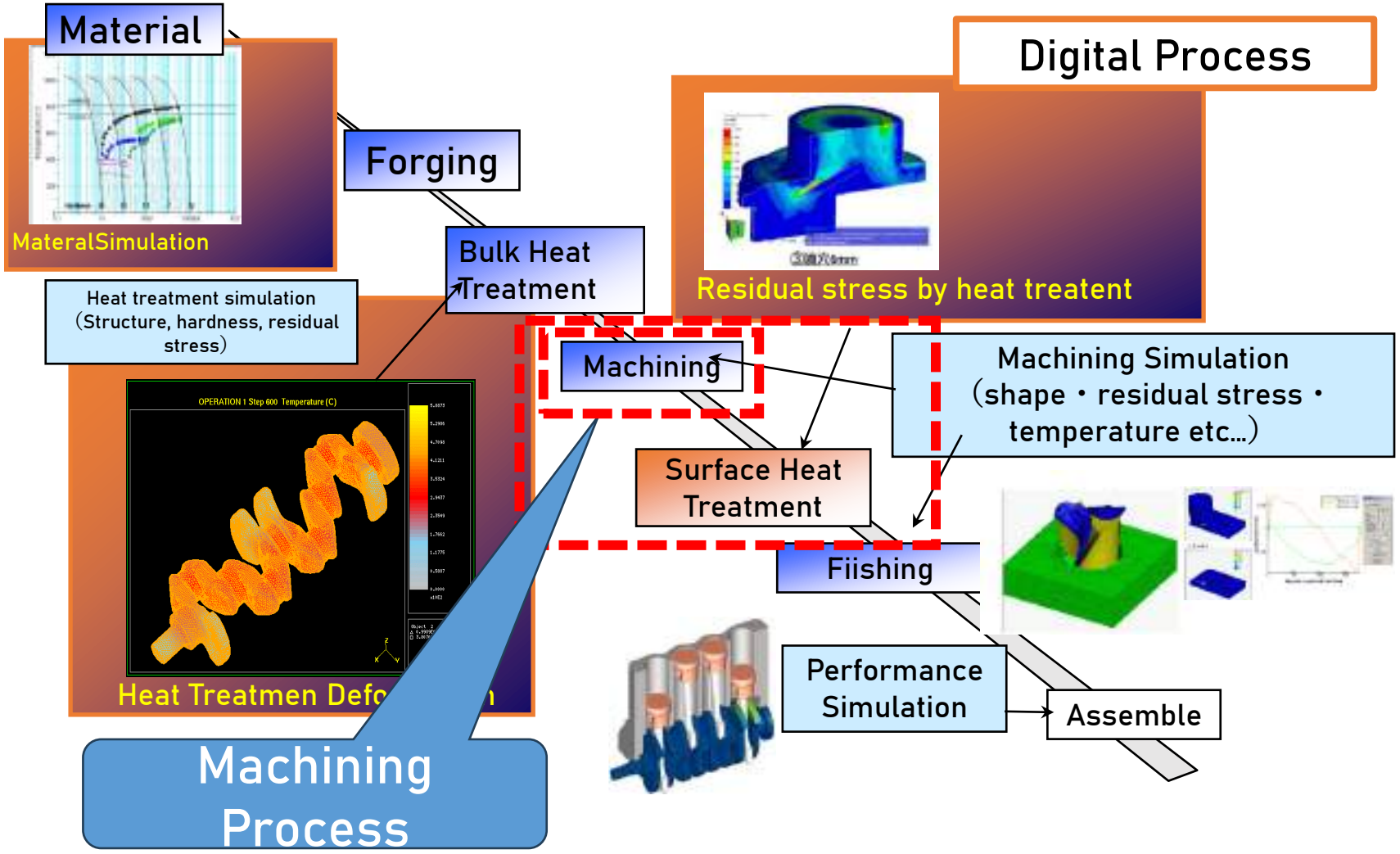


Φ180mm-100(ID) x t=50mm
space 10mm

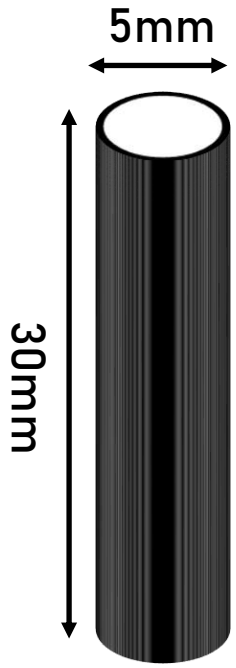




Process Through Simulation



Check the Effect of Machining



JIS SCM420H

Raw Material

↓

Machining as Left Figure

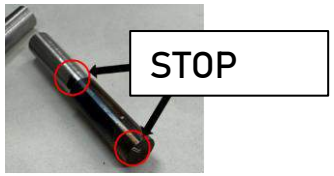
↓

Stress relief annealing
(600deg.C 1hour > FC)

↓

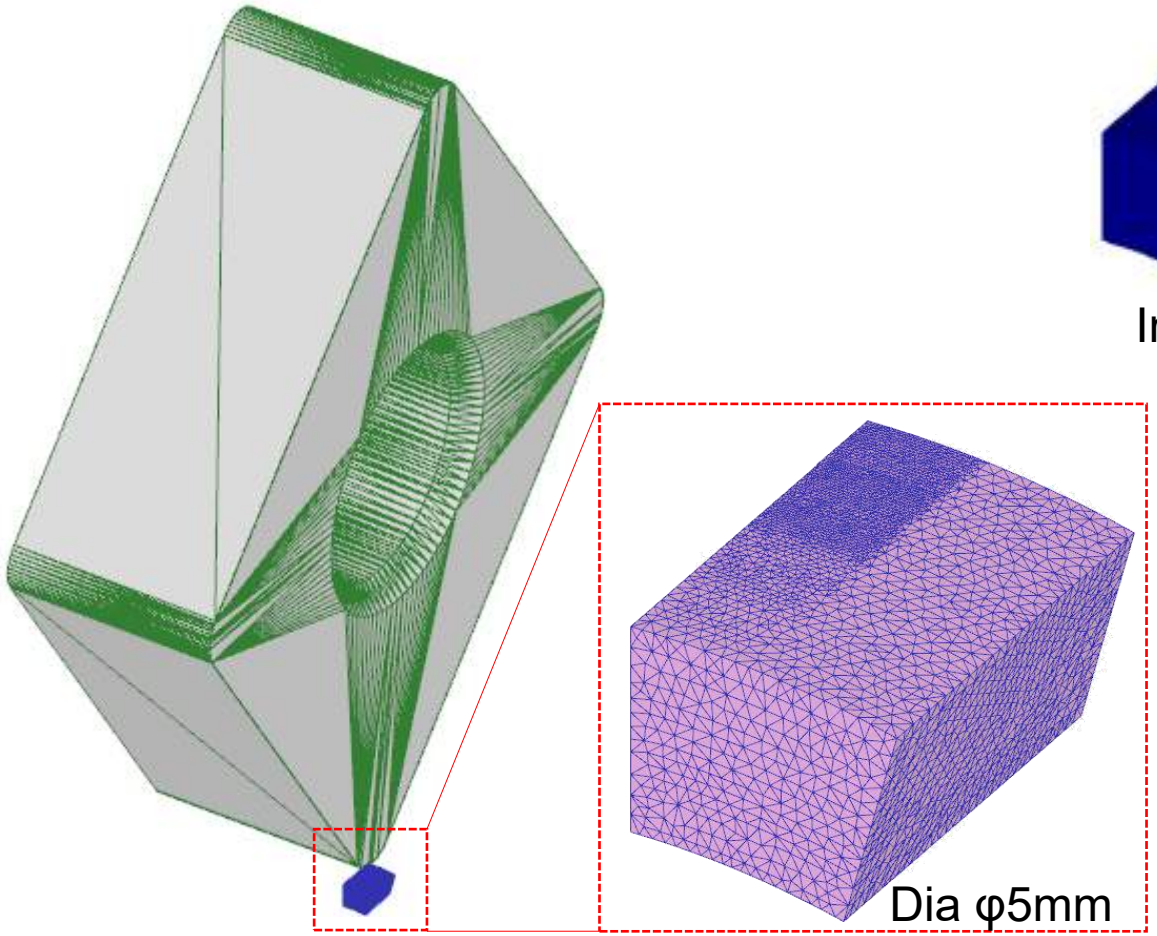
Machining is performed
halfway and stopped halfway.

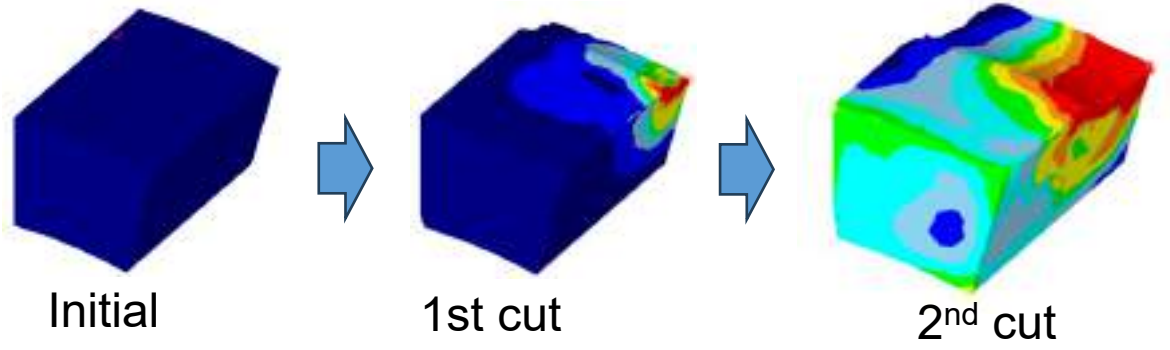
↓

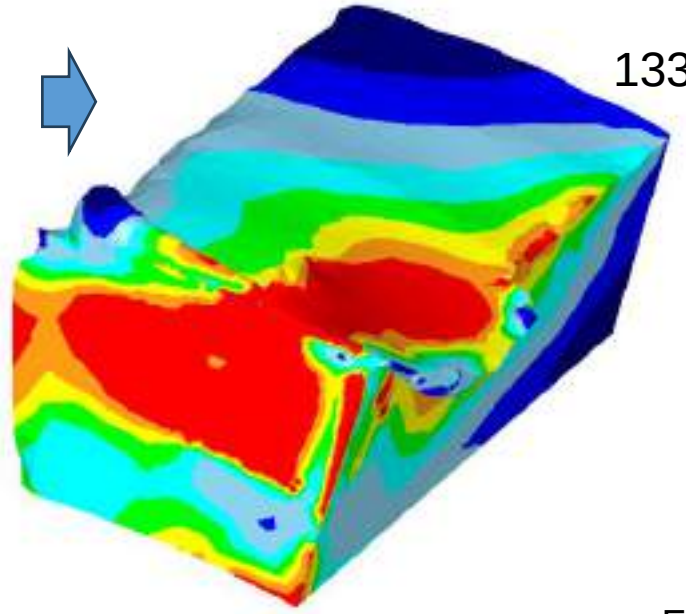


Measure

Machining Simulation



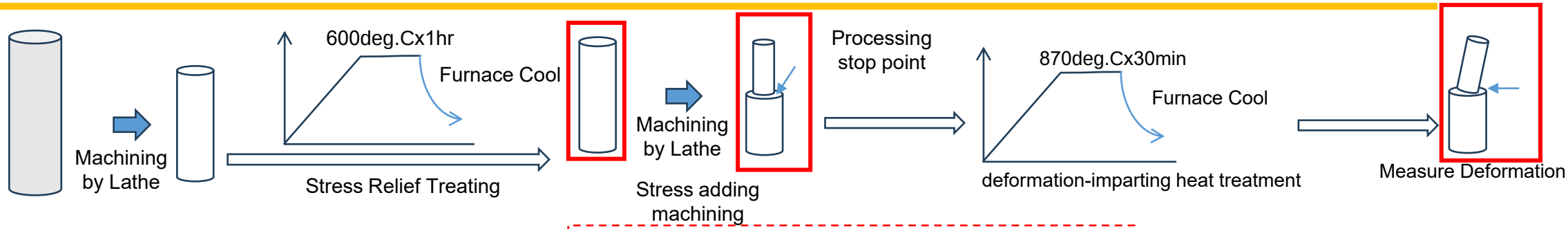


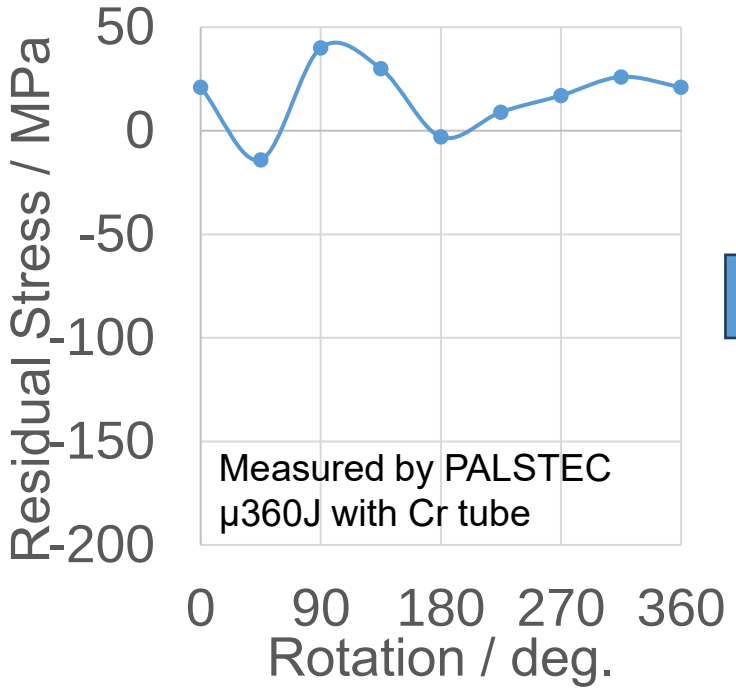


Stress of 1330 MPa was applied by repeated machining by lathe

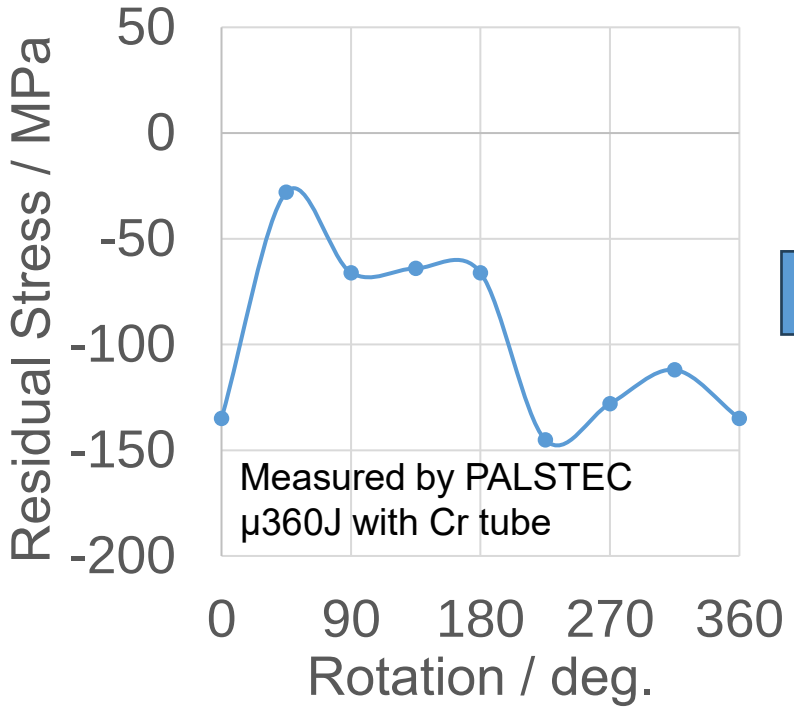
DEFORM Ver 14.0
Material JIS SCM420HC
Elements 55330, Nodes 12228(Adaptive)

Effects of Residual Stress of Machining through Experiments

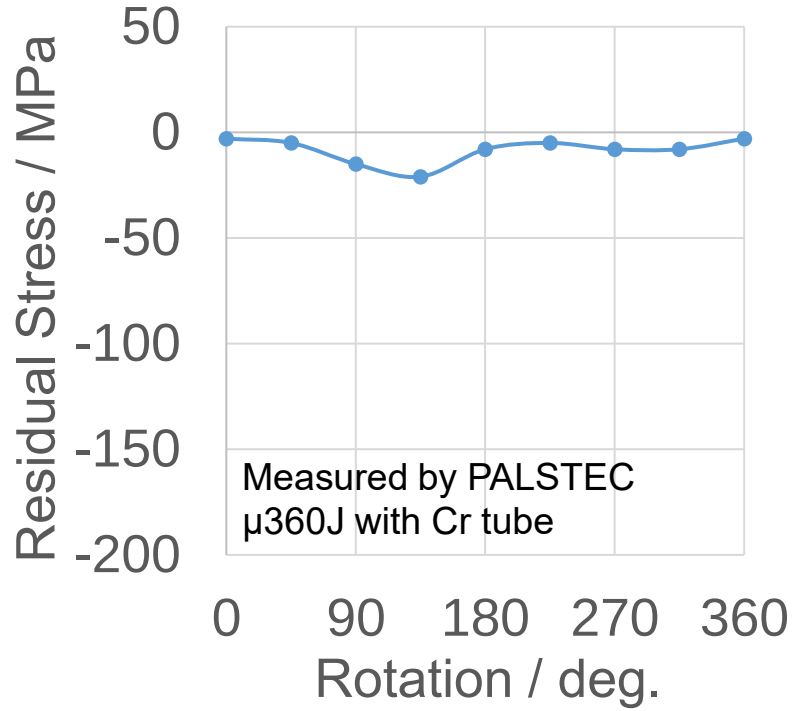




As Stress Relief

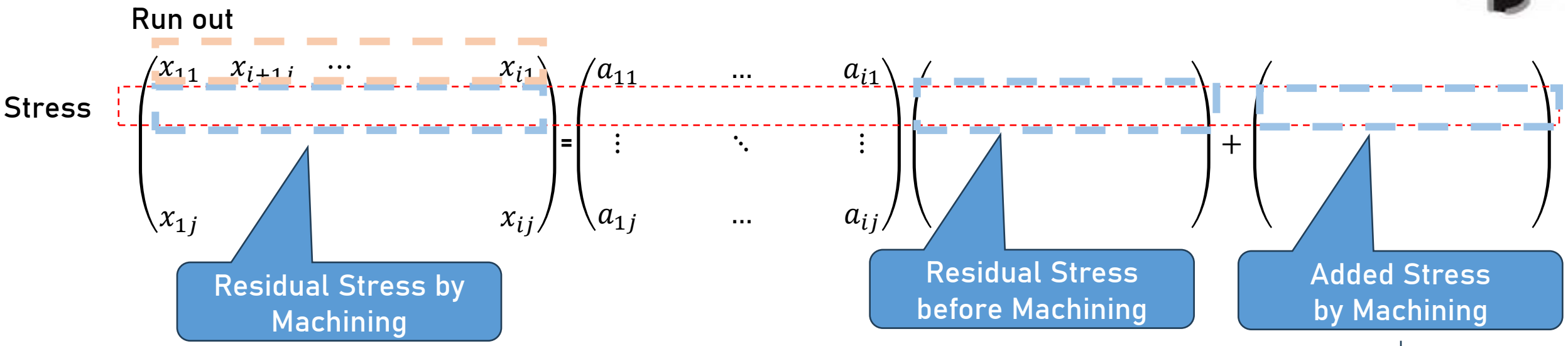


As Stress Adding Machining



As deformation-imparting heat treatment

Calculation of Adding of Machining Stress

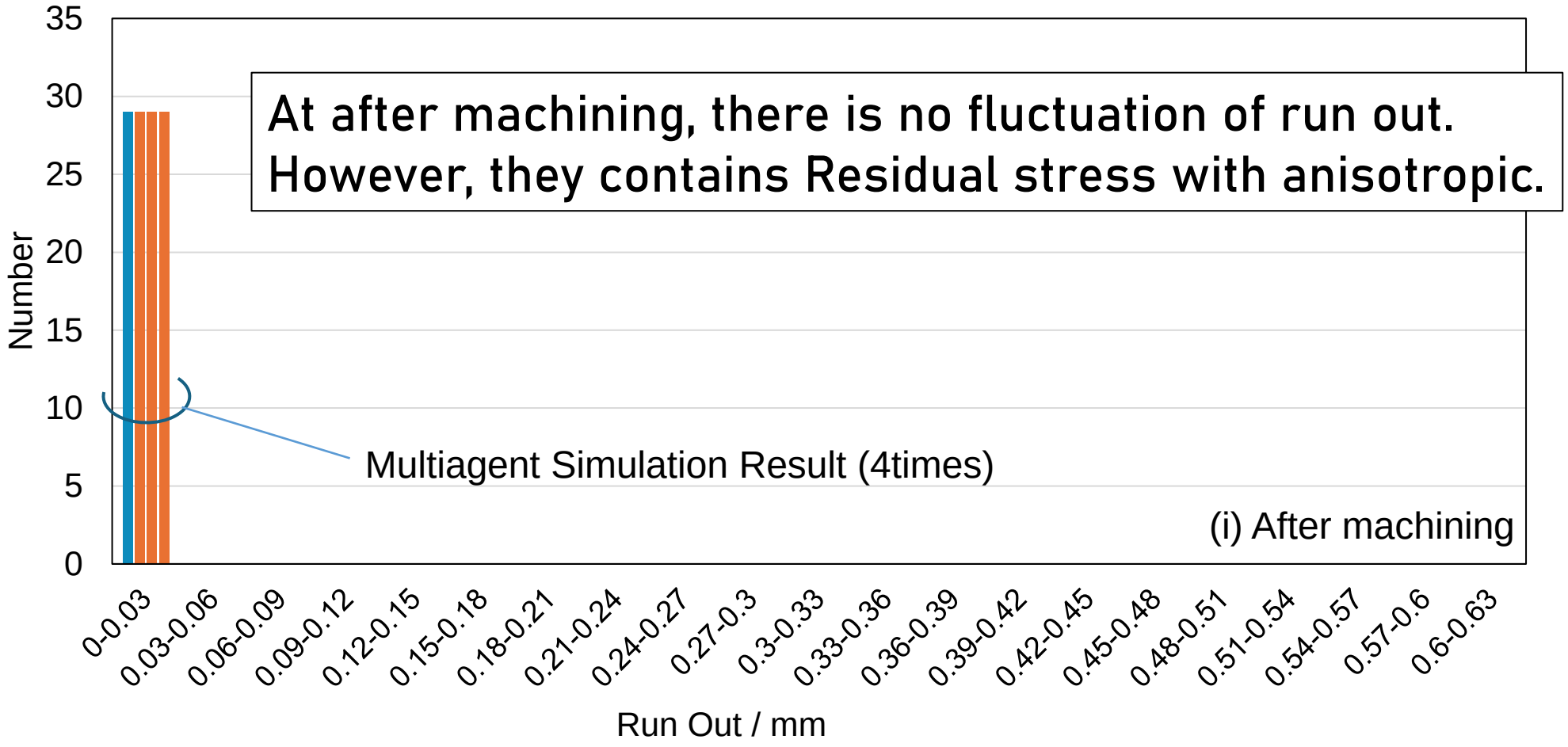


$$a_{ij} = r_{ij}(\cos\theta + i\sin\theta)$$

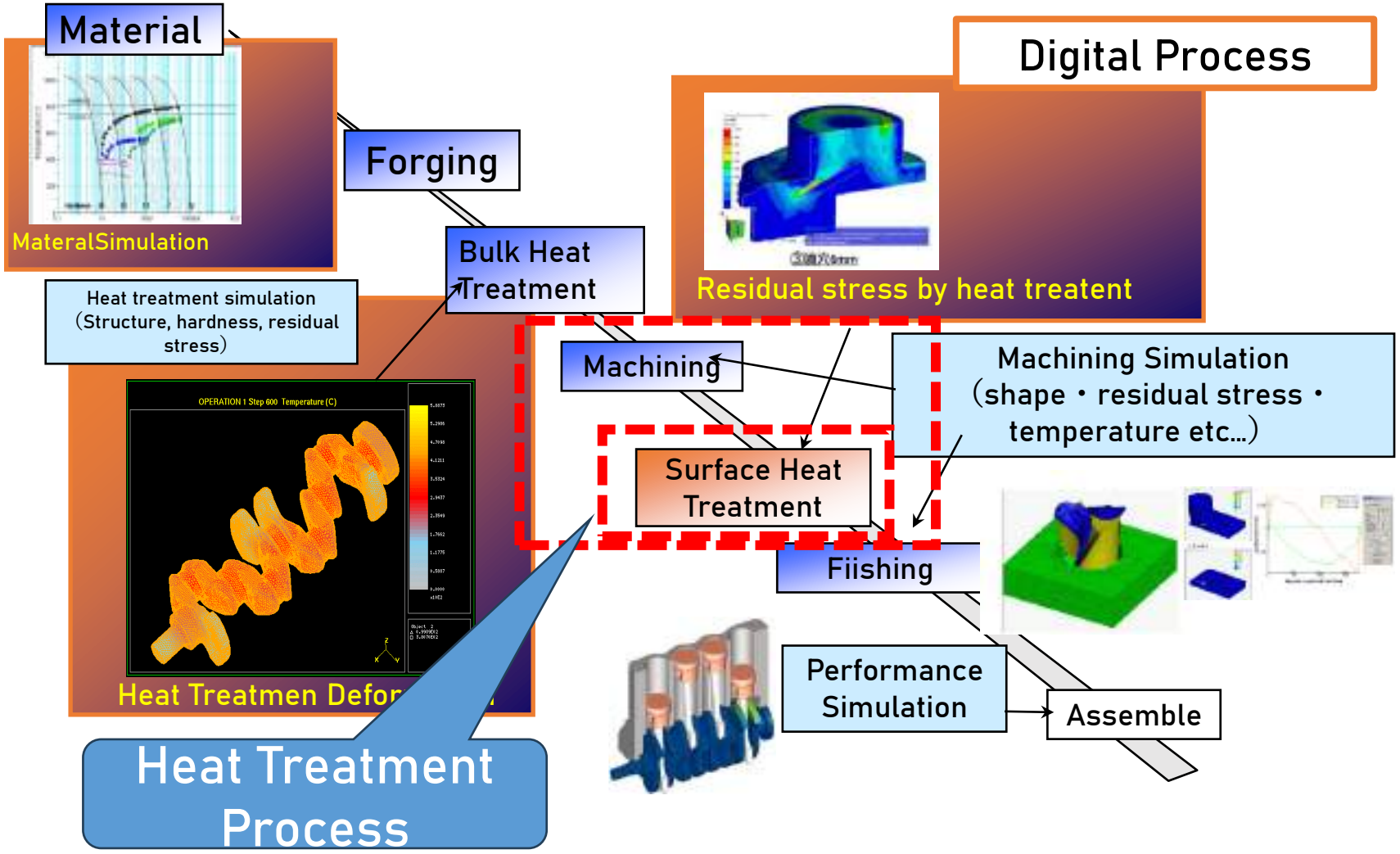
r_{ij} -150MPa(Effective)

θ random (Set direction is not defined in Process)

Run out after Machining

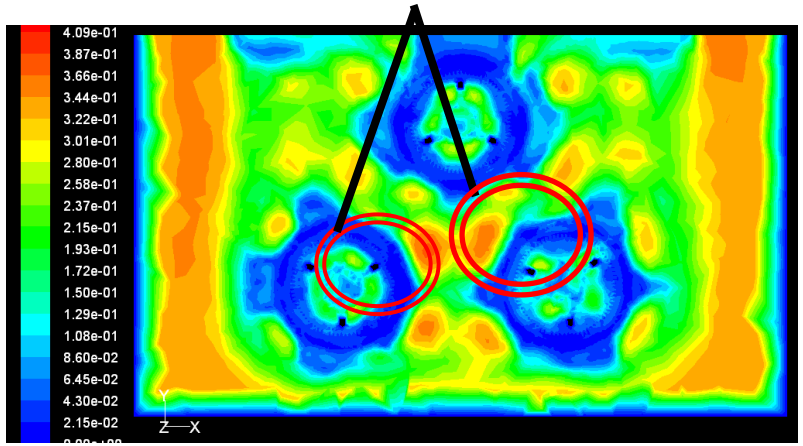


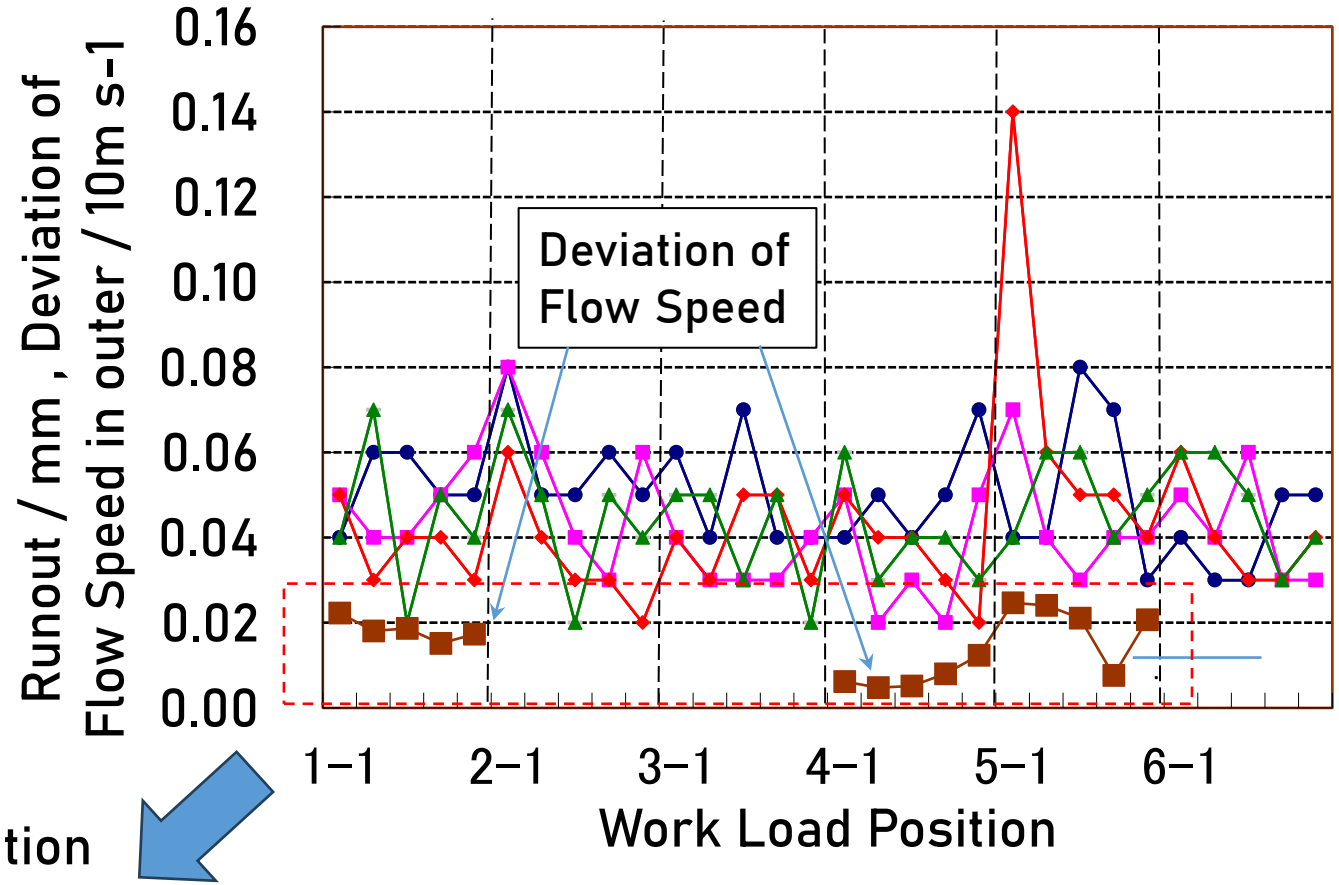
Process Through Simulation



Cooling Anisotoropy in Actual Setting

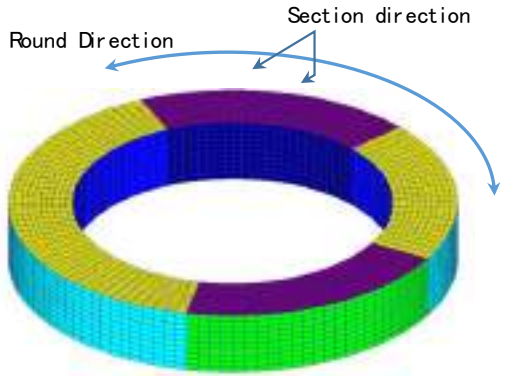
Areas with large velocity gradients
(spatial derivative of flow velocity)





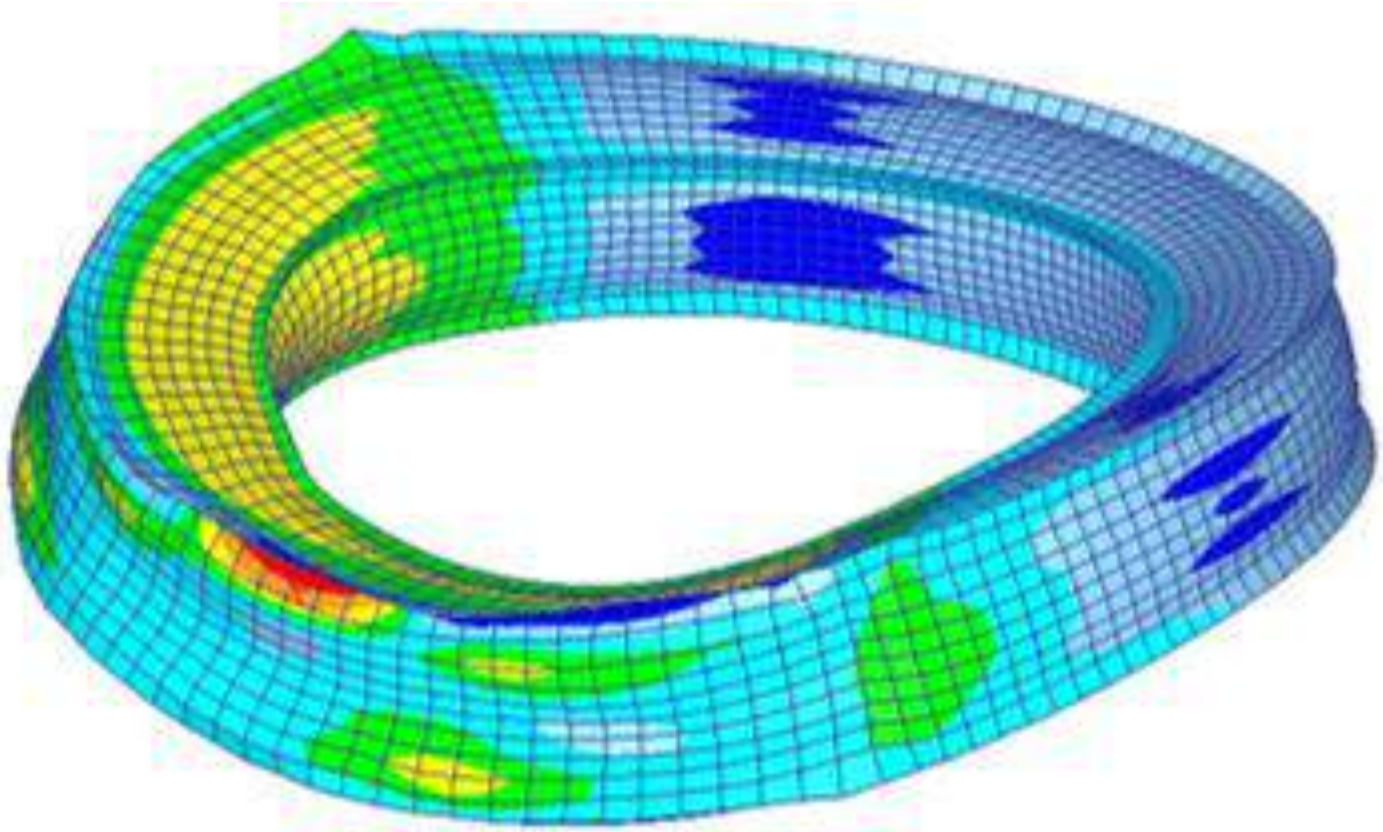
Able to calculate correlation between Flow speed & runout

Deformation Calculation Result with Anisotropic Cooling



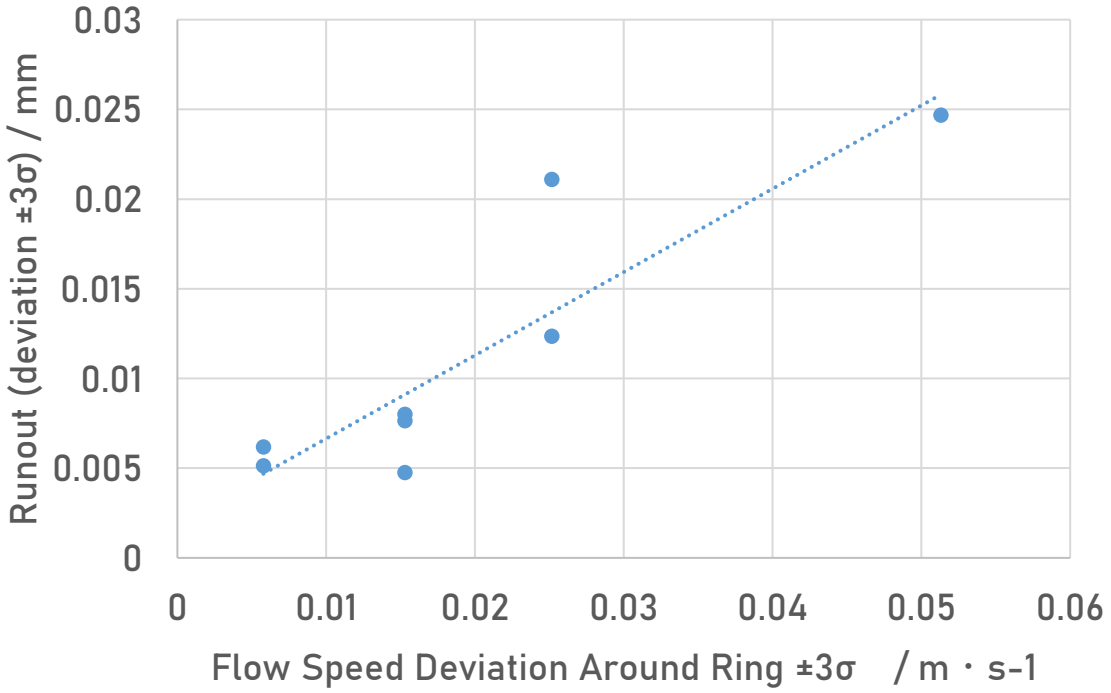
Calculation Condition

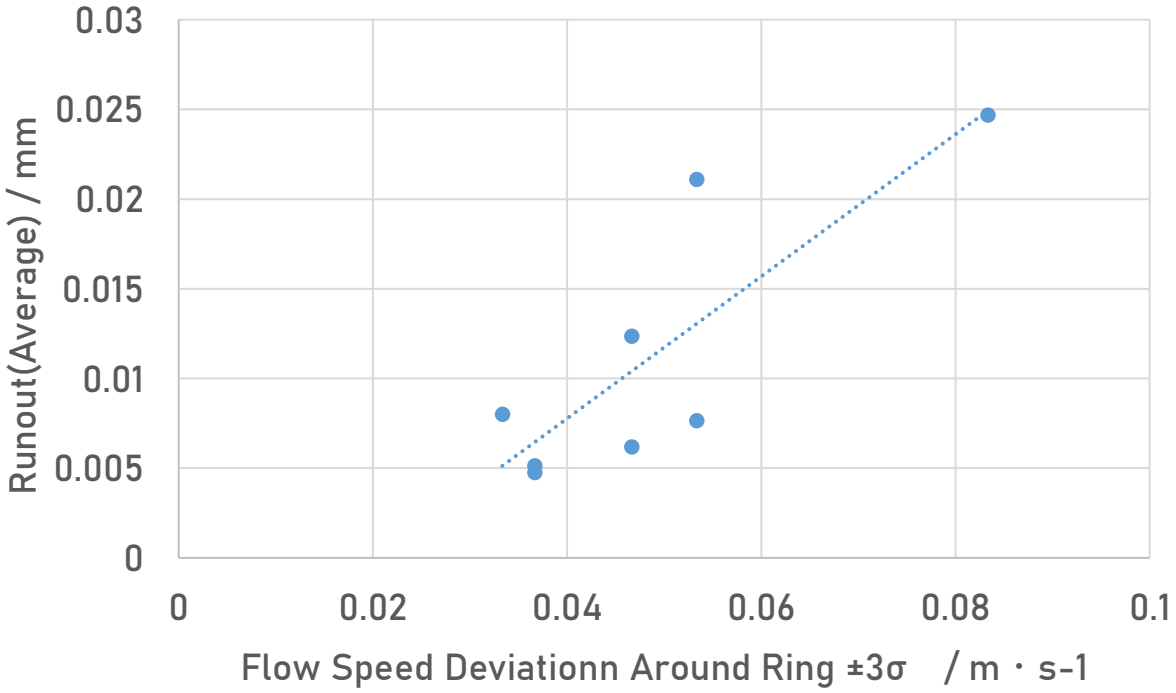
Solver	SFTC DEFORM-HT ver14.0
Nodes	14520
Elements	12000
Coating Mesh	0.1mm /per layer
Element shape	Hexagon

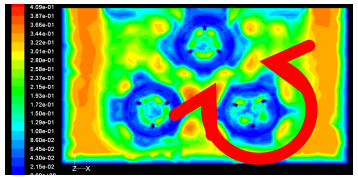


Correration between Runout and Flow Speed

Flow Speed Dispersion and Run out have good correlation.







Calculation of Adding of Machining Stress

Run out

$$\begin{pmatrix} x_{11} & x_{i+1\,i} & \cdots \\ & & \\ x_{1j} & & \end{pmatrix} = \begin{pmatrix} x_{i1} \\ \\ x_{ij} \end{pmatrix} \begin{pmatrix} a_{11} & \cdots & a_{i1} \\ & \ddots & \vdots \\ j & \cdots & a_{ij} \end{pmatrix} \begin{pmatrix} \\ \\ \\ \end{pmatrix} + \begin{pmatrix} \\ \\ \\ \end{pmatrix}$$

Total Run Out

Residual Stress Effect For Run out With anisotoropic

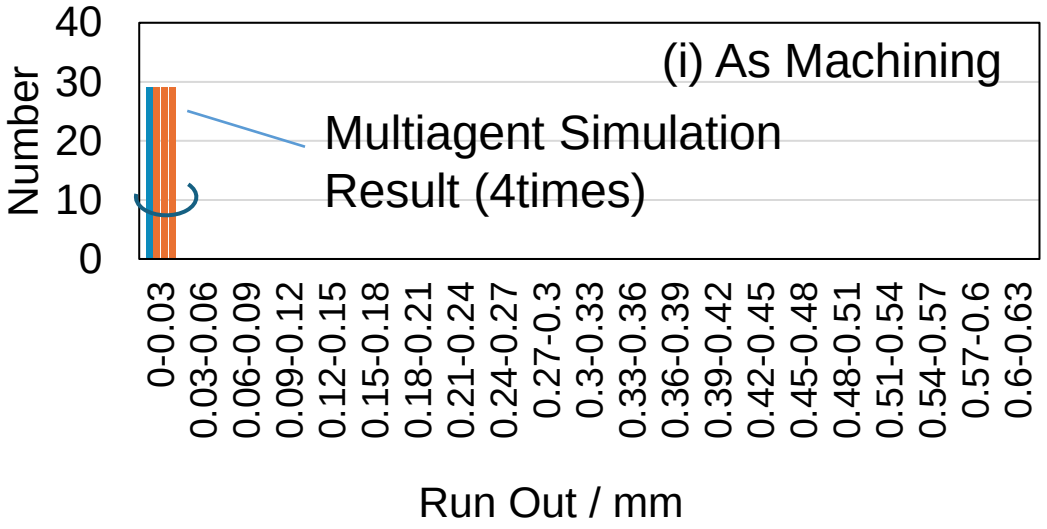
Residual Stress before Heat Treatment

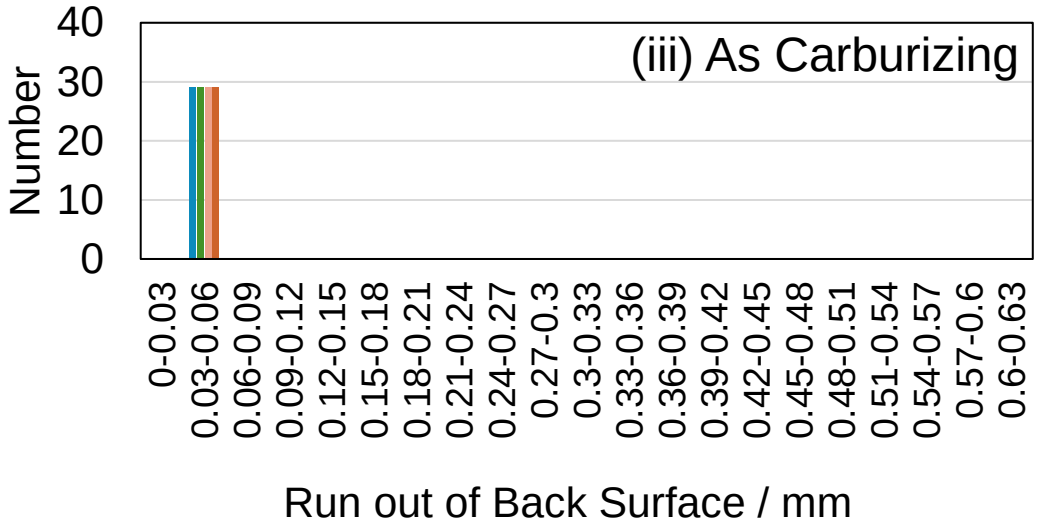
Basic heat treatment deformation

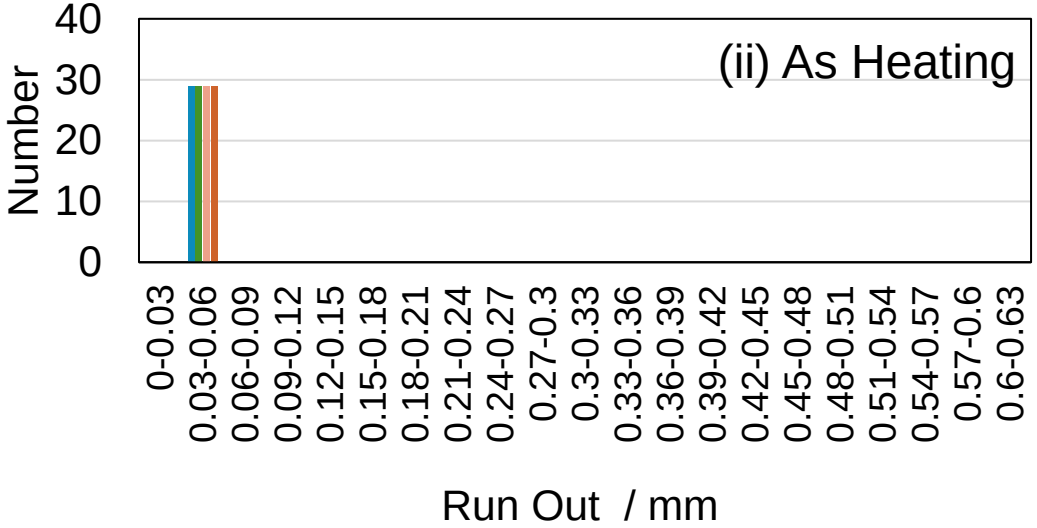
$$a_{ij} = r_{ij}(\cos\theta + i\sin\theta)$$

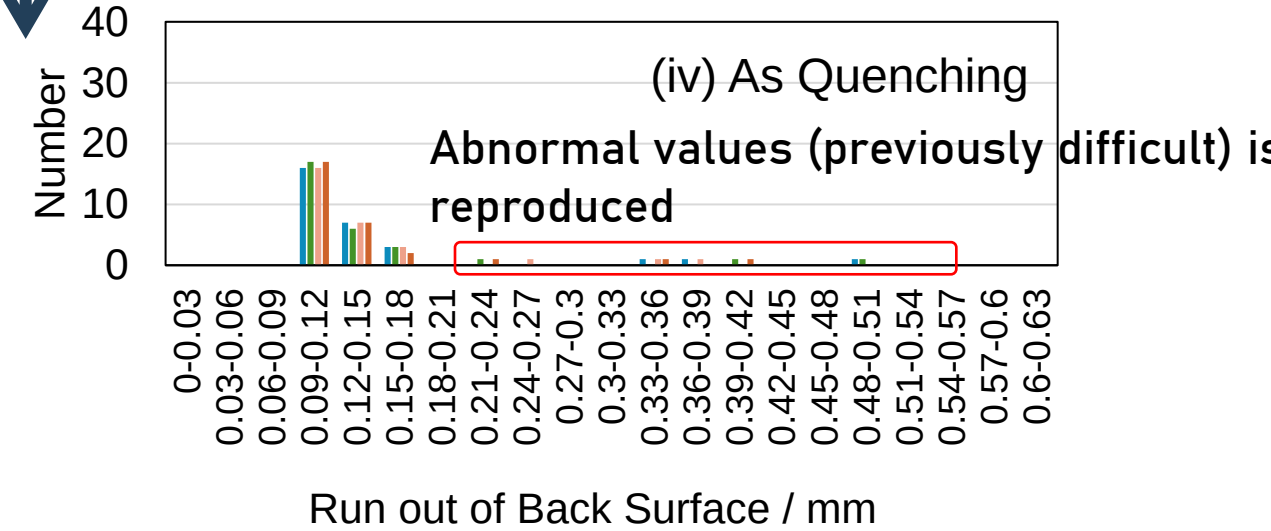
Contain Cooling Speed Anisotropy

Result of Heat Treatment Deformation Calculation







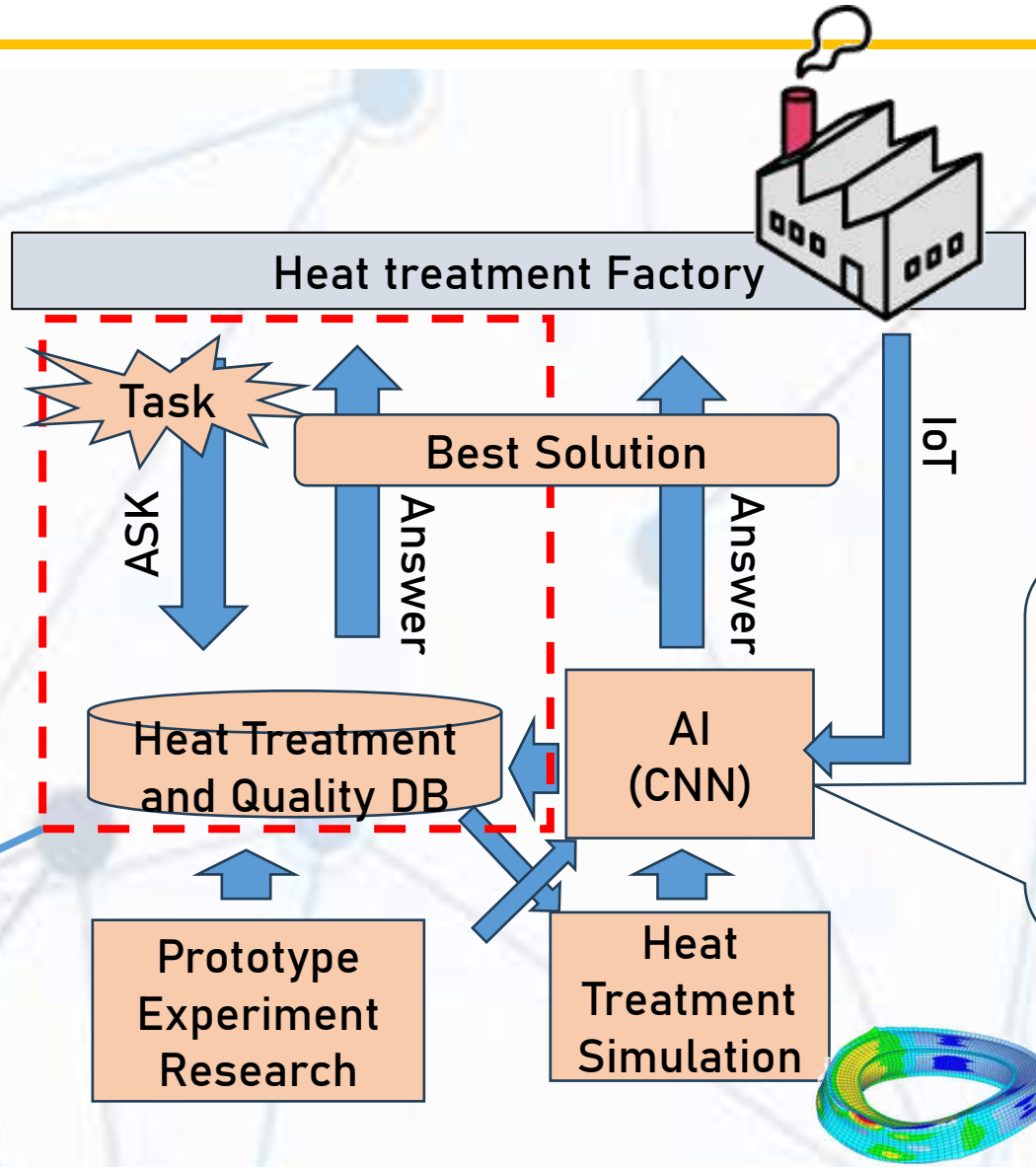


Conclusion

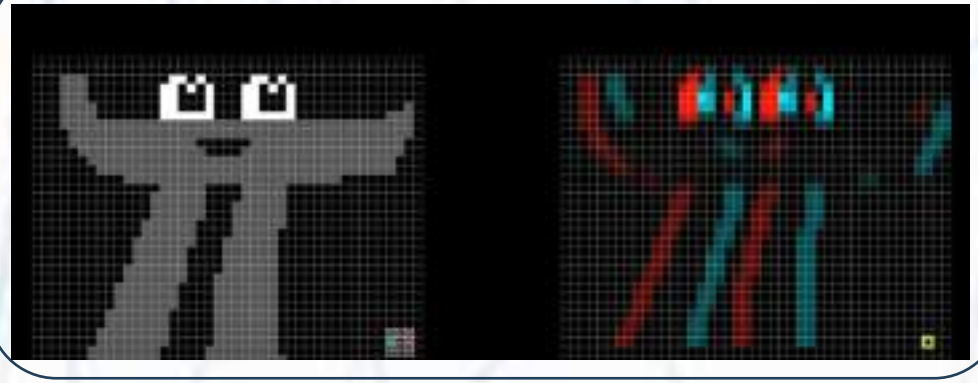
- ✓ A hierarchical multi-agent simulation including condition anisotropy was able to accurately reproduce the heat treatment quality distribution, including abnormal values.
- ✓ The connection matrix can be derived by repeating the heat treatment and related simulation.
- ✓ By performing multi-agent simulation for each characteristic shape part, it is possible to predict overall deformation and quality.

This research is supported by JSPS Grant No. Research 25K17526 "Heat treatment simulation considering machining- processing-induced variations that contribute to life cycle CO2"

Future



Multi-agent Simulation can Contribute to IoT



Extract features from real data and simulation data and create the transition matrix